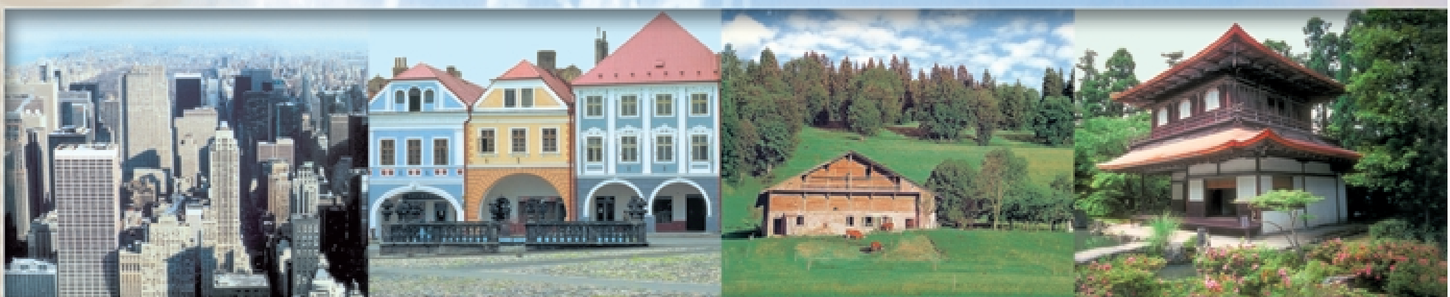
International Telecommunication Union

FIXED WIRELESS ACCESS



Handbook on Land Mobile (including Wireless Access)

Volume 1

2nd Edition

Radiocommunication Bureau

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PREFACE

The present handbook on Land Mobile (including Wireless Access) has been developed by a group of experts of Radiocommunication Study Group 8 under the Chairmanship of Mr. S. Towaij (Canada), Chairman of Radiocommunication Working Party 8A.

The handbook consists of several volumes covering all categories of the land mobile service, such as cellular mobile, cordless telephones and cordless telecommunication, fixed wireless access, dispatch, paging and other land mobile applications. The contents include detailed explanations and references that can be consulted for additional details.

Volume I on Fixed Wireless Access describes the basic principles, access requirements, technology criteria, deployment planning and technical descriptions of typical systems. The technical content is intended for use by administrations and operators in both developing and developed countries. Wireless access applications are considered as a very important element of today's telecommunication infrastructure. Considerable emphasis is thus being placed on wireless access applications in the land mobile service as a means of providing fast and economic telecommunication services.

The purpose of this handbook is to assist in the decision-making process involving planning, engineering and deployment of wireless access based land mobile systems, especially in the developing countries. It should also provide adequate information that will assist in training engineers and planners in the regulating, planning, engineering and deployment aspects of these systems.

Robert W. Jones
Director, Radiocommunication Bureau

FOREWORD

Wireless access is an important and fast-growing application of radio technologies in general and of the land mobile service in particular.

Volume I on Fixed Wireless Access describes the basic principles, access requirements, technology criteria, deployment planning and technical descriptions of typical systems. The technical content is intended for use by administrations and operators in both developing and developed countries. Wireless access applications are considered as a very important element of today's telecommunication infrastructure. Considerable emphasis is thus being placed on wireless access applications in the land mobile service as a means of providing fast introduction of economic telecommunication services.

Mr. S. Towaij
Chairman, Radiocommunication Working Party 8A
Canada

Prologue to the Second Edition

The original version of this handbook was compiled in November 1996 and was published by mid-year in 1997. Both the technology and the applications have changed significantly since then and the handbook had to be updated. Some of main changes in the market include the explosive growth of Internet applications and the increasing need to provide Universal Access to the Internet in most parts of the world, in addition to the need to support existing access services. New broadband wireless access systems are emerging that will satisfy that need.

A summary of the changes that have been made to the second edition with respect to the original publication (first edition) are as follows:

- The terminology has been updated to conform with the latest ITU-R Recommendations. For example, the original title of this handbook was "Wireless Access Local Loop". However, the term "local loop" not only carries negative connotations of limited bandwidth, but also it is not technically correct. Hence, its use has been explicitly deprecated in ITU Recommendations. The new title of the handbook, "Fixed Wireless Access" (FWA) is more accurate and follows the ITU Recommendations.
- New sections on industry trends have been added, for example, the access to the Internet, the convergence of wireline and wireless access, etc.
- Technologies that were described in the first edition of the handbook, but that have become disused or that are not being deployed any more, have been removed from the handbook.
- Substantial material has been added on broadband wireless access (BWA), following the most recent industry trends.

Jose Costa
Editor

CHAPTER 1

INTRODUCTION

1.1 Purpose and scope

The purpose of this handbook is to assist in the decision-making process involving planning, engineering and deployment of wireless access based land mobile systems, especially in developing countries. It should also provide adequate information that will assist in training engineers and planners in the regulation, planning, engineering and deployment aspects of these systems. The term "wireless access", as used in this handbook, refers to end-user radio connection(s) to core networks (Ref.: Rec. ITU-R F.1399), which include mobile applications such as in-building and out-of-building communication systems, cellular-based mobile systems and fixed wireless access. Core networks include, for example, PSTN, ISDN, PLMN, PSDN, Internet, WAN/LAN, CATV, etc.

The users of this handbook are likely to fall into two categories. The first category includes the decision-makers and planners for whom the handbook provides sufficient information to aid in making a decision on choice of systems as far as the systems suitability to meet the decision-making requirements. For this purpose, the Handbook provides analysis on the various systems taking into consideration factors such as traffic estimation and projection, frequency band and spectrum requirements, investment, regulation and policy requirements and experiences, deployment strategies, short and long term implications, as well as other elements that are required for planning and decision-making purposes.

For the second category of users, including engineers and other technical experts, the handbook provides in-depth technical information on the characteristics of the various systems and applications, systems design, traffic analysis and estimation, spectrum estimation, channelling plans, cell design and selection, deployment strategy, mobile and base station equipment, as well other pertinent information.

The handbook provides information on state-of-the-art technology in terrestrial wireless access systems. It also projects near and long term trends in systems and technology.

1.2 Background

This section provides an overview of the major incentives and motivation towards fixed wireless access, leading from the past towards the future.

1.2.1 Traditional telephony wireless access

The land mobile (including wireless access) service is growing very rapidly. In the early 1980s, the first generation analogue cellular systems were introduced. By 1990 there were 11 million mobile cellular users[1]. In June 1996, worldwide cellular usage, based on the ten largest networks, was estimated at 53.5 million users[*]. The ITU World Telecommunication Development Report - 1999

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[1] ITU World Telecommunication Development Report 1999 - Mobile Cellular.

[*] This is based on June 1995 estimation of the ten largest users in the world including: Australia, Canada, Germany, Italy, Japan, South Korea, Sweden, the United Kingdom, and the United States of America.

shows estimates of mobile and fixed telephone subscribers going up to 3 billion in 2010, and they might still be conservative. Indeed, since the introduction of cellular-based mobile systems, there has been a dramatic increase in the use and application of wireless access land mobile and fixed telecommunication systems. The development and deployment of second generation cellular systems worldwide, employing more efficient and flexible digital technologies, is on-going. Third-generation systems are also starting to be deployed. Other wireless access applications, such as in-building, out-of-building (e.g., campus) and fixed wireless access, etc., are being implemented in all regions of the world. All of the above applications and systems under development revolve around the concept of providing telecommunications between people rather than between places with the ultimate theme of "***communications with anyone, anywhere, at any time***".

In developing countries, wireless access systems are also being used as a fast and cost-effective means of deploying telecommunication networks. In the developed countries, wireless access is seen by service providers as a way to reduce the high cost of deploying local access lines to subscribers, as well as economically serving customers in suburban, rural and remote regions in homes, small businesses and educational institutions. This is the last and the only leg of the wireline networks which is provided on a cost per single subscriber basis rather than cost shared among many. Using a fixed wireless access system not only reduces the cost to the service provider by sharing the cost of the facilities down to the user (e.g., base stations) and eliminating the need of cables directly to the subscriber premises, but also makes the provision of services to new subscribers faster and easier.

Telecommunication is the backbone of every nation. In present-day society every aspect of daily life depends on telecommunications. The prosperity, health, education, and welfare of a country is greatly dependent on how good and how widely deployed are its telecommunication facilities. Telecommunication not only makes information available to everyone but also provides the basic requirements of industrial and commercial endeavours.

1.2.2 Broadband wireless access (BWA)

Broadband wireless access at or above the primary rate was introduced in the 1980s in response to new end-user needs that the existing wireline local infrastructures could not satisfy in a timely and cost-effective manner. In the USA, large-scale usage started in the 18 GHz band and soon extended to the 23 GHz band. In the 1990s, advancing deregulation and competition in the local access provided additional stimulus for broadband wireless access development much beyond the deployment capacities of the 18 GHz and 23 GHz bands into other bands such as 2.5 GHz.

This stimulated the introduction of WRC-97 agenda item "1.9.6 the identification of suitable frequency bands above 30 GHz for use by the fixed service for high density applications". The term "High Density applications in the Fixed Service (HDFS)" is used to describe a significant level of ubiquitous deployment of point-to-point (P-P) and/or point-to-multipoint (P-MP) systems within a given area. These systems are generally intended to support broadband applications.

Recommendation ITU-R F.1401 (Frequency bands for fixed wireless access systems and the identification methodology) includes a categorization of fixed wireless access (FWA) systems, and a basic description of the broadband wireless access (BWA) category, intended for operation at or above the primary rate (i.e., above 1 544 kbit/s or 2 048 kbit/s) in frequency bands of up to about 70 GHz.

Since BWA is a distinct form of FWA, the generic FWA coverage in this handbook applies to BWA, as well. Chapter 8 and Annex 6 cover the distinctive aspects of BWA. In addition to the broadband feature, there are two more generic distinctions of BWA:

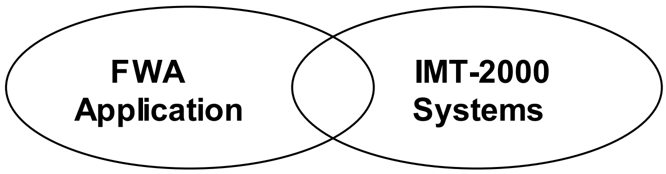
- the use of technology that has originally been developed for conventional "radio-relay" applications in the fixed service, and for fixed point-to-multipoint (P-MP) systems;

- the use of frequency bands at the higher end of the FWA spectrum range, which may requires line-of-sight link operation.

In the absence of alternative subscriber access (fiber, XDSL, cable, modem), which may apparently take years to materialize even in developed countries, there is an increasing immediate need for BWA in all countries that participate in the worldwide rapid growth of Internet usage in business, industry, finance, government and education. While the necessary extent of BWA deployment varies from country to country, and within countries, according to the level and pace of development, the basic need for BWA is universal, similar to the universal need for air traffic. And while FWA providing basic telephone access competes with existing or planned wireline local access, BWA has few competitors at this time.

1.2.3 Relationship between FWA and IMT-2000

Fixed wireless access (FWA) is an application which can be provided with a variety of alternative wireless access systems. IMT-2000 systems are third-generation mobile systems that support both mobile and fixed wireless access applications. The following figure shows this relationship in a diagrammatical manner.



Recommendation ITU-R M.687 describes the concepts and objectives for IMT-2000 and Recommendation ITU-R M.819 contains specific IMT-2000 requirements pertaining to fixed wireless access.

1.2.4 Wireless access to the Internet

With the explosive growth of the Internet, wireless access to the Internet will likely become a major driving force for the industry. The wireless access to the Internet is based on IP packet-switched technologies and it is integral to the overall goals of wireless access. This is being addressed as part of the ongoing developments in standards activities related to second- and third-generation personal communications, fixed wireless access, broadband wireless access and satellite services. Wireless personal area networks (PANs) and wireless local area networks (LANs) fit into the overall scheme of wireless access, but they are outside the scope of this handbook (cf. Recommendations ITU-R M.1450 and ITU-R M.1454). Some of the key issues related to wireless access to the Internet are covered in Annex 8.

1.3 Organization and use of the handbook

The handbook is organized into a number of volumes and chapters providing key information to the reader, with detailed technical, operational, and regulatory information provided in annexes. This volume deals with fixed wireless access, including broadband.

Chapter 2 describes some of the access requirements and Chapter 3 highlights some of the advantages of wireless access. Technology/evolution and design considerations are covered in Chapter 4 and key factors affecting technology choices in Chapter 5. Guidelines for planning the deployment of wireless access systems are given in Chapter 6.

Chapter 7 gives a general overview of fixed wireless access systems, which fall into two groupings:

- systems based on existing radio interface standards;
- systems based on proprietary radio interface technologies.

Chapter 8 covers specifically the aspects related to broadband wireless access (BWA) systems.

Chapter 9 gives a view towards the futures, both in terms of market trends and emerging enabling technologies.

The annexes provide a description of existing and emerging fixed wireless access systems, with emphasis on capabilities and relationship among the various system elements. The objective is to assist the reader to quickly gain a solid understanding of wireless access systems and to assess these technologies against the needs and requirements in their countries.

Annex 1 provides a list of terminology and acronyms used in this handbook, Annex 2 covers spectrum sharing considerations. Annex 3 summarizes the main criteria that need to be considered to assess how the various systems and technologies meet the needs and requirements.

Annexes 4 and 5 cover the various wireless access systems in some detail, providing basic characteristics and system configuration, applications and service provisioning.

Annexes 6 and 7 cover broadband wireless access in more detail; deployment considerations in Annex 6 and descriptions of specific systems in Annex 7.

Annex 8 provides a view of the important area of wireless access to the Internet.

Finally, Annex 9 contains a list of references.

CHAPTER 2

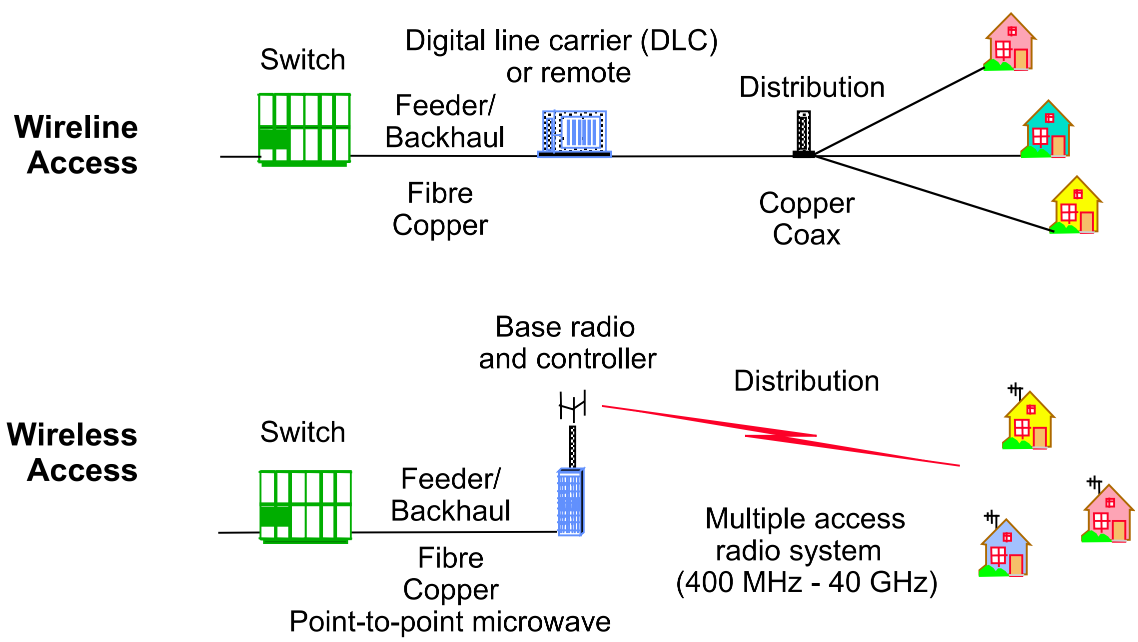
ACCESS REQUIREMENTS

Advances in technology and competitive access are driving the revolution towards wireless access infrastructure for the provision of basic telephone service. Traditionally, the most difficult component of the network to build, and the least cost-effective to maintain, has proven to be the local access network regardless of a developing or a developed economy. The sheer scope of investment and engineering efforts required to build and maintain copper-based networks has created primarily lofty barriers to entry and has made high penetration rates for basic telephone service available only to the industrialized nations of the world. Even the relatively low target subscriber density (teledensity) rate of 20 lines per 100 of population set by the ITU, has, until recently, been far beyond the capability of many nations.

Fixed wireless access (FWA) previously referred to as radio local loop (RLL), wireless local loop (WLL) or wireless access local loop, is an application of radio technology and personal communication systems experiencing tremendous growth, especially in developing economies. Various technologies and applications are discussed in this section with the aim to assist in choosing the most appropriate one for each environment. Figure 1 introduces wireless access by comparing it to wireline access. The key characteristic of wireless access is the use of a multiple access radio system instead of wires (e.g., copper or coaxial) in the distribution/access network, whether or not radio (point-to-point microwave) is used in the backhaul network.

FIGURE 1

Wireline access and wireless access comparison



In general, any radio system could be used for fixed radio access and the suitability is a function of a number of factors. The most suitable system for a particular application will tend in general to depend on the requirements of the end-user (plain old telephone service (POTS) only or many service features), the cost of deployment (which will depend on the density of the subscriber population and the type of system being considered), and the availability of the appropriate radio-frequency spectrum for that system. The requirement for mobility, or evolution for mobility, would tend to drive the deployment of systems derived from cellular or personal communications service (PCS) systems. Alternatively, the requirement for wireline quality and services (such as G3 fax and voiceband data or even integrated services digital network (ISDN)) would tend to be drivers towards special-purpose designed systems. Another important consideration is how to approach integration of the fixed wireless access system with the overall network philosophy of the operator. In particular, any problem (such as end-user and operator requirements) may be best solved with a mixed solution of wired and wireless technology. Understanding the drivers for the deployment of each technology is a key factor in minimizing the cost and maximizing the effectiveness of the solution.

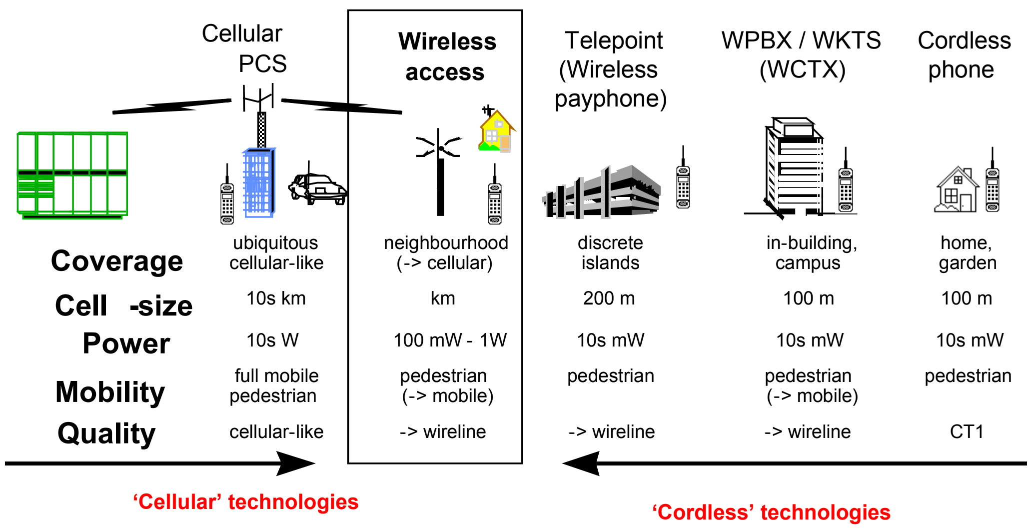
There is significant variation in the characteristics of the local access lines, particularly in developing countries, from the perspective of teledensity and access line length. Urban and suburban applications require high capacity – hundreds and sometimes thousands of subscribers per square kilometre. Villages and towns, on the other hand, often isolated from major population centres, may have lower teledensity capacity requirements and may require service for only a few hundred subscribers. Rural areas have unique requirements, small clusters of a few lines each in very isolated pockets.

In addition to terrain topography and teledensity, other factors differentiate network applications, for example, service set, performance and quality objectives. On a network basis, solutions must satisfy cost and build-out timing objectives. A country's specific situation, such as infrastructure which may already be in place, mandated air interface standards, a variety of interface requirements, and even terrain and climate can influence what the optimal wireless solution is. The variation in access characteristics necessitates a family of wireless access products to meet specific needs.

Figure 2 shows wireless access as one of the applications of wireless technologies and personal communications systems, compared with other applications in terms of coverage, cell-size, power, mobility, quality and relative cost. Wireless access characteristics are somewhere in between those of cellular technologies and cordless technologies.

FIGURE 2

Comparison of wireless technology applications



CHAPTER 3

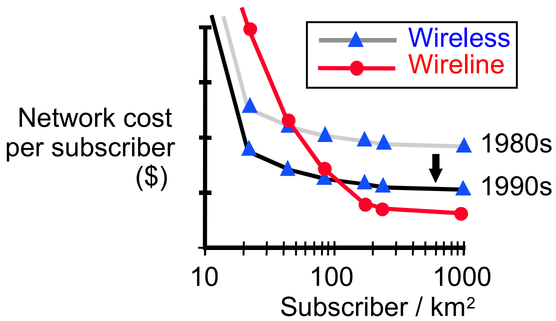
ADVANTAGES OF WIRELESS ACCESS

The advantages of employing wireless access are lower life-cycle cost, flexibility in network design and faster deployment. These advantages are illustrated in Figs 3a to 3d.

Traditional copper networks consist of distribution cables, pedestals or splice boxes, and feeder plants. The last leg of the local access line including the dropwire is very expensive to install and costly to maintain. It has been estimated that up to 80% of an operating company's total maintenance expenditure is allocated to maintaining the local access line. Most of the cost of constructing access lines can be associated with the vast, branching network of copper cable that connects with individual homes. In fact, the last few hundred metres of distribution copper may account for up to 50% of the total cost of the local access lines. Most capital cost associated with the construction of a wireless network can be characterized as being "electronics". By contrast, in a copper network, significant cost is incurred for cable material and construction, whose costs over time do not decrease nearly as fast as "electronics" costs (see Fig. 3a).

FIGURE 3a

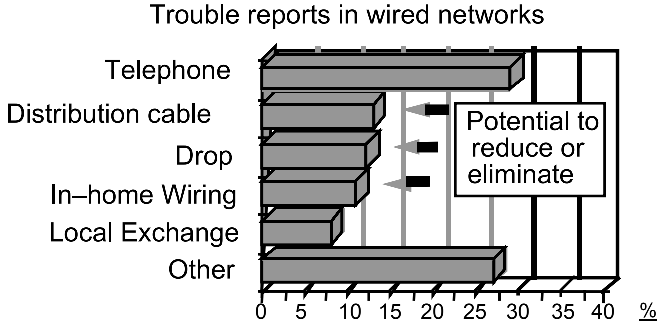
Comparison of wireless and wireline systems in terms of capital costs



Operational cost savings represent another advantage of employing wireless access lines (see Fig. 3b). The elimination of copper distribution and copper drops reduces operations costs due to fewer trouble reports, dispatch and repair activities. Studies have shown that wireless access lines can reduce operating expenses by as much as 25% per subscriber per year. A reduction in installation and operating costs, coupled with capital cost savings, results in lower life-cycle costs for wireless access systems. Also, a wireless infrastructure involves less outside-plant; hence it is less vulnerable to theft and vandalism.

FIGURE 3b

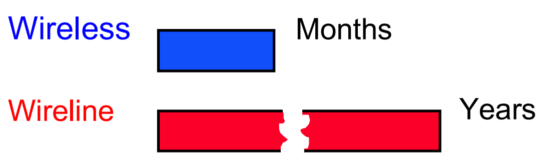
Comparison of wireless and wireline systems in terms of operational costs



Customers waiting for telephone service represent an opportunity cost, therefore rapid deployment of any access system is critical to the business case. As evidenced in the cellular-based mobile industry, wireless systems can literally be installed in a matter of months, or even weeks, as opposed to years often associated with copper-based access build out. This will accelerate returns which can be reinvested to continue building network capabilities further (see Fig. 3c).

FIGURE 3c

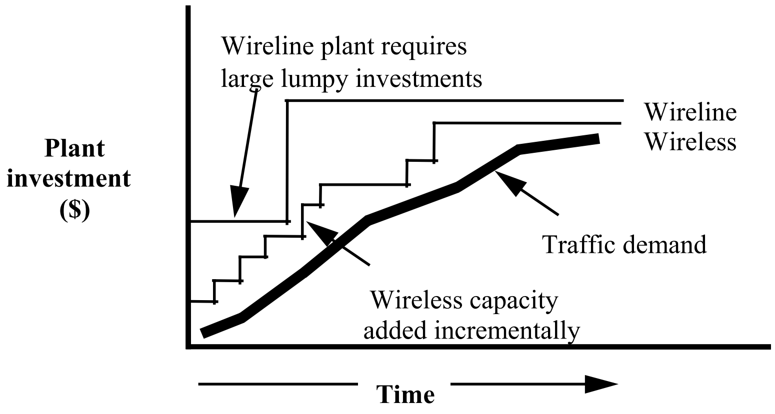
Comparison of wireless and wireline systems in terms of time to deploy



Another positive attribute for wireless access is that wireless distribution is more "forgiving" to uncertainty in subscriber demand forecasts (see Fig. 3d). Wireline infrastructure requires a larger, up front investment which is exposed to uncertainty in demand. Traditionally, telephone companies over-provision (just-in-case) since construction in already established neighbourhoods is even more expensive. In the wireless environment, incremental investment can more closely track subscriber demand and results in faster payback, which reduces financial exposure to over-provisioning.

FIGURE 3d

Comparison of wireless and wireline systems in terms of flexible network design

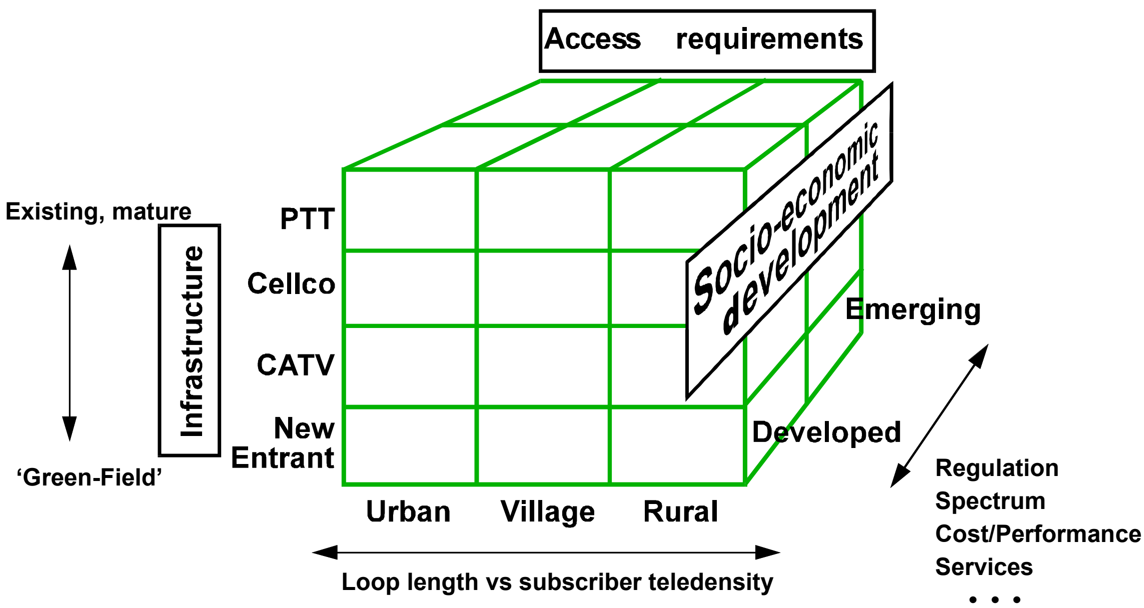


In addition, in some cases wireless access may offer potential for evolution and synergy with mobile services. An infrastructure supporting a fixed wireless system using an air interface developed for mobile services (e.g. Recommendations ITU-R M.622, ITU-R M.687-1, ITU-R M.819-1, ITU-R M.1033, and ITU-R M.1073) might be readily extended to support mobile users. Alternatively, special-purpose systems can be designed to meet the quality requirements in an optimal manner.

Hence, the overall access requirements, socio-economic development, and infrastructure must be considered carefully before designing the system. This is illustrated in Fig. 4.

FIGURE 4

Tremendous variation in business design and system requirements according to market segments



CHAPTER 4

TECHNOLOGY/EVOLUTION AND DESIGN CONSIDERATIONS

Recent advances in wireless technology have been accelerated by the tremendous growth seen in the cellular-based mobile industry. Increased volume generates lower product costs, expanding markets further and so on. There is tremendous overlap between technology applied to mobile systems and that used to provide a "fixed" telephone service. This section of the Handbook briefly outlines design objectives and architectures for wireless access systems.

4.1 Fixed wireless access systems design objectives

The access requirements discussed previously establish key design parameters for wireless access systems:

– achieve low life-cycle cost (capital, installation, operations),

– ability to meet projected teledensity requirements/capacity,

– rapid time-to-deploy,

– employ maximum use of in-place infrastructure (switching, transport etc.) where there is economic advantage,

– offer good performance (voice quality, delay, blocking, reliability),

– deliver the required service-set (voice, fax, data, etc.),

– potential for evolution or option to interwork with a mobile network.

These objectives must be met within the context of a country's terrain and environmental characteristics which can influence the appropriate wireless solution.

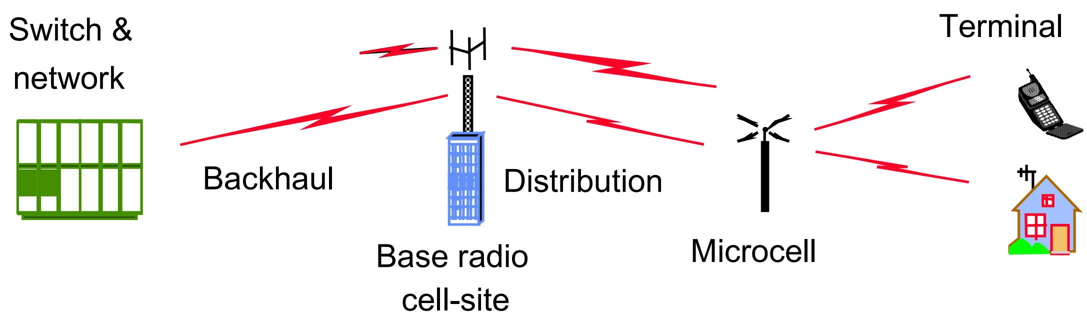
4.2 Fixed wireless access systems architecture

Historically, cellular networks have been provisioned for high-speed mobile applications in large cells using high power with relatively low traffic per subscriber. Use of wireless systems to provide basic "fixed" telephone service does not automatically infer user-mobility and in general higher traffic and performance (voice quality, reliability, blocking etc.) is expected. In order to understand the emerging markets requirements, propagation tests and simulations must continue to gather better knowledge of end-user traffic behaviour and characterization of the propagation channel under "fixed" conditions.

Figure 5 illustrates the components of a wireless access architecture-switch and network, backhaul interconnecting base radio cell-sites, and distribution to homes or handsets directly, or as shown, to intermediary microcells. Microcells can provide higher capacity or better coverage at discrete points or traffic "islands" within the network.

FIGURE 5

Wireless access architecture



Within a traditional telephone company architecture, the wireless access backhaul may consist of copper or fibre trunks. In addition, copper distribution may be used to interconnect microcells. In a more cellular-like architecture, microwave links may be used for backhaul and distribution.

4.3 Spectrum

Key input parameters to the design of a wireless network are teledensity over time and subscriber usage (e.g., Erlangs per subscriber). These variables establish the traffic density (e.g., Erlangs per square kilometre) that the wireless system needs to support. The availability of spectrum, channelization of the particular radio access technology, the extent to which frequencies can be re-used (N), and cell-size, influence the traffic carrying capacity of a radio-based system. Wireless access systems, from an RF planning/network viewpoint, are deployed in a similar way to cellular systems, even though the teledensity requirements may be different (see Chapter 6 for more details).

Radio spectrum requirements and availability needs to be examined. Figure 6 shows bands of the radio spectrum where fixed wireless access systems operate in some countries (the acronyms used in this figure are defined in Annex 1). The precise availability of radio spectrum for these applications is subject to local regulations. For example, in addition to the bands 1.4 and 2.4/2.6 GHz, the 3.5 GHz and 10.5 GHz bands have been endorsed by CEPT/ETSI for use in Europe. Also, in Region 2 the 3.4-3.7 GHz band is being considered for wireless access applications in some countries. The applications shown in Figure 6 for different frequency bands may be known by different names that are related to the traditional use of these bands. However, the common underlying aspect is wireless access, which may take many flavours depending on the signal transfer capabilities offered (e.g., voice, data, image, video), mix of service (e.g., purely fixed, mixed fixed/mobile, nomadic), range (e.g., use of repeaters), etc.

FIGURE 6

Examples of bands of radio spectrum for wireless access used by different operators

- 400 MHz TACS / NMT, D-AMPS/TDMA
- 800 MHz AMPS / D-AMPS
- 900 MHz GSM / TACS/NMT
- 1.4 GHz point-to-multipoint (subscriber radio system)
- 1.8 GHz GSM/DECT
- 1.9 GHz PCS/PHS
- 2.4-2.6 GHz MDS (multipoint distribution systems) and point-to-multipoint systems
- 3.4-3.8 GHz MDS, FWA
- 5 GHz radio local area networks
- 10.5 GHz point-to-multipoint systems
- 24/26/28//32/40 GHz LMCS/LMDS local multipoint communication/distribution systems

Frequency

4.3.1 Role of ITU Radio Regulations and national spectrum utilization policies

The terms fixed (radio) service and mobile (radio) service are defined by the ITU Radio Regulations:

***Fixed service*:** a radiocommunication service between specified fixed points.

***Mobile service*:** a radiocommunication service between mobile and land stations, or between mobile stations.

Indeed, these radio service definitions form the basis for the allocation of radio spectrum internationally by the ITU as well as domestically within each country. For the most part, the ITU has made joint allocations to the mobile and fixed services in various frequency bands. Traditionally, in some countries a choice has been made between the two services.

Certain evolving applications do not fit explicitly into the definitions of either the fixed or the mobile service. The appropriate approach is to apply some flexibility in the interpretation of these definitions to be able to embrace these integrated applications under the umbrella of the fixed and mobile services. A key to the interpretation of the use of these terms is the concept of mobility. If the device is intended to be used in motion or is normally moved from place to place, it may be considered as part of the mobile service. If not, then it may be considered to be in the fixed service.

Applications are envisaged for fixed radio service providers operating in spectrum designated primarily to the fixed service where it is required to have the integration of wireless access devices that function as mobile radio stations. These situations have resulted from the converging requirements of both mobile and fixed radio services and the use of wireless access devices in integrated radio applications. A suitable spectrum utilization policy is to support a mix of integrated mobile and fixed service applications in certain frequency bands.

Countries usually need to apply some flexibility in their interpretation of frequency allocations. This flexibility has permitted, for example, radio licensees to operate their systems according to the primary frequency allocation while accommodating secondary service requirements subject to certain conditions which are consistent with the ITU Radio Regulations, as well as in accordance with national regulations. Generally, a balanced approach is required when applying flexibility to spectrum policy in the spectrally congested bands, as the needs of users of the primary allocations must be met within the primary designation of the bands. This approach may be applied whether the service is fixed or mobile.

Another potential application is the use of a number of radio stations in a fixed mode for interactive data transmission (e.g., point-of-sale devices and other data transactions, telemetry and data acquisition). In some cases, the mobile dispatch and voice communications devices are operated permanently at one location. In other cases, there are fixed stations in multi-point communications systems that are highly portable within a coverage area. There are also cases where the fixed stations are nomadic devices that can be operated in any location on a national network. The integration of applications may prove to be an efficient and economical means of meeting diverse consumer needs while maintaining an efficient use of spectrum.

There may be cost benefits or spectrum efficiencies that accrue to radio users if fixed and mobile applications can be integrated within the same frequency band provided that the primary use of either the fixed or mobile service allocation is sustained to meet the demand of the primary allocation. The Administration needs to establish whether adequate spectrum is available for the primary use while permitting a secondary application. It must also develop the options or alternatives for mobile or fixed service spectrum use in the event that there are spectrum shortfalls. In such cases, the Administration would continue to require these radio systems to migrate to a more appropriate co-primary band.

Policy flexibility to support a mix of integrated service applications, has the potential to use up a considerable amount of mobile or fixed spectrum. In the heavily congested areas of a country, this may result in additional scarcity of primary spectrum. In the past, spectrum users/service providers in the fixed and mobile services were designated to operate in specific frequency bands for their respective purposes. Usually very few frequency bands exist where users can jointly operate fixed and mobile systems in the same spectrum. Consequently, any policy flexibility to support a mix of integrated service applications must be balanced in order to retain enough spectrum to meet primary service objectives.

Radio service providers are striving to meet customer demands in a competitive environment with the potential efficiency of integrated radio service offerings. The emergence of integrated radiocommunication systems is evident in other areas of radiocommunications. National spectrum policies should provide the necessary flexibility to help radio service providers respond to customer needs.

4.3.2 Summary of Recommendations in place

This section summarizes the relevant Recommendations in place produced by the major national and regional bodies (ITU-R, CITEL, CEPT, etc.) on the use of the spectrum for fixed wireless access, including sub-band plans, spectral masks, co-existence, sharing, etc.

There are many FS, some MS, bands available in the Radio Regulations for potential FWA usage. The ITU-R is developing a compilation of the most attractive candidates together with their associated compatibility issues where this is appropriate. At the time of writing the following six bands are of the greater priority in terms of a mix of different factors, including sharing issues, propagation, legacy factors, bandwidth, systems and deployment characteristics, recent and current usage etc. and in the near future a new Recommendation is expected on each of these bands summarizing these issues for the guidance of administrations, operators and manufacturers. It will be noted that one of the bands listed here, 32 GHz (31.8-33.4 GHz), has been identified as available for HDFS applications, and provides a relatively high absolute bandwidth (1.6 GHz), relatively low legacy usage by other services and good international acceptability in all three Regions. Clearly more sharing and frequency arrangement Recommendations are in preparation at this time.

Freq band (GHz)	Bandwidth available (MHz)	ITU-R Recommendations	Regional Recommendations	Share Recommendations/ studies underway
3.5 GHz		(see Note 1)		
3.4-3.6	200	SF.1486, F.1107, 1108, 1190		Radioloc.
3.4-3.7	300	F.1107, 1108, 1190	CITEL PCCIII Rec. 26	Radioloc.
3.41-3.6	190	F.1107, 1108, 1190	CEPT/ERC Rec. 14-03	Radioloc.
3.425-3.575	150			Radioloc.
3.6-3.8	200	F.1107, 1108, 1190	CEPT/ERC Rec. 12-08	
3.65-3.7	50	F.1107, 1108, 1190		Radioloc.
38 GHz		(see Note 2)		
37-40	3 000	F.749, 1107, 1108	CITEL PCCIII Rec. 55	FSS
37.5-39.5	2 000			FSS
38.05-38.5	420		ARIB STD T58, 59	FSS
39.05-39.5	420			
24/29 GHz		(see Note 3)		
24.25-24.45	200			RNS, FSS
25.05-25.25	200			
24.25-24.75	500			RNS, ISS, EESS
25.5-26.7	1 200			
24.25-27.5	3 250			RNS, ISS, EESS, FSS
24.5-26.5	2 000	F.748, 1249 SA.1276, 1278	CEPT/ERC Rec. 13-02	
25.25-27.0	1 750	F.758	ARIB STD T58, 59	Radioloc.
25.35-28.35	3 000	F.748, 1249 SA.1276, 1278		ISS, FSS, EESS
26.4-28.35	1 950			ISS, FSS
26.7-27.1	400			EESS, FSS, ISS
27.1-27.5	400			
27.5-28.35	850	F.758	CITEL PCCIII Rec. 57	FSS
27.5-28.35	850			FSS
27.5-29.5	2 000	F.748	CEPT/ERC Rec. 14-03	FSS
29.0-29.25	150	F.758	CITEL PCCIII Rec. 57	FSS
1.8/1.9 GHz		(see Note 4)		
1.710-1.785	75	F.701, M.1073		
1.805-1.880	75			
1.850-1.990	140	F.701, M.1073	CITEL PCCIII Rec. 26	

Freq band (GHz)	Bandwidth available (MHz)	ITU-R Recommendations	Regional Recommendations	Share Recommendations/ studies underway
1.880-1.900	20		CEPT/ERC DEC 9403	
1.880-1.900	20	F.701, M.1073		
1.960-1.980	20			
1.886-1.918	32			
1.893-1.919	26	F.757	ARIB STD 28	
1.900-1.920	20			
450 MHz		(see Note 5)		
0.415-0.420	5	M.478, M.1085		
0.425-0.430	5	SA.1260		
0.440-0.450	10	M.478, M.1085	CITEL PCCIII Rec. 39	
0.485-0.495	10	SA.1260		
32 GHz		(see Note 6)		
31.8-33.4	1 600	F.1520		RNS, SRS, ISS

NOTES:

3.5 GHz

SF.1486, Sharing with VSAT

F.1107 Probabilistic analysis, interference from GSO satellite

F.1108 Protection from non-GSO satellite

F.1190 Protection from radar systems

38 GHz

F.1107, F.1108 and F.749, RF channel arrangements, 38 GHz

24/29 GHz

F.748, RF channel arrangements, 24, 25 and 26 GHz

F.1249, Sharing with ISS, 25.5 GHz

F.758, System characteristics, for sharing studies

1.8/1.9 GHz

F.701, RF channel arrangements, 1 350-2 690 MHz

F.757, Performance, mobile-derived technologies

450 MHz

M.478, Frequency channels between 25 and 3 000 MHz for the FM land mobile service

M.1085, Wind profiler radars around 400 MHz

SA.1260, Sharing between active spaceborne sensors and other services

32 GHz

Doc. 9/BL/4, Radio-frequency channel arrangements

Most of these bands have established frequency channelization plans, but it may be that these are not always most appropriate for the newer generation of systems. This is an area of considerable study, and frequency block-based arrangements seem particularly suited to many FWA situations, and for several bands there is work underway to prepare more such Recommendations to better reflect the market and systems needs for the evolving new FWA and other FS applications. There is also new Recommendation **(Doc. 9/BL/3)** addressing general guidance material on block-based frequency arrangements. The above listing is a simplified snapshot prepared at this time, and it is essential that the interested reader consult the latest Regional and ITU-R Recommendations and work in progress, as well as the corresponding national administration/s, to verify the situation in any particular country/ies.

4.4 Radio system and network design methodology

The choice of technology needs to be related to capacity and cost requirements (see Figs. 7 and 8). For example, considering a hypothetical situation (a real calculation should be carried out with careful reference to the local parameters and those of the system being considered), with IS-54 TDMA, there are approximately 400, 30-kHz, frequency division duplex (FDD) channels in a 25 MHz allocation. Using a 60° sectored system, frequency sets can be re-used every 4 cells (i.e. $N = 4$). One hundred RF channels are available in every cell or about sixteen per sector within the cell. In a TDMA-3 system, a 30-kHz RF channel supports three traffic channels each. Each sector therefore supports 48 traffic channels or 36 Erlangs (1% blocking). Under these conditions, the cell-site supports over 200 Erlangs or 4 000 subscribers at 0.05 Erlangs per subscriber. Assuming a 1 km radius cell, the effective density supported is over 1 200 subscribers k^2.

FIGURE 7

Access requirements: need a family of wireless access solutions to meet diverse requirements

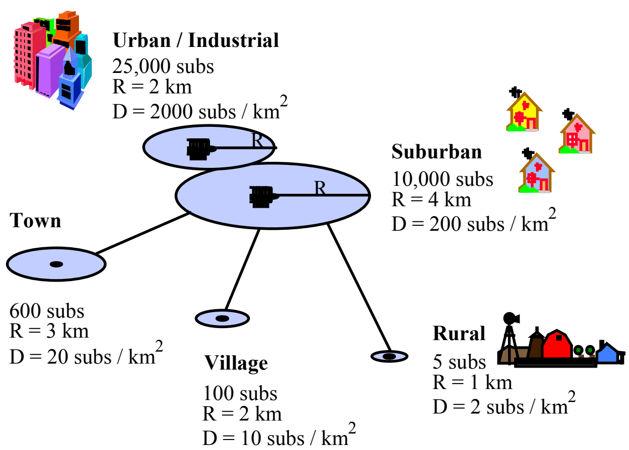
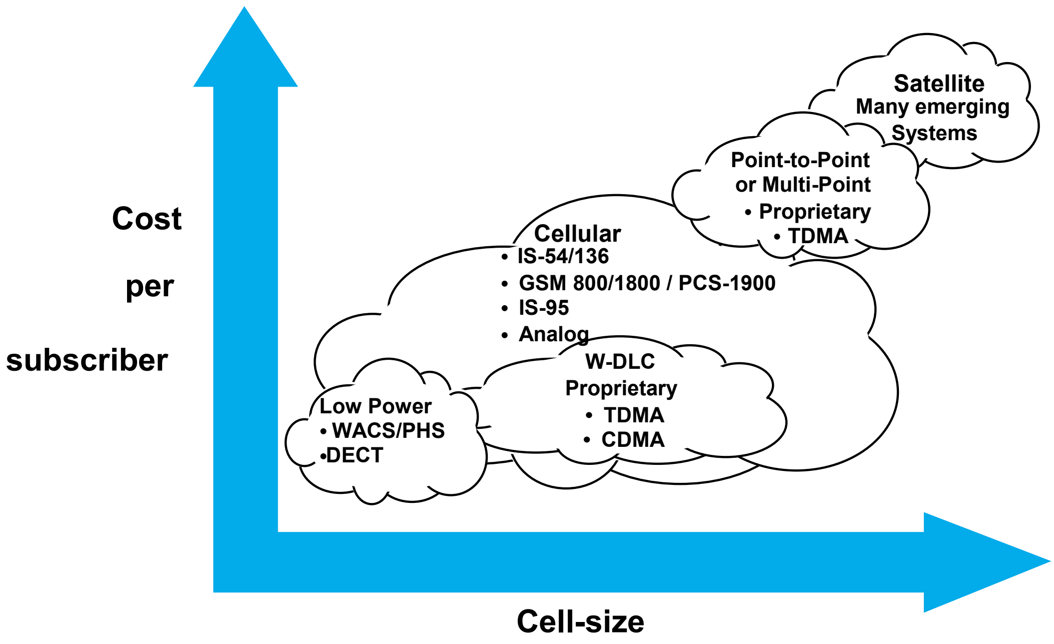


FIGURE 8

Mapping technology onto appropriate requirements



Network design

Two typical network design configurations are shown in Figs. 9 and 10.

The mobile system based implementation (Fig. 9) offers the following advantages:

– consolidated numbering and billing,

– easy integration of separate mobile service,

– efficient for large networks.

The digital line carrier (DLC) based implementation (Fig. 10) offers the following advantages:

– existing numbering and billing,

– easy integration of wired services,

– efficient for secondary use.

FIGURE 9

Mobile system based implementation

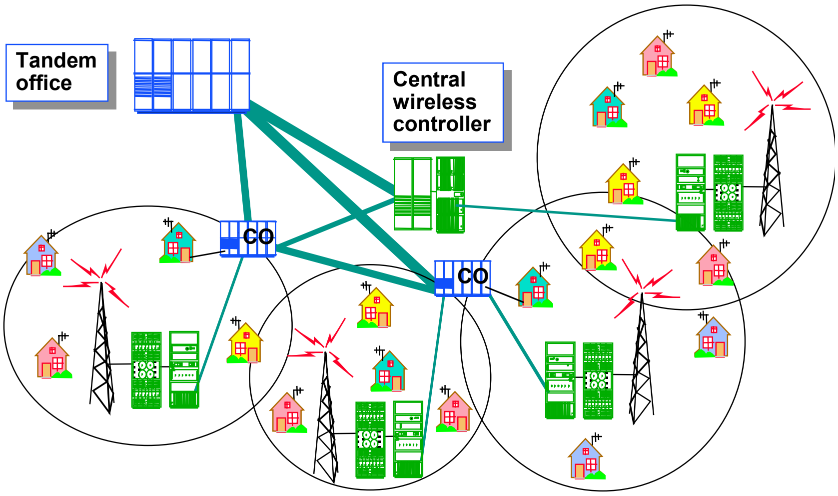
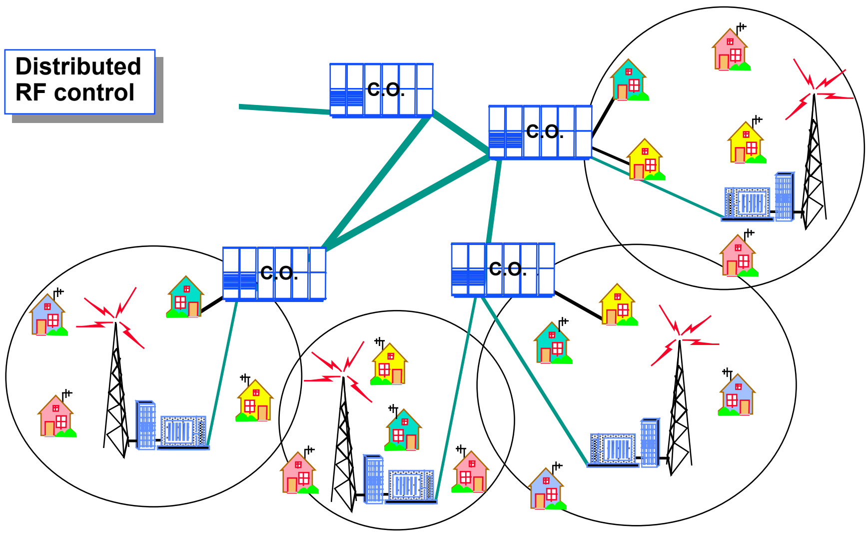


FIGURE 10

DLC based implementation



4.5 Technology evolution

This section of the handbook describes how wireless technology is evolving to support the wireless access application. Terminals, cell-site and base radio, backhaul, and switch/network technology components will be addressed.

4.5.1 Terminals

The key drivers in wireless terminal technology will continue to be low-cost and miniaturization. Longer-life, more-efficient battery technology is aggressively being pursued. In addition, the challenge is to increasingly provide wireline-like quality, performance, and feature-set.

4.5.2 Cell-site/base radio

Multi-channel RF access technologies (TDMA, CDMA) are increasing the traffic-carrying capacity of wireless access systems. High-speed digital signal processing (DSP) techniques and software-definable radios are yielding further advancements in radio flexibility, performance, size, and cost. Codec technology is rapidly moving forward to attain higher and higher levels of voice quality.

Radio resource management, and improved operations, administration and maintenance (OAM) are redefining performance and provisioning rules in the network. Clever dynamic channel assignment methods, powerful diversity schemes and hand-off algorithms, and effective dynamic power control methodology reduce co-channel and adjacent channel interference resulting in higher network capacity and performance. Sophisticated fault detection, isolation, performance monitoring, and automatic commissioning and calibration sub-systems are adding flexibility and operations efficiency in wireless networks. Wireless network test-beds and simulators are used to evaluate the capacity-performance and OAM trade-offs of the various radio resource management options.

Integrated circuit technologies will continue to be the key for future wireless communications. Superior performance, lower cost, smaller size and reduced power consumption are the key drivers for the various integrated circuit technologies being evaluated. Filter and interconnect devices, both direct and dual conversion transceiver architectures, and an array of mixers and power amplifier topologies are under examination in the context of power handling, noise figures, and power consumption.

Silicon and gallium arsenide (GaAs) semiconductors exhibit different performance parameters as a function of frequency. This influences the choice of circuit topologies and transceiver architecture. RF, IF, and baseband filter research is under way. In addition, interference suppression and spectral shaping have been evaluated under various digital modulation formats. Finally, packaging technology is being evaluated in the laboratory, including chip on board (COB), tape automated bonding (TAB), and flip-chip mounting techniques.

Future wireless systems require more cost-effective, less obtrusive antennas. Adaptive electronic antennas that automatically optimize carrier-to-interference ratio (*C/I*) will further increase capacity and performance of wireless networks.

4.5.3 Backhaul

Higher network capacity through use of smaller and smaller cells increases backhaul infrastructure cost since more sites need to be interconnected to the switch. Backhaul systems must be carefully designed in the context of existing and evolving physical plant – twisted pair, coax, fibre, and radio to achieve acceptable cost structures.

4.5.4 Switch/network

Intelligent network (IN) functionality, and high-performance network processing and signalling allows transfer of subscriber data across the Public Switched Telephone Network (PSTN) and cellular (IS-41, GSM) networks. This ensures transparency of service to subscribers across both mobile and wireline network. This is essential to delivering innovative services and accurate billing records.

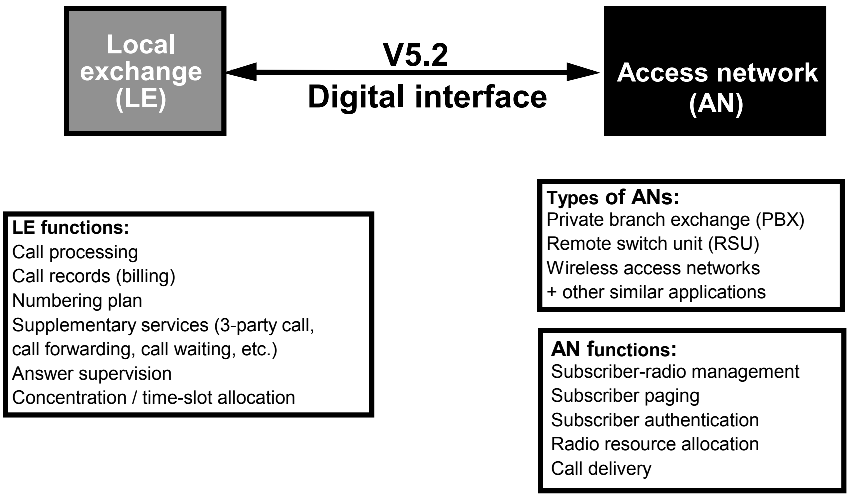
Wireless access system - PSTN V5.2 Interface

The V5 interface, as specified by ETSI and ITU-T and indicated in Fig. 11, is an open interface between the local exchange (LE) and an access network (AN), such as a wireless access network, remote switching unit, or private branch exchange. The LE provides the landline call processing control, call record collection, numbering plan and supplemental services for the system, such as three party calling and call waiting. The wireless access system handles call delivery to the end user. The V5 specification allows a wireless access system to leverage off the existing landline network functions and provides end users access to PSTN services.

The V5 interface is an open control protocol designed to deliver the telecommunications services residing on a local exchange to multi-vendor equipment in the landline distribution or access network. Because V5.2 is an open interface, it frees telephony service providers from being locked into proprietary switch interfaces for network interconnection with wireless access networks, remote switching units, or private branch exchanges.

FIGURE 11

The V5.2 interface



For wireless access applications, the AN provides for radio subscriber management, subscriber paging and authentication, radio call delivery, radio resource allocation and transcoding between the air interface and the standard 64 kbit voice trunks on the E1 lines to the local exchange.

V5 has two parts, as specified by ETSI and ITU-T. V5.1 (ITU-T Recommendation G.964 V-Interfaces at the Digital Local Exchange V5.1 Interface for the Support of Access Network) requires one time slot per subscriber and offers no trunking of subscriber time-slots. V5.2 (ITU-T Recommendation G.965 V-Interfaces at the Digital Local Exchange V5.2 Interface for the Support of Access Network) allows time-slots to be "trunked" or shared among subscribers, enabling concentration and associated cost savings.

V5.2 provides wireless access subscribers the following advantages:

– Wireless customers receive the same level of service as wired customers – V5.2 allows transparent delivery of PSTN or LE functions and services such as billing, numbering plans and supplemental services delivered by the switch (such as call forwarding, call waiting, 3-way calling etc.).

– Telephony service providers have several options for line expansion – V5.2 supports PBXs, two wire pairs, remote switching units, high speed data lines and fibre access systems, in addition to wireless access networks.

– Telephony service providers can realize the advantages of multiple LE vendors – V5.2 open interface provides many choices in vendors and hence choices in services and competition in prices.

– Fewer LE connections to the access network – V5.2 is a trunked interface which allows time slots to be allocated and shared between subscribers on a per-call basis. This approach is both more cost-effective and more robust.

– Reduced complexity of network and hence reduced cost – V5.2 allows functions traditionally performed by the LEs to remain there (such as billing and advanced feature delivery) and frees the access network to provide only those call delivery functions required by wireless access, e.g. radio subscriber management, subscriber paging and authentication, radio resource allocation and transcoding.

FIGURE 12

V5.2 Local exchange to access network connectivity

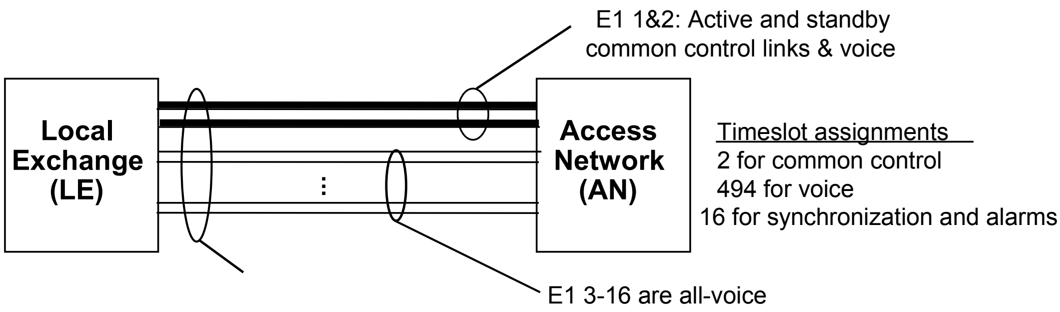


Figure 12 illustrates the V5.2 connectivity with active standby common control signalling utilizing the V5 protocol. Each V5 route consists of 16 E1 links that support 32 time slots each. Time slot 0 is per the E1 specification used for synchronization and alarms. The first two E1s contain one common control link, one is active and the other is on standby, each consisting of one E1 time slot (time slot 16). The remaining time slots and E1s are used for dynamically allocated voice channels. A total of 494 voice trunks are available (16 E1s x 31 time slots -2 control channels). Where V5.1 multiplexes a single time slot to each user, V5.2 adds concentration, which dynamically allocates a time slot to each user.

The V5.2 interface provides the system with greater operational control and functional efficiency. V5.2 supports more subscribers per E1 link and thus can be implemented at a lower total cost and is thus more efficient than V5.1, and many other types of non-V5, non-concentrating PSTN interfaces. V5.2 also provides for increased fault tolerance which results in overall improved quality and reliability for the customer.

4.6 Classification of fixed wireless access systems

Fixed wireless access systems can be classified as "cellular-grade", "wireline grade" and "broadband".

Cellular-grade systems are characterized by the use of air interfaces standardized for mobile telephony applications. The advantage of this strategy is the economy of scale that results from using major radio components which are manufactured in high volume for the mobile market. Cellular-grade wireless access systems may share the same cell site and network infrastructure used for mobile cellular systems, or they may use dedicated networks. Cellular-grade systems typically use low bit rate speech coding and offer link reliability comparable to mobile cellular calls made over a cellular-based mobile system. The networks supporting these systems tend to be based on stand-alone switches developed for cellular-based mobile systems, rather than as adjuncts to existing telephone central office switches. Thus, cellular-grade systems are especially well-suited to large rural or urban areas of low traffic density, previously unserviced, or to be served by a second telephony service provider.

Wireline-grade systems tend to be based on proprietary air interfaces. These systems tend to use higher bit rate, toll quality speech coding, which allows fax and modem signals to be passed transparently in the speech band. Often, such systems are deployed as autonomous adjuncts to existing telephone central office switches. In most cases, subscriber sites require directional, rooftop antennas in order to provide link reliability comparable to a wireline link. In addition to systems which provide circuit-switched voiceband connections, some wireline-grade systems provide packet-switched connections which offer comparable burst rates and features to digital subscriber line wireline technology and cable modems. Such systems include advanced communications applications such as MMDS in the 2.5 GHz band.

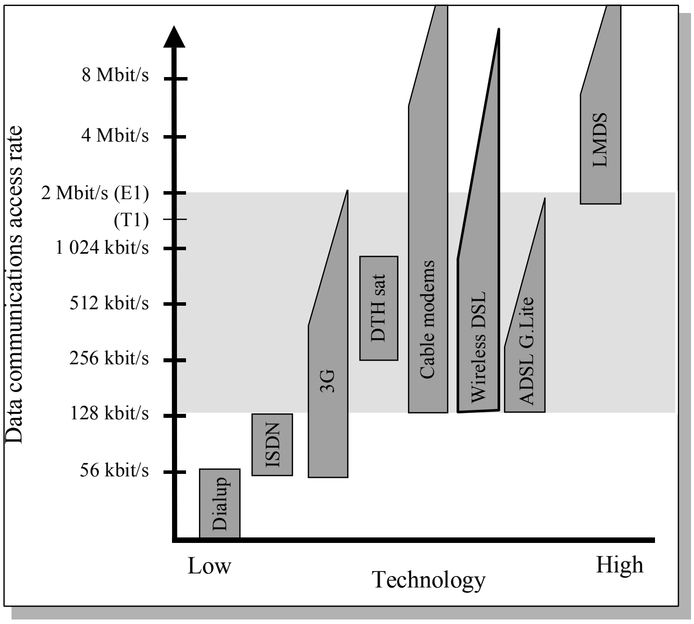
Fixed broadband wireless access (BWA) systems offer bit rates to each subscriber site above primary rate access. The systems that operate at frequencies above 10 GHz require line of sight paths and highly directional subscriber antennas. Link reliability is engineered to be high, comparable to a wireline or fibre-optic connection. The systems that operate at frequencies below 10 GHz also support non-line-of-sight and near-line of-sight paths and are suitable for individual residential subscribers and small offices.

4.7 Broadband wireless access

One type of broadband wireless access system is referred to as wireless digital subscriber line (wDSL), which provides high-speed data service capabilities comparable to cable modem and xDSL offerings over a wideband wireless access channel. The product offering provides a new wireless access solution that eliminates "last mile" bottlenecks which inhibit high-speed data/internet access abilities. Depending upon subscriber loading, average data rates will be 256 Kbit/s-2 Mbit/s per user, with peak rates up to 10 to 30 Mbit/s. Figure 13 shows wDSL data rates in relation to other high-speed access solutions.

FIGURE 13

Access rate vs. technology



• Dialup/ISDN for BW below 128 kbit/s
• Cable modems (CMs) for 128 kbit/s to 20+ Mbit/s
• xDSL/G.Lite for 128 kbit/s 1 Mbit/s + service
• Wireless access emerging to compete with CM/xDSL
• wDSL suitable for medium rate connectivity
256 kbit/s –> 2 Mbit/s
• LMDS a high end system
T1/E1 and above

Land 013m

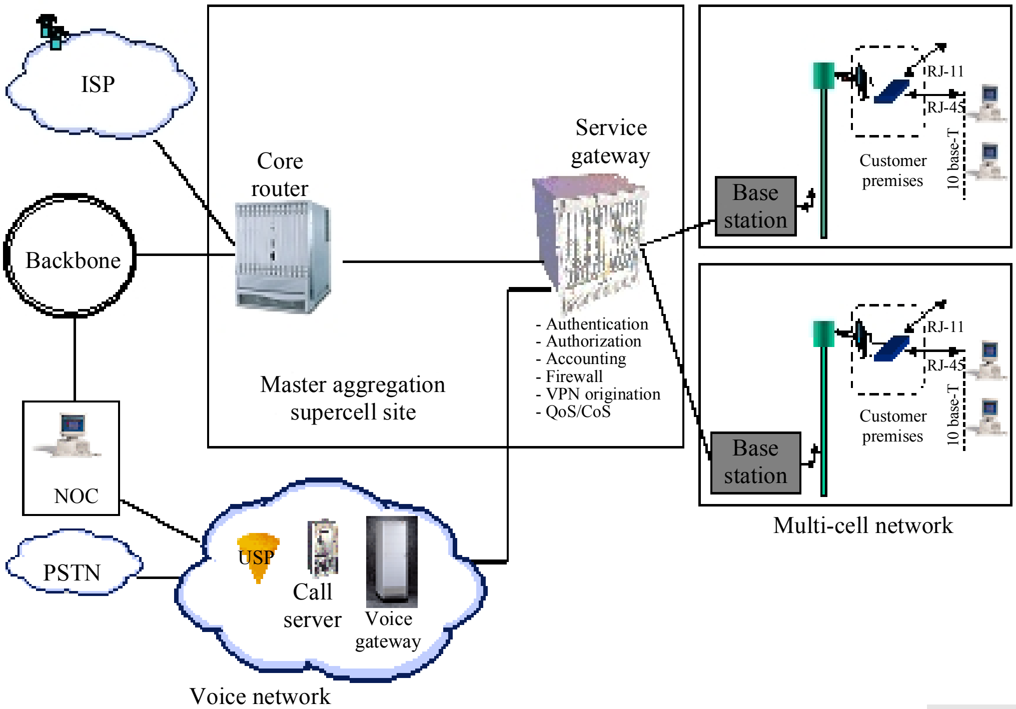
A typical end-to-end Wireless DSL solution provides the following capabilities:

- The single or multi Cell implementation approach enabling cost effective market penetration.
- As much as 30 Mbit/s per customer site in a burst mode downstream application.
- A range of CPE solutions for single dwelling, multiple dwelling unit (MDU), small office-home office (SOHO) and small to medium business (SMB) applications.
- Firewall, addressing, authentication and overall O&M integration.

The diagram below illustrates a typical wireless DSL system deployment for high-speed data and voice service.

FIGURE 14

Wireless DSL system architecture



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CHAPTER 5

KEY FACTORS AFFECTING TECHNOLOGY CHOICES

5.1 Introduction

The contents of this chapter (Chapter 5) are based on a study commissioned by the European Bank for Reconstruction and Development on key technological and policy options for the telecommunication sector in Central and Eastern European countries*. The purpose of the study was to provide relevant information and guidance to both network operators and policy makers in decision-making regarding technological options to be used in introduction, replacement, modernization and extension of telecommunication networks in their countries. In reviewing the report of this study, it became clear that its findings and conclusions would be very useful to the developing countries in their efforts to improve and enhance their telecommunication facilities.

The existing telecommunication networks in the developing countries are either obsolete or inadequate to provide the platforms on which modern industrial economies are built. Failure to remedy this critical shortcoming will limit the ability of many developing countries in improving living standards for the majority of their people.

The need to make rapid and significant progress in telecommunications is well documented and well understood. There is also a commonly held view that developing countries are well positioned to "leapfrog" their peers in the developed economies, with respect to the introduction of wireless technology. There is less agreement, however, regarding the technologies which should be employed and the policies which could be pursued to promote development in telecommunications. The two main themes to be considered are:

– **Technology choice:** what technologies are (or will be) available to operators in the developing countries and what factors will influence the choices between these technologies?

– **Sector policy:** what impact will alternative policy choices have on the performance of the telecommunications sector and economic welfare more generally in the developing countries?

The economic characteristics of the industry and technology have had a significant bearing on the policies which have been pursued in the telecommunication industry to date, particularly regarding the provision of services and infrastructure. Among those which are most relevant are:

– the high fixed costs and lengthy lead times typically associated with establishing a telecommunications network;

– the presence of economies of scale and scope;

– the significance of a relatively small number of key cost drivers (number of customers, customer densities and calling rates);

– the presence of network externalities (such as the benefit derived by existing customers when a new customer joins the network).

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* DAVIES, G., CARTER, S., MACINTOSH, S., *et al.* (COOPERS and LYBRAND) and STEFANESCU, D. (EBRD) [March, 1995], Key Technological and Policy Options for the Telecommunications Sector in Central and Eastern Europe and Former Soviet Union. Coopers and Lybrand and the Telecommunications Team European Bank for Reconstruction and Development (EBRD), London, United Kingdom.

5.2 Wireless access technology

The development in wireless technology – either current or future – reinforces the change in view regarding the local network. They also herald other significant changes to the way in which telecommunications infrastructures will be developed over time. For example:

– experience from a large number of countries now demonstrates that competition in the provision of mobile cellular services is viable;

– wireless and specifically fixed wireless access services are likely to provide a more cost-effective access solution in some locations (compared with the cost of a wireline network solution);

– finally, wireless access technologies are capable of being deployed much more rapidly than wireline technology, particularly in the local network, thus offering the prospect of responding very rapidly to the demand for service.

Clearly, much depends on the continued pace of advance in wireless technology but the prospects are that over the next decade wireless access based solutions will have a significant impact on the development of those telecommunication networks which are not currently particularly mature, as well as on the overall competitive structure of the industry.

5.3 Technology choice

In the following sections analysis and conclusions are provided to assist the developing countries in the decision-making on choice of wireless access technologies available for use in the access network, for existing operators or new entrants.

The purpose of the analysis is twofold:

– **first**, to provide guidance to network planners on current and future trends in technology, and

– **second**, to provide specific quantitative estimates of the costs of alternative technologies.

5.4 Technology models

The analysis model made use of the following elements:

– defining the relevant demand parameters (number of customers/customer densities and calling rates);

– designing the networks required to meet the specified levels of demand – which in turn determines the type and volumes of equipment required;

– determining the costs of building and operating the networks taking into account capital equipment costs, installation costs, and direct operating costs;

– converting the network costs into a cost-per-line to allow comparisons between different technologies.

The models are used to analyse the costs of a number of wireless access technologies in comparison to the traditional copper pair networks.

Clearly, in developing these models a number of assumptions are necessary regarding, for example:

– customer volumes and densities;

– network dimensioning rules;

– equipment costs;

– installation costs;

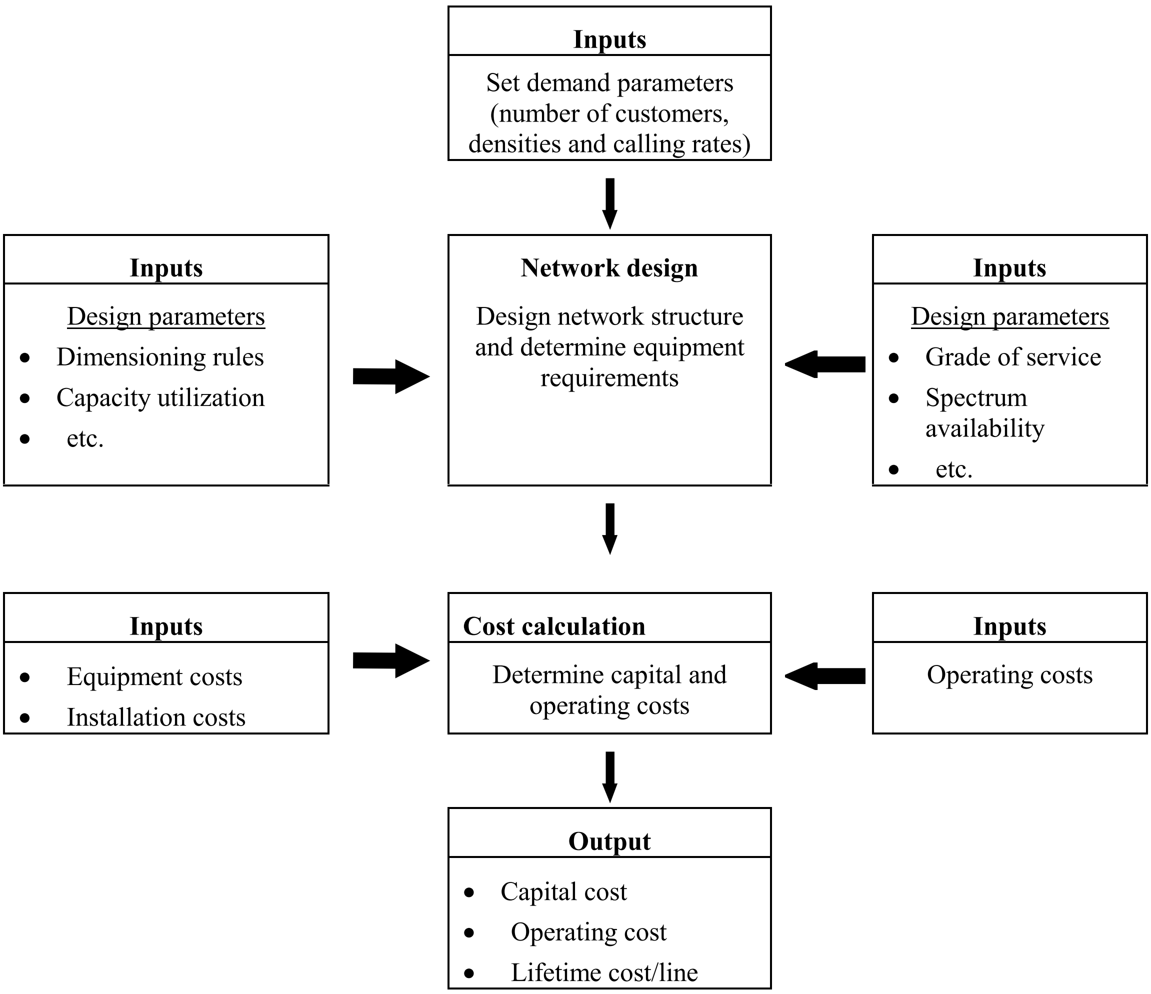
– network fill rates (i.e. capacity utilization);
– grade of service;
– operating costs;
– trends in equipment and labour costs;
– the availability of frequencies (which is critically important for wireless based technologies).

In computing the costs associated with different technologies, the "lifetime cost" per subscriber is used rather than measures such as capital cost per line or per subscriber. The definition of lifetime costs attempts to capture all of the direct costs associated with using a particular technology – capital, installation and direct operating costs – and allows for the replacement of equipment where appropriate.

Technology selection must take into account not just acquisition cost and service factors but a wide range of technical and non-technical considerations such as the availability of skills and expertise and the sensitivity of the selection to forecasting errors. Technology selection must also be based on a sound understanding of the planned development of the network – a network master plan (see Fig. 15).

FIGURE 15

Technology models and structure



No single technology is likely to meet all market and operational requirements. In many cases there will be no clear cut "optimum" technology, but rather a number of technologies each with slightly different characteristics. In choosing between technologies, for either a new network or an existing network, a very wide range of factors need to be considered. There is, almost inevitably, a tendency to focus on two main factors; conformity with the relevant technical specification, and the acquisitions cost of equipment.

These, however, do not capture the full complexity of some of the decisions facing operators. In particular, consideration also needs to be given to:

– the maturity of the technology;
– the scope for knowledge transfer;
– the availability of local skills for installation and maintenance;
– the ongoing maintenance cost;
– the expected level of on-going support;
– the sensitivity to network planning errors and amendments;
– the cost of interworking with existing technologies;
– avoidance of being "locked-in" to particular suppliers or technologies;
– the extent of "future proofing" provided by the technology.

These factors greatly complicate the decisions facing the developing countries and inevitably limit the extent to which general considerations on technology choice can be expected to apply regardless of the specific local circumstances.

A further crucial factor is the need for each operator to establish and maintain a strategic direction for its network and to ensure that equipment selection is undertaken within the framework of that plan. This will ensure the strategic development of the network, and should limit, for example, problems of interworking between different parts of the same network.

5.5 Market requirements

Traditionally, more than 90% of the revenue of public telecommunications comes from telephony, although this may be changing due the explosive growth of the Internet. Voice communications is the key service both for the existing and new operators. Furthermore, in excess of 80% of the traffic on telephone networks in most developed countries, is live speech and in the developing countries is even higher. Given the continuing dominance of telephony traffic and the acute supply shortages prevalent in the developing countries, it is clear that the overwhelming need is for technologies, which offer and support basic services.

Nevertheless, it is also important to recognize the growing needs of businesses for both basic and advanced telecommunication services, particularly in view of the role of the private sector in promoting growth in the developing economies. While voice traffic will continue to dominate, value added services, high-speed data, mobility and, ultimately, video will increasingly be required. This is particularly significant for the choice of technologies in the access network as the capabilities of various technologies to support these services differ markedly.

This poses a dilemma for network operators: should the thrust in development of new access technologies be placed on high cost, high bandwidth technologies, or on lower cost, but lower bandwidth, technologies?

All of the technologies considered are capable of supporting speech communications and other services which can be data encoded in 4 800 bit/s and below. The technologies will, however, differ in their ability to support other services as illustrated in Table 1. As technologies progress, further capabilities will be added to access services (e.g., wireless access video).

TABLE 1

Access technologies and services

	Services				
Access technologies	Speech	Low speed data	High speed data	Single channel video	Multi-channel video
Copper pair lines	✓	✓	✓	✓	
Fibre	✓	✓	✓	✓	✓
Wireless access	✓	✓	✓	✓	✓
Mobile wireless	✓	✓	✓		

5.6 Technology criteria in the access network

Current and future service requirements can be broadly categorized by customer segment as is shown in Table 2. This table illustrates the extent to which service requirements are likely to develop differently across customers segments. Given that these differing requirements may also require the deployment of differing technologies, operators will have to take medium-to-long-term views regarding the choice of technology in anticipation of both market requirements and the likely developments in technology to avoid being locked into redundant technologies and to reduce the cost of meeting new and emerging needs.

TABLE 2

Service requirements

Customer type	Current service needs	Additional future service needs
Large business	Multi-channel telephony Fax Data Mobility	Video telephony Video conferencing High speed data
Smaller medium sized enterprises	Telephony Fax Data Mobility	Video telephony High speed data Videoconferencing
Residential	Telephony Data Mobility Fax	Mobility Entertainment video Fax

5.7 Access

The access is defined as the transmission path between a customer's fixed telephone terminal equipment and the local exchange.

Since the introduction of the telephone, the access has been provided almost universally by means of twisted copper wires. This provided a simple and relatively low-cost means of connecting subscribers which can be used over a very wide range of subscriber densities, from the most dense urban areas (in excess of 1 000 subscribers/km^2) through to very low-density rural areas (with less than 1 subscriber/km^2).

The major limitation of a copper pair network (used for speech) is a restriction on the maximum length of an individual cable-beyond which the signal is too weak to provide satisfactory transmission quality. Thus copper pair networks have developed around the concept of siting a local exchange at the geographic centre of subscribers with cables being extended in a star configuration up to a maximum distance of, typically, 15 or 20 km. This configuration is then replicated throughout the area in question to provide access to all subscribers.

The access is a critical element of a telecommunications system for a number of reasons:

– **first** the access is the delivery mechanism for telecommunications services, and its cost, quality and functionality has a major bearing on the overall characteristics of the individual service as perceived by the subscribers;

– **second** the access accounts for a significant part of the overall capital and operating cost of any telecommunications network. The cost of the access can account for up to 60% of the overall capital cost incurred by a new operator, while even for an established operator the access can account for more than 30% of overall costs*;

– **third** the access represents the greatest "sunk" investment incurred by an existing or new operator;

– **finally**, it has been suggested by many commentators that the access constitutes a "natural monopoly" – i.e. the economies of scale (and scope) are such that one operator is able to provide service more cost effectively than two or more operators.

5.8 New technologies in the access network

While copper-based wire networks are still used in the majority of local distribution networks, considerable effort is being directed towards the development and application of wireless access technologies in the access network. The cost of a wireline network increases with distance, while the cost of a wireless network is constant up to the limit of the range of the radio system. Thus there is a break-even distance above which a wireless system will be cheaper.

The costs of the wireline network are dominated by the labour costs (digging up and reinstating the roads, installing ducts and laying the cable) and these are expected to increase over time. The costs of the wireless access network on the other hand are dominated by equipment costs and these may be expected to continue to fall over time. The result is that the break-even distance between wireline and wireless access will decrease, thereby increasing the opportunities for a wireless access solution.

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* Typical figures from various telephone operating companies in the United States of America.

In examining the choice of technology for the access network the critical factor from a cost perspective is subscriber density. The cost per subscriber of a wireline access rises as the density falls, and at very low densities the cost rises very rapidly. For example Telia has estimated that in Sweden the cost of serving the 5% of subscribers in the least dense area represents almost 25% of the total access costs. Subscriber numbers and subscriber densities are the fundamental determinants of access costs. But no single technology is ideally suited to all subscriber densities.

5.9 Wireless access systems

The last three years have seen a rapid growth of interest in the use of wireless access based systems in the access network. Many new technologies and standards have been proposed, some of which are offshoots of "mobile" technologies while others are designed specifically for fixed use.

Wireless access technology has a number of key characteristics which make its deployment in access networks potentially very attractive:

– **Speed of implementation:** fixed wireless access can be implemented some 5 to 10 times quicker than equivalent copper based systems;

– **cost structure:** wireless access exhibits distance independent cost within the coverage area which is particularly important in relatively low density areas where the distances between subscribers are high;

– **operational benefits:** operating costs may be reduced as wireless access systems are not subject to the physical disturbance problems that are associated with copper based systems;

– **capacity planning and utilization:** the investment cost curve associated with wireless access systems more closely follows subscribers growth than is the case for wireline based networks – i.e. the investment can be made in smaller steps as the subscriber's population grows;

– **subscriber planning:** wireless access systems require significantly less in way of local network planning than in the case of wireline based systems. In general, wireless access systems are more tolerant of an operator having a lack of detailed knowledge of the precise location and density of customers. This is particularly attractive to new, competing network operators who cannot be sure precisely which customers will find a competitive offer attractive.

However, wireless access systems also suffer from a number of disadvantages:

– **constraints on spectrum availability:** this is one of the biggest hurdles for deploying wireless access systems in the developing countries since the most appropriate frequencies may already be employed in alternative uses;

– **restrictions on bandwidth per customer:** this significantly limits the services which can be offered to customers;

– **absence of agreed international standards:** the lack of agreed standards means that manufacturers are offering either mobile technologies (for which the spectrum may already be in use for mobile services) or proprietary systems which may lessen the choices available to operators once the initial technology choice has been made.

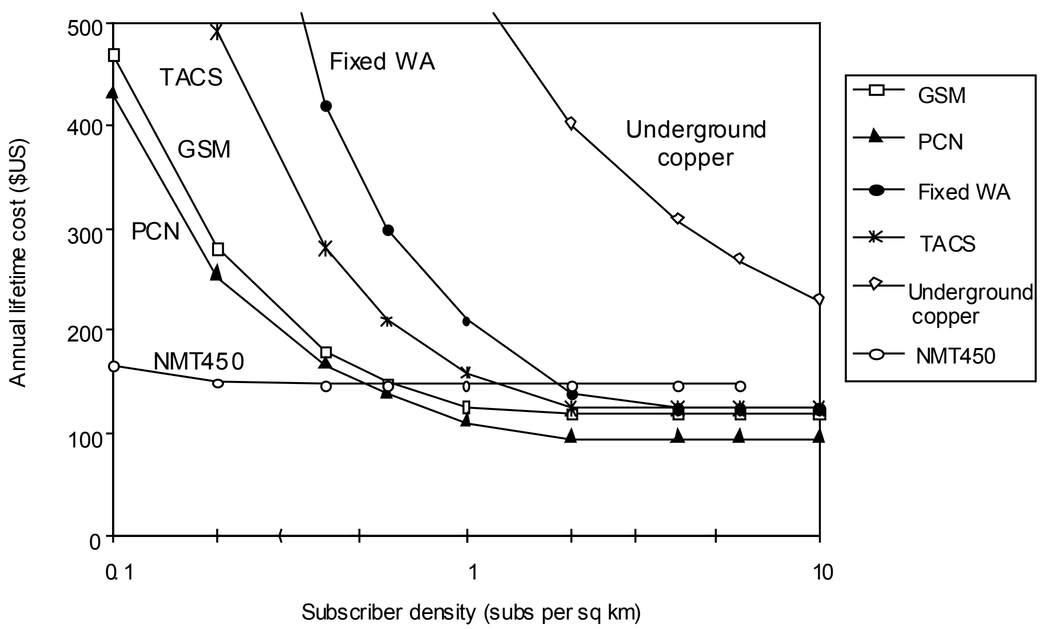
Some of the different technologies are described in Annexes 4 and 5 whilst Chapter 7 gives an overview.

The lifetime costs per subscriber were analysed for a number of wireless access technologies that have been proposed or are in use for the access network: In particular: NMT 450; TACS, AMPs; GSM; DCS 1800, PCS 1900 (US), Fixed WA (TDMA based). For details on the models and assumptions used for the calculations the reader should refer to the study*. The annual lifetime cost contains the capital cost, the operating cost and the replacement cost.

The analysis shows that the costs of wireless access has fallen considerably in the last few years and that wireless access solutions are now capable of providing a cost-effective alternative to a wireline access system. In particular wireless access systems are attractive at lower subscriber densities as the costs of a wireless access system do not increase with the distance to the subscriber (up to the propagation limit of the cell) (see Fig. 16).

FIGURE 16

Comparison of lifetime costs – Wireless access vs. wireline systems for very low subscriber densities



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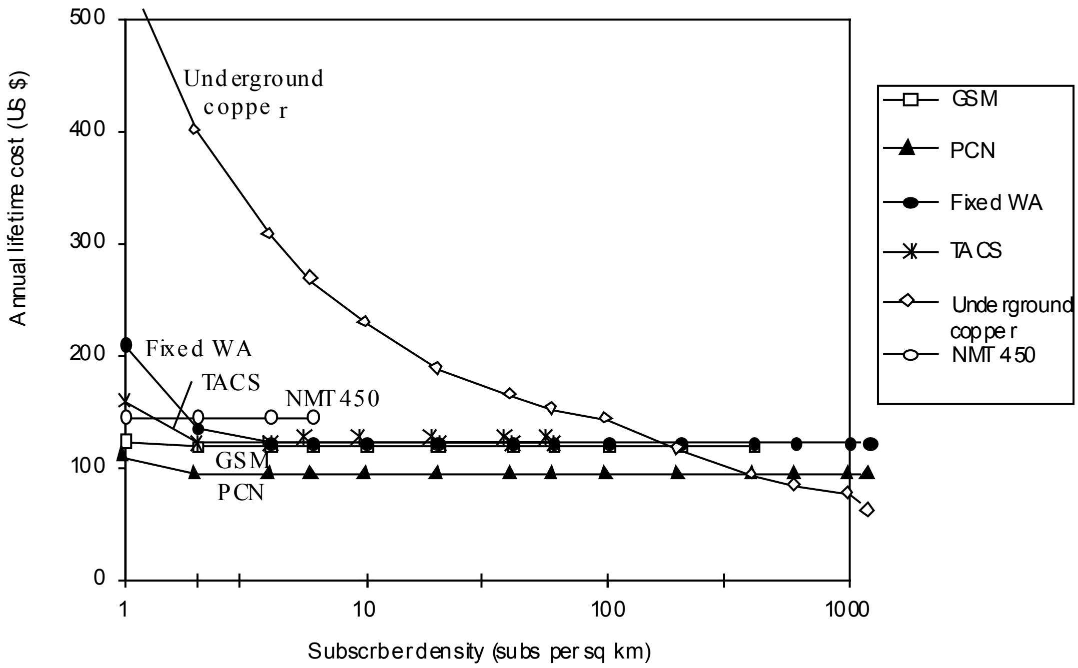
* DAVIES, G., CARTER, S., MACINTOSH, S., *et al.* (COOPERS and LYBRAND) and STEFANESCU, D. (EBRD) [March, 1995], Key Technological and Policy Options for the Telecommunications Sector in Central and Eastern Europe and Former Soviet Union. Coopers and Lybrand and the Telecommunications Team European Bank for Reconstruction and Development (EBRD), London, United Kingdom.

FIGURE 17

Comparison of lifetime costs – Wireless access vs. wireline systems for low to high subscriber densities



Wireless access systems offer lower lifetime costs per subscriber than a wireline based network at lower subscriber densities – below approximately 200-400 subscribers/km^2 (assuming average residential calling rates). This assumes, however, that spectrum is available.

The exact position of the crossover point depends inevitably upon the assumptions made, and will vary depending on traffic levels and the actual distribution of subscribers.

Nevertheless the analysis suggests that a significant percentage of residential subscribers could be cost effectively provided with fixed wireless access. This does not mean that current operators will rapidly replace their existing copper networks with wireless access systems, but it does indicate that new market entrants, or operators in new areas, are likely to make increased use of wireless access.

Wireless access based systems are cost-effective for the provision of telephony and broadband services to typical residential subscribers, small businesses and educational institutions particularly in rural and suburban areas, or for new entrants in competitive urban markets.

The analysis clearly suggested that wireless access is a very attractive local access technology for new market entrants. The figures presented are in terms of subscriber density not population density. In practice it could take a new operator several years to achieve subscriber densities approaching 400 subscribers/km^2 even in urban areas, and in suburban and rural areas this figure may never be achieved where there is more than 1 competing operator. At very low densities, below about 1 subscriber/km^2 – the majority of the wireless systems exhibit a rapid increase in the cost per subscriber as the cells reach their maximum size and additional cells have to be added to accommodate increased subscriber spacing. By the time the subscriber density has fallen to 0.1 subscriber/km^2 the lifetime cost has increased to between 500 and 1500 US $ per line except for low frequency systems (such as NMT450). However wireless access would still provide a cost-effective way of providing the services relative to wireline (see Fig. 16).

5.10 Conclusions

The main conclusions are:

– that wireless access based systems are likely to be cost-effective compared to traditional copper networks at customer densities below 200-400 subscribers/km^2. Many residential consumers will therefore be most cost-effectively served via wireless access systems; the attractiveness of wireless access based systems will also be influenced by customer acceptance;

– wireless access based systems can be developed cost-effectively and their roll-out can be tied closely to the take-up of service by customers. Sunk costs can also be minimized and wireless access based systems are likely to be preferred by new operators who wish to provide large scale telephony services.

CHAPTER 6

DEPLOYMENT PLANNING OF WIRELESS ACCESS SYSTEMS

6.1 General

This section outlines and describes the areas that must be carefully, thoroughly and thoughtfully, addressed in planning the deployment of wireless access systems. In each area described, the important factors to be considered are noted and briefly discussed. However, it must be recognized that the information provided here is only an outline and a summary. Books could be, and have been, written on each of the areas discussed below. More detailed information on this subject is provided in Annex 3.

Successful deployment planning of a proposed new wireless access system requires a thorough understanding of the proposed business plan, and the intended customer/subscriber base. It also requires a good knowledge of the demography and the topography of the territory where the service is to be deployed/provided. Another essential component in the planning process is detailed radio engineering knowledge, experience, and skill.

6.2 Service needs planning

Careful consideration has to be given to the services which are to be provided, both initially and in the future. Areas which must be considered are outlined below.

6.2.1 Functionality

It is necessary to define with considerable precision the services which are to be provided. This definition must include both voice and data services, the interfaces which are to be supported, the type of mobility that is required, and other needed features.

a) Voice and data services

Since radio spectrum is scarce and costly, use of low bit rate encoding provides economy of spectrum utilization at the expense of voice quality and data rates. High bit rate encoding provides higher quality voice service, and higher data rate capability at the expense of spectrum utilization. As coding algorithms improve, there is a gradual rise in the quality of voice transmission that can be supported by a given bit rate.

Low bit rate service provides good economies, especially in satellite services where the cost of the space segment power/bandwidth may be high; while "mid range" bit rate service uses more bandwidth, it provides full toll grade voice service (see ITU-T Recommendation G.711), and supports fast personal computer modems. For satellite services, the voice quality entails high power/bandwidth costs.

ISDN basic rate service requires higher bit rates. It can provide 7 kHz voice service (see. ITU-T Recommendation I.241.7), and data service at a bit rate of 64 kbit/s (see ITU-T Recommendation I.231.1).

Higher data rates may be required, for example 1.5 Mbit/s, or 2 Mbit/s, or ISDN primary rate service. Land mobile services which support these data rates, or higher, for example providing network quality full motion video, require much more radio spectrum.

b) Mobility

Mobility requirements must be considered, defined, and provided for. For technical reasons, there is a trade-off between mobility and service quality, and between mobility and network complexity which increases network cost. A higher mobility requirement will lower service quality and increase network cost.

A fixed service has no handover requirement, and provides the highest quality service at the lowest network cost. Pedestrian speed mobility involves modest quality loss and modest network cost increase. Mobility at motor vehicle speeds leads to greater loss of quality, and more network complexity and cost to accommodate the rapid cell switching which is required.

c) Other service features required

– Authentication

Networks that provide mobility typically require authentication procedures, to confirm that every access to the network originates from a legitimate, authorized and billable subscriber.

– Privacy

This may be a required service feature, requiring the selection and provision of appropriate network-based encryption arrangements.

– Terminal types supported

It is necessary to define specifically the types of terminals that will be supported, including data terminals (e.g., V.11, V.24, V.35, etc.), and voice terminals (for example payphone types – prepay, semi-postpay, etc.). Will standard, low cost, readily available wireline sets be supported?

6.2.2 Future service capabilities

a) Evolvability

It is important to make appropriate provision in the deployment planning process to ensure that future service requirements can be met. Service attributes noted under § 6.2.1, may not be required initially, but may be needed in the future. In fact, other functions and attributes, not now contemplated, and sometimes not yet even known, may become a future requirement. The network deployment plan, and the technology chosen, should be sufficiently flexible and sufficiently capable to respond effectively and economically to future functionality needs.

b) Customer base

The number of customers served will undoubtedly grow over time. The network deployment plan must be able to increase capacity in a convenient and economic manner, so as to provide good continuing service as the customer base grows.

c) Coverage area

It may well be appropriate in the future to expand the coverage area in which service is provided. The network deployment plan should be prepared so as to ensure that expansion opportunities can be implemented in an orderly and economic way.

6.3 Telecommunications network planning

6.3.1 Traffic carrying needs

Wireless access systems invariably suffer from contention in the access. For this reason, traffic engineering considerations are essential in the initial deployment planning and design of wireless access systems, and in their ongoing operation. In "conventional" cabled access networks ("wireline access networks"), each main telephone (or data) line ("network access service") is physically connected by a unique, dedicated cable pair between the terminal and the telephone exchange. Under this arrangement, there is no contention, and no traffic engineering requirement, since all terminals can have access to the exchange at all times.

Digital line carrier systems are also available and are widely used. These systems, depending on their basic design, may or may not involve concentration. If there is no concentration, each main telephone line has independent access to the telephone exchange. If the system provides concentration, its deployment planning must consider the traffic engineering considerations described below.

The traffic engineering of a wireless access system must relate the traffic-carrying capacity of the system to the traffic which is expected from the customers which the system will support. Experience indicates that, in general, business customers offer more traffic than residence customers, and pay phones offer more traffic than business customers. The traffic offered by individual customers varies over a wide range, and the offered traffic also varies by time of day. Where service is provided to customers in previously unserved areas, experience indicates that their calling rates will increase over time.

The use of data services must also be considered. A system which "stacks" multiple low speed data services on a single system trunk can greatly increase the system's data traffic capacity. It is also important to ensure that sufficient capacity is provided for inward calls, especially those that are long distance, to be able to reach their destination. Inward long-distance calls which do not reach their destination represent lost valuable high-margin revenue.

It is a characteristic of traffic flow that the relationship between the number of system trunks and the traffic capacity is not linear. Larger trunk groups provide relatively more capacity, so that doubling the size of the trunk group more than doubles the traffic carrying capacity.

The initial deployment planning and design of a wireless access system must use the best information available. After the system is put into service, the actual traffic performance of the system must be monitored and managed, to determine how closely the in-service performance matches expectations, and to make appropriate adjustments if and when necessary.

6.3.2 Operations and maintenance

To ensure the ongoing sustained provision of high quality service by the new wireless access system, arrangements for its continuing operations and maintenance must be carefully planned and provided for. It will generally be desirable to integrate these functions as closely as possible with the operations and maintenance procedures that are already in place for the public switched telecommunications network (PSTN) that the new wireless access system will connect to. Wide experience has indicated that conformance to, and integration with, existing arrangements is much more satisfactory than implementing unique or special procedures.

Trouble reports from subscribers and failure reports from the radio system should follow normal existing reporting channels and procedures. Testing procedures should be possible for both the radio system and the subtending terminals from the existing test centre location. Repair dispatch and trouble clearance procedures should conform to existing arrangements.

For the efficient use of human resources, the telecommunication staff who already work the territory or adjacent areas should be trained and equipped to operate and maintain the new wireless access system. The installation, operation and maintenance of different wireless access systems requires varying levels of radio skills and expertise. As a practical matter, the lower the level of radio skill required, the better.

To address terminal troubles, for mobile terminals it will generally be appropriate to have these terminals transported to a designated, conveniently located repair centre. For fixed terminals, which may often be installed in remote and relatively inaccessible communities, an appropriate decision and arrangement is needed as to who will be responsible for their installation and maintenance. Here, particularly, the need for only low-level radio skills is clearly preferable.

Suitable support arrangements must be put in place. This will include the necessary training of the individuals in the field who will be responsible for system operations and maintenance, and the provision of the required test sets and an adequate supply of replacement spares. A field support arrangement will also be needed, to provide back-up support when field problems are encountered which are beyond the capability of the field personnel. Also, as noted above, there will be an ongoing need to monitor and manage the traffic capacity and the traffic load on the system, making appropriate adjustments as and when required.

6.3.3 "Backhaul" – Network connection and integration

In every case, the new wireless access system will be connected through a telephone switch in a switching centre to the PSTN. As previously indicated in Fig. 1, the linkage between the base radio/controller and the switch is defined as the "backhaul". The base radio/controller may be located within the switching centre, in which case the backhaul connection is very short.

However, if the base radio/controller is located remote from the switching centre, an appropriate backhaul capability must be provided, which could be via a fibre optic, coaxial, or copper cable, or via another radio system, for example a point-to-point or point-to-multipoint microwave system.

In the latter case, the backhaul radio system provides a separate but related deployment planning challenge. Both the backhaul system and the wireless access system have requirements in terms of functionality, service capabilities, traffic carrying capacity and management, and operations and maintenance. Provision of the backhaul by a point-to-multipoint microwave system with an integrated wireless access system provides for these requirements in an integrated, seamless way within a single management system. Where the backhaul radio system does not offer this integration, its functions and features need to be reasonably consistent with the wireless access system.

Under these quite typical circumstances, the deployment planning challenge is to optimize the overall plan and design, either integrating the backhaul and the wireless access system, or taking the best opportunity to relate the characteristics of the two separate radio systems.

6.4 Radio characteristics and engineering

6.4.1 Subscriber density

Subscriber density is a key factor in planning the deployment of a wireless access system, noting that this density addresses "subscribers" to the system, not merely "population" in the area. Of great importance within the concept of density is the distribution of the service requirement, whether it is approximately evenly spread over the area to be served, or as it is more typically by the case where and how the expected subscribers are clustered.

Growth in the subscriber base must also be considered, since not all potential customers will sign up for the service initially. Experience indicates that the subscriber base will increase over time, and the inherent difficulty in predicting where and when this will occur must be recognized.

In fact, information regarding subscriber density can have a significant impact on the choice of system, since some types of systems serve clustered requirements more cost-effectively, and others are better suited to serving widely distributed, isolated requirements.

6.4.2 Coverage area

The selection and definition of the intended coverage area is an important subject in planning the deployment of a wireless access system. Three factors are key in this decision area, and these factors influence and interplay with each other. The three factors are:

– the location and distribution of the intended subscriber/customer base;

– the practical coverage capability of the intended system, considering the topography and the distances in the area to be served;

– the ability to expand the coverage area, and the customer base, gracefully and economically when it is appropriate from a business perspective to do so.

These three factors are interactive, each affecting the others. As a result, the coverage area decision-making process will of necessity be iterative, in order to progressively approach and then to achieve the optimum solution.

6.4.3 Cell planning

Cell planning of the intended and future coverage area is a fundamental radio engineering issue in the deployment planning of a wireless access system. A significant level of radio engineering expertise and experience is required in this decision area. The cell planning must consider the entire area to be covered, even if the coverage requirement is not continuous. For example, this would be the case when service is being provided to specific separate villages throughout a rural area.

Several fundamental cell plans are possible. Selection of the best alternative depends on all of the factors outlined in this Chapter. Once the cell plan has been selected and implemented, it is relatively fixed. Future changes will involve significant disruption. A well planned network which provides appropriate flexibility will minimize disruption and expense. More information on cell planning is provided in Annex 3, § 8.

6.4.4 Radio propagation aspects

This area involves very key aspects of the science and art of radio engineering. A brief discussion of some significant aspects follows. More extensive and detailed information is provided in Annex 3.

A fundamental aspect of radio propagation is whether a line-of-sight exists between transmitter and receiver antennae. If a line-of-sight exists, good quality service can be assured, using lower power over longer distances. However, if line-of-sight cannot be assured, as is typically the case in applications which provide mobility, then the assured range will be curtailed and higher power will be needed.

Other factors which influence radio propagation include topography, for example a path over a large flat area, such as a body of water or a flat plain. Also, weather conditions, such as rain, influence the radio signal. These effects vary significantly between different frequencies. The adverse impact can be greatly reduced by making use of diversity arrangements, space diversity and/or frequency diversity, but these measures are both complex and costly.

Another frequency-dependent aspect is shadowing, the extent to which the signal is attenuated or cut off by hills and in valleys, and by intervening buildings or trees and forests. An additional aspect of concern is the shielding which occurs within steel-framed buildings, including, for example, parking garages and shopping malls.

Radio propagation characteristics depend on the frequency band selected, on the topography and the natural environment, on climatic conditions, and on obstacles in or near the radio path. The available spectrum for a specific service depends on government spectrum allocations and spectrum management. All of these factors influence the selection of an appropriate frequency band.

6.5 Summary

To be carried out most successfully, the deployment planning of wireless access systems requires substantial knowledge and understanding in three distinct and separate areas.

These are:

– the business plan and the intended customer/subscriber base;

– solid demographic and topographic knowledge of the area where service is to be deployed/provided;

– detailed, relevant radio engineering knowledge, experience, and skill.

These areas of required information involve three quite different skill and knowledge sets. Almost invariably, access to the necessary information and expertise will require involving at least three different individuals. It is important that these individuals work effectively together, so that the information, knowledge and experience that each brings to the task fits together in a complementary way, in order to achieve the most successful solution.

By its nature, the process of deployment planning is an interactive and iterative activity. It is necessary and appropriate to work progressively through several tentative solutions, each one bringing improvement to the overall result, until the optimum solution is reached and agreed on.

It must be recognized that the information provided in this section is not definitive. It points the way to effective and successful deployment planning of wireless access systems, but each of the subject areas considered above is a major area of knowledge and expertise in its own right.

CHAPTER 7

OVERVIEW OF FIXED WIRELESS ACCESS SYSTEMS

The wireless access systems available can be described by the following groupings and categories. A more detailed description of each system category follows in Annexes 4 and 5.

Wireless access systems may be based on existing and emerging digital mobile systems standards, such as those described in the following ITU-R Recommendations and their future updates:

Rec. ITU-R M.622 "Technical and operational characteristics of analogue cellular systems for public land mobile telephone use"

Rec. ITU-R M.1073 "Digital cellular land mobile telecommunication systems"

Rec. ITU-R M.1033 "Digital and operational characteristics of cordless telephones and cordless telecommunication systems"

These systems are summarised in § 7.1 and described in more detail in Annex 4.

Other wireless access systems may be based on proprietary radio technologies. These systems are summarised in § 7.2 and described in more detail in Annex 5.

7.1 Systems based on existing radio interface standards

Analogue	AMPS, TACS, NMT
Digital cellular	D-AMPS/TDMA, IS-95 CDMA, GSM,
Cordless	DECT, PHS

7.1.1 D-AMPS/TDMA-based fixed wireless access systems

D-AMPS/TDMA-based fixed wireless access systems comply with the IS-54 standard. Currently in use on four continents, D-AMPS/TDMA-based systems operate in digital or analogue mode in the 800 MHz or 400 MHz frequency ranges. These systems provide an array of flexible subscriber features and terminal designs. Three users can simultaneously be supported on one radio channel.

7.1.2 IS-95 CDMA-based wireless access systems

The IS-95 CDMA-based wireless access systems use CDMA spread spectrum technology to deliver high-quality voice and data services to subscribers. The IS-95 CDMA-based air interface operates in the 800 MHz and the 1 900 MHz frequency ranges, and provides an operator the potential to deliver multiple services to the subscriber with efficient use of radio spectrum.

7.1.3 GSM-based wireless access systems

The GSM-based wireless access systems enable operators to deliver voice, data and message services to their subscribers with GSM digital technology – 900 MHz, 1 800 MHz and 1 900 MHz.

7.1.4 PHS-fixed wireless access

The Personal HandyPhone System (PHS)-fixed wireless access system is designed for PSTN/ISDN wireless access facilities using the PHS air-interface standard. The PHS air-interface standard (operating in the 1 900 MHz frequency band) is defined in RCR STD-28 and is described in Recommendation ITU-R M.1033.

7.1.5 NMT-based wireless access systems

The Nordic Mobile Telephone (NMT)-based wireless access system was the first analogue cellular telephone standard to enter commercial operation, in 1981. The NMT standard was defined in collaboration with the public telecommunications operators in the Nordic countries (Denmark, Finland, Norway and Sweden). Networks in those four countries were brought into commercial operation during the latter part of 1981. The first NMT network used radio frequencies in the 450 MHz band (hence NMT 450), and later expanded to 900 MHz (hence NMT 900) for capacity reasons since more radio channels were made available in that band. Recently, the original NMT 450 specification has been revised and enhanced, to become the NMT 450i standard, which allows for many more features and capabilities in that frequency range.

7.1.6 DECT-based wireless access systems

A Digital Enhanced Cordless Telecommunications system (DECT) uses a combination of time division multiple access (TDMA) and time division duplex (TDD). The DECT standard is defined for the frequency range 1 880-1 939 MHz. DECT has standardized dedicated profiles for Fixed Wireless Access applications, including Plain Old Telephone Service (POTS) (voice, voiceband data modem, etc) and Packet Data transmission up to 552 kbit/s

7.1.7 AMPS-based wireless access systems

AMPS-based wireless access systems comply with EIA/TIA 553 standard and is currently in use on four continents. These systems operate only in analogue mode in both 400 MHz and 800 MHz frequency ranges. Features are generally limited to basic voice service and inband fax/data services with one RF channel supporting one traffic channel.

7.1.8 TACS-based wireless access systems

TACS-based wireless access systems comply with United Kingdom Total Access Communications System Compatibility Specification, Issue 4. Currently in use on four continents, these systems operate only in analogue mode in both 800 and 900 MHz frequency ranges. Features are generally limited to basic voice service and inband fax/data services. One RF channel supports one traffic channel. The major distinction between AMPS and TACS systems is that AMPS has 30 kHz channels and TACS has 25 kHz channels. Therefore TACS systems will have a higher capacity in a given bandwidth.

7.2 Systems based on proprietary radio interface technologies

7.2.1 Nortel Networks Internet fixed wireless access system

Nortel Networks Internet fixed wireless access system has been designed as an alternative for the traditionally deployed telephone lines. This system offers high quality voice and data services and provides transparency of services from a Class 5 switch. The radio base station connects to any Nortel Networks or third-party switch emulating a local exchange or remote concentrator, utilising the network's standard support infrastructure. The system operates in the 3 500 MHz frequency band, conforming to ETSI draft European standard EN 301 021, 1997.

7.2.2 SR Telecom SR500-s wireless access subsystem

The wireless access subsystem of SR Telecom's point to multipoint SR500-s closes the gap between the Central Office and the subscriber premise by completing the concept of Radio To The Home (RTTH). The wireless access replaces the last leg of the local access – i.e. the drop wire to the home, with a radio link. The wireless access subsystem offers transparent, fixed, equivalent to wired service over a 5 km obstructed path via a TDMA air interface.

7.2.3 TRT/Lucent Technologies IRT wireless access system

The TRT/Lucent Technologies proprietary IRT wireless access system is a fixed digital TDMA point-to-multipoint system, operating in the frequency bands 1.4 GHz or 2.4/2.6 GHz or 3.5 GHz according to the channel arrangements defined by ITU-R Recommendations. It provides the connection from the exchange to the subscriber terminal point. The wireless connection between the last remote station and the premises of the subscriber ("the last kilometre") is based on the DECT technology. This end-to-end transparent digital system gives to the operators the possibility to receive the full benefit of the radio technology, regardless of the network architecture characteristics. Furthermore, limited mobility is provided to the subscribers.

7.3 BWA systems

Typical BWA systems provide multiple high-speed digital access services using a point-to-multipoint radio architecture. Operating in various frequency bands around up to 70 GHz, such systems typically provide multiple primary rate connections, as well as LAN bridging, to single- or multi-tenant business premises. Voice, video and data traffic is merged over the air, either in the form of ATM cells or IP packets, which are seamlessly connected to ATM or IP switching/routing networks at the cell site. BWA systems provide a competitive alternative to primary rate leased wireline facilities and coaxial cable access.

Broadband Wireless Access in general is covered in Chapter 8, BWA systems deployment considerations in Annex 6 and descriptions of specific systems in Annex 7.

NOTE – Proximity, Reunion and DMS are trademarks of Nortel Networks. SR500 is a trademark of SR Telecom. IRT is a trademark of TRT/Lucent.

CHAPTER 8

BROADBAND WIRELESS ACCESS

Broadband Wireless Access (BWA) emerged through a combination of several parallel developments, primarily the following:

- increasing subscriber demand for an increasing number and variety of services at ever lower cost and ever higher data rates;
- deployment of metropolitan fiber infrastructures which brought broadband transport within the range of a single hop millimeter wave link to prime potential subscribers;
- deregulation that promotes competition in the local access;
- commercial availability of high performance, cost effective BWA systems.

The first BWA applications date back to the 1980s, large scale applications started in the late 1990s in the United States. It was stimulated by the Telecommunications Act of 1996 which opened local access to competition, by the availability of the frequency band 38.6-40 GHz for exclusive FS usage, as well as by the availability of the Local Multipoint Distribution Service (LMDS) band in the 24, 26 and 28 GHz range, and advanced communications applications, including broadband two-way multichannel, Multipoint Distribution Service (MMDS) in the 2.5-2.7 GHz band.

Sections 8.1 to 8.8 complement the generic Chapters 2 to 7 with corresponding BWA specifics.

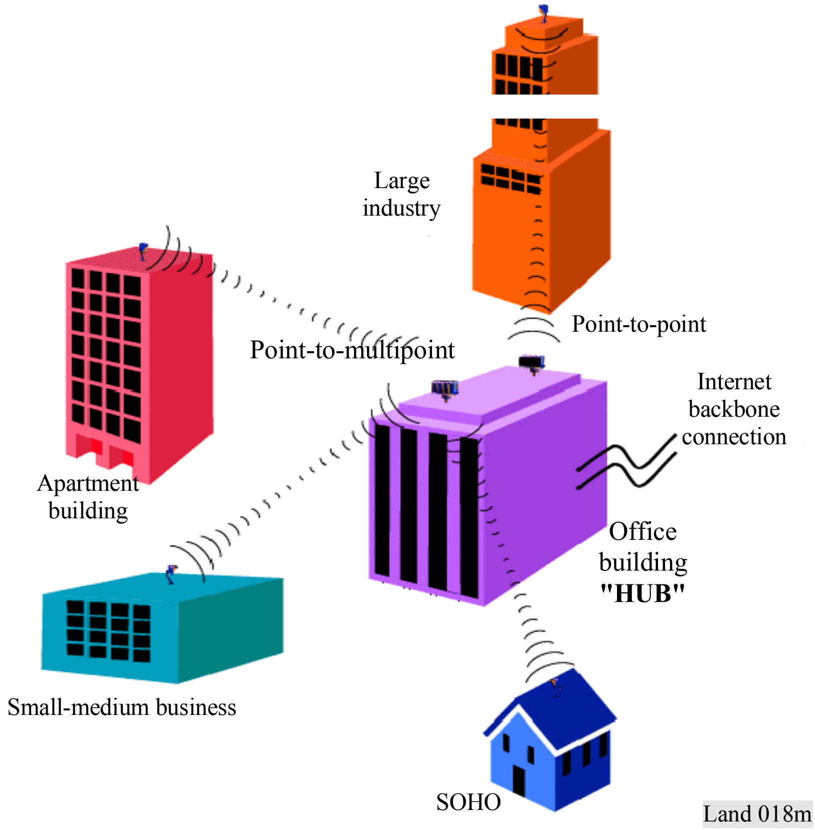
8.1 Access requirements

BWA satisfies a substantial range of access requirements for which fibre access is another alternative at this time. Currently, alternative BWA providers compete with each other in some service areas, but in the future they will increasingly compete also with fibre and other access providers.

Figure 18 is a conceptual illustration encompassing a range of existing and potential BWA applications of both point-to-point (P-P) and point-to-multipoint (P-MP) systems.

FIGURE 18

A conceptual illustration of broadband wireless access



Widely deployed BWA systems operate in the 24, 26, 28, and 38 GHz bands, serving businesses and other subscribers whose access requirements range from a fractional or full primary rate of 1.544 Mbit/s or 2.048 Mbit/s to the STM-1 rate of 155.52 Mbit/s. System development for data rates up to 622.08 Mbit/s is in progress.

Large scale BWA deployment with similar access requirements is emerging in several frequency bands ranging from 2.4 GHz to 31.3 GHz, and is being planned in the 40.5-43.5 GHz frequency band. The most widely used generic name for this broad BWA category is local multipoint distribution system (LMDS) which was coined for the initial proposal of a wireless competitor to cable television, planned for the 28 GHz band. As planning progressed, it became increasingly clear that the rapidly growing telecommunications traffic, notably including Internet, presents more promising BWA business opportunities than video distribution, and that all the available frequency bands in the 24.25-31.3 GHz range can be used for the same new kind of service. The LMDS development parallels the evolution of multichannel multipoint distribution systems (MMDS) in the 2.5-2.7 GHz band from video distribution to digital BWA applications. Similarly, the 40.5-43.5 GHz band was initially targeted for multipoint video distribution systems (MVDS), and later re-targeted for multimedia wireless systems that are meant to include MVDS.

Sections 8.5 and 8.8, and Annex 6 provide additional detail on access requirements.

8.2 Spectrum Usage

The provision of competitive BWA to all potential subscribers within a service area depends on adequate spectrum availability. Since business and other subscribers that require access at or above the primary rate are mostly concentrated in urban areas, industrial areas and campuses, serving such high concentrations of subscribers requires frequency spectrum ranging from hundreds of MHz to above 1 GHz in a frequency band that is suitable for link lengths up to a few kilometres. These BWA requirements can be met with HDFS (see Section 1.2.2) in frequency bands above about 17 GHz.

Recommendation ITU-R F.1401 (Frequency bands for fixed wireless access systems and the identification methodology) indicates that BWA applications may extend up to about 70 GHz. However, the upper limit is likely to move upward as technology progresses. The same Recommendation includes a stepwise methodology for the identification of suitable frequency bands for the implementation of FWA systems. In this methodology, frequency spectrum sharing considerations greatly impact the selection of frequency bands for BWA applications, because most candidate bands are allocated to several services on a co-primary basis. See Annex 6.

Since HDFS deployments for BWA generally have a cellular architecture, it is preferable to use frequency block assignments on an area basis rather than conventional link-by-link frequency channel assignments. This assures the necessary flexibility of deployment on subscriber demand, and facilitates the optimization of frequency reuse which is of key importance in HDFS applications.

8.3 Performance and availability objectives

Recommendation ITU-R F.1400 (Performance and availability requirements and objectives for fixed wireless access to public switched telephone network) covers BWA systems under the "Type 3" FWA system category (operating at or above the primary rate), and recommends that these "should comply with Recommendation ITU-R F.1189 for access network sections".

Recommendation ITU-R F.1189-1 (Error performance objectives for constant bit rate digital paths at or above the primary rate carried by digital radio-relay systems which may form part or all of the national portion of a 27 500 km hypothetical reference path) allows the necessary flexibility in setting the performance objectives according to the application requirements which depend on the BWA market segment served. For example, a 28 GHz local multipoint distribution system (LMDS) serving analog TV subscribers has less stringent objectives than an LMDS serving business subscribers using digital BWA as a substitute for multimedia fibre access which is not yet a viable competitor.

Recommendation ITU-R F.1400 states that for Type 3 FWA systems the availability objectives are yet to be defined. However, for Type 1 FWA ("analog signals such as voice and voiceband data at rates up to 64 kbit/s") and 2 FWA ("access bearer service from 64 kbit/s to bit rates below the primary rate"), the recommended availabilities are 99.99% "for medium quality applications", and 99.999% "for high quality applications". No other ITU-R recommendation on availability covers BWA systems, but most BWA service providers and planners currently also quote availability objectives ranging from 99.99% to 99.999%.

Significantly, the historical trend toward increasingly demanding performance and availability objectives (e.g. 99.9999% availability) continues as technological progress makes it feasible in cost effective ways. The trend in BWA performance objectives is to match those of fibre access, which will be a necessity when the latter becomes available at competitive cost.

More detail on performance and availability objectives is provided in Section 8.8 and Annex 6.

8.4 Propagation conditions

Rain attenuation is the predominant propagation impairment at frequencies above about 17 GHz. It is estimated on the basis of rain rate intensity for the relevant availability objective. The applicable method is covered in Recommendations ITU-R P.530, ITU-R P.838, and ITU-R P.1410, using statistics obtained from Recommendation ITU-R P.837. See also Annex 6. Recommendation ITU-R P.1410 describes the propagation information and prediction methods to use when designing terrestrial BWA systems operating in a frequency range of about 20-50 GHz.

8.5 BWA architectures

The selection of BWA architecture depends on the service requirements. Point-to-point (P-P) links can satisfy a wide range of requirements, ranging from small-scale deployment, as may be the case in some developing countries, to large-scale deployment in highly developed metropolitan areas.

FIGURE 19

An actual BWA deployment pattern and potential additional subscriber sites

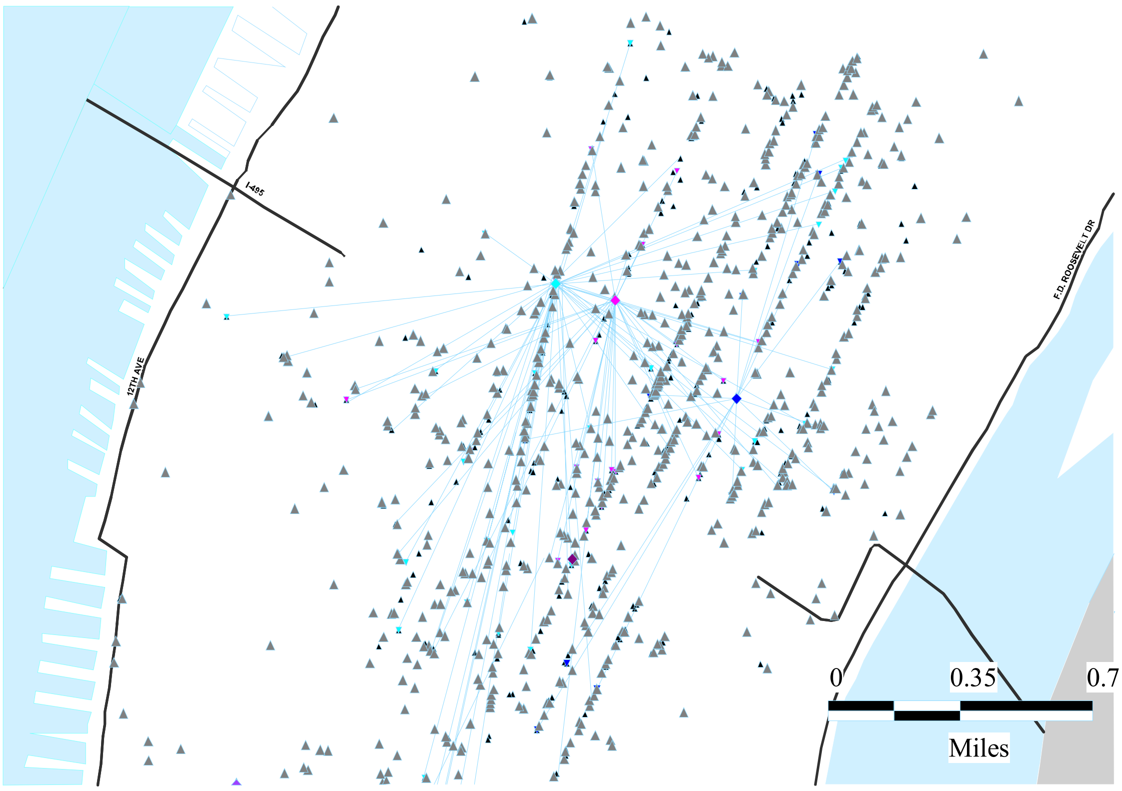


Figure 19 illustrates the initial phase of an actual large-scale BWA deployment consisting of point-to-point (P-P) systems deployed in hub configurations. This was the only feasible architecture in the beginning of BWA deployment because only P-P systems were commercially available at the time. Its primary advantage, irrespective of deployment density, is the flexibility of deployment in response to market demand.

The subsequent introduction of point-to-multipoint (P-MP) systems into P-P system deployment areas further increased the BWA deployment flexibility in HDFS applications. The use of P-MP systems reduces the deployment cost per subscribers because the cost of a common hub station used at or near its capacity limit (e.g. several hundreds of subscribers) is substantially lower than the cost of a hub station consisting of the equivalent number of P-P terminals.

The new P-MP systems operating in the frequency bands above 20 GHz use basically the same architecture as the thin route P-MP systems operating in the 1.5 and 2.5 GHz bands, which were introduced in the 1980s in rural areas of many developing countries and some developed countries. In some of the former, such P-MP systems were also deployed as thin route overlay digital networks in metropolitan areas with inadequate local access infrastructure. BWA networks are being deployed in the 2.5 GHz band in many countries.

There are also multipoint-to-multipoint (MP-MP) systems under development, which utilize a mesh topology and promise to further increase the deployment flexibility and versatility of BWA applications.

8.6 Technological implementations

Recommendation ITU-R F.1101 (Characteristics of digital radio-relay systems below about 17 GHz) includes a comparison of the basic modulation and coding techniques utilized in BWA systems, whereas the complementary Recommendation ITU-R F.1102 (Characteristics of radio-relay systems operating in frequency bands above about 17 GHz) covers some additional technological aspects of P-P systems that are of relevance to BWA applications. Recommendation ITU-R F.755-2 (Point-to-multipoint systems in the fixed service) covers a variety of P-MP systems for operation in the different fixed service bands ranging up to about 32 GHz at data rates up to 8.192 Mbit/s.

The technological implementations of commercially available P-P and P-MP systems for BWA applications have advanced from simple modulation techniques (e.g. QPSK) to more complex ones (e.g. 64-QAM), which substantially improve the spectral efficiency. Powerful coding techniques are used to enhance the error performance. More detail is provided in Section 8.8 and Annex 6.

Progress in semiconductor devices and circuit integration brings about substantial improvements in subsequent radio equipment generations. The resulting benefits include improved transmission performance, lower primary power consumption, increased reliability, reduced size and weight, easier installation and maintenance. Significantly, these benefits come at reduced pricing, which continues to improve BWA competitiveness.

8.7 Network planning

BWA network planning considerations can be broadly subdivided into two sets: one that is location dependent, and the other that applies across the board.

The major location dependent considerations include:

- the potential subscriber base;
- frequency spectrum availability;
- topography and man made structures;
- building access rights;
- the availability of a local fibre infrastructure;
- the propagation conditions.

Provided the assessment of the potential subscriber base justifies planning a local BWA service, and adequate frequency spectrum is available in the prospective service area, the next most important consideration is building access for the installation of hub and subscriber stations. Building access is the BWA "right of way".

The availability of a local fibre infrastructure is desirable but not indispensable, because a microwave link infrastructure can be deployed instead with routing that best fits the potential subscriber base. But if a local fibre infrastructure exists, its routing influences the selection of BWA hub station sites. Expansion of a fibre infrastructure with microwave links is a practical means of BWA network optimization for the dual purpose of improved subscriber coverage and reduced deployment cost.

The BWA network planning considerations that apply across the board include:

- performance and availability objectives;
- the need for optimal frequency reuse;
- commercial availability of equipment;
- cost effectiveness and competitiveness.

Section 8.3 drew attention to the BWA service provider's flexibility in setting performance and availability objectives, and to the fact that this is basically a matter of competitiveness. Section 8.8 and Annex 6 provide some specifics.

The need for optimal frequency reuse is generic to cellular systems. However, compared to cellular systems in the mobile service, frequency reuse in BWA cellular deployment has more degrees of freedom. BWA systems depend not only on inter-cell frequency reuse based on location separation, but also on extensive intra-cell frequency reuse based on combined location and angle separation.

The commercial availability of equipment for BWA applications is rapidly improving with the service proliferation. This increases the options of BWA network planners in meeting the subscriber demand which is rapidly growing in quantity and variety.

8.8 Overview of BWA systems

FIGURE 20

Representative point-to-multipoint metropolitan BWA deployment

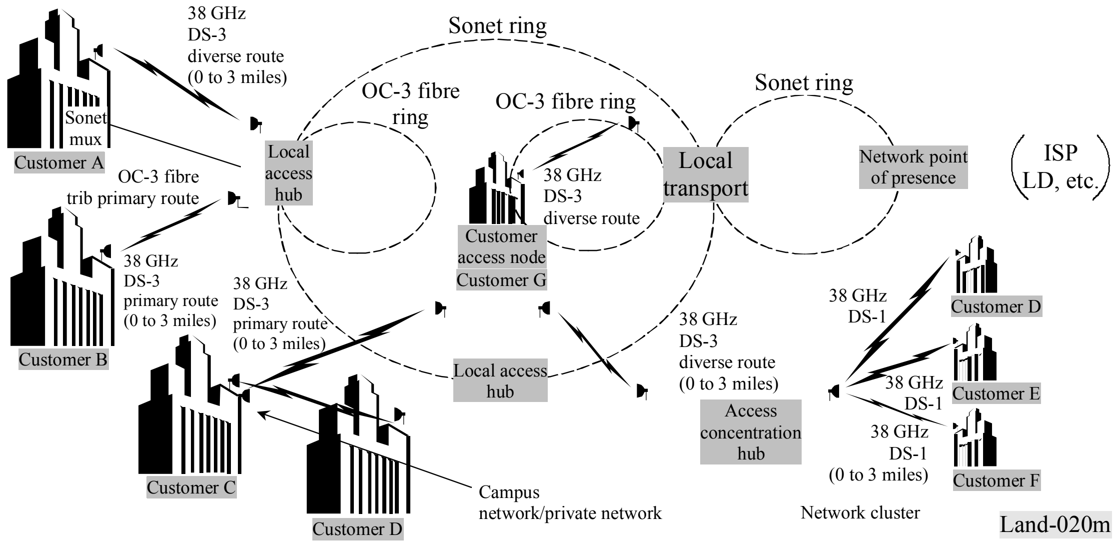


Figure 20 illustrates a multimedia BWA deployment example that consists of a fibre ring infrastructure and of superimposed P-MP hub stations with associated ATM switches that access subscriber station groups through sectoral antennas. The possible variations not shown in Figure 20 are the alternative or supplementary use of P-P subscriber links, possibly in hub configurations, and of wireless P-P links in the BWA infrastructure.

Compared to the conventional FWA systems for operation in the lower frequency bands, which include a number of systems based on existing mobile wireless access (MWA) radio interface standards (see Chapter 7), the existing and developmental BWA systems, both P-P and P-MP, all use proprietary radio interface technologies, as is the rule in conventional microwave and millimeter wave systems. Examples of such BWA systems are described in Annex 7.

Nevertheless, stimulated by the benefits of standard radio interfaces in existing MWA and FWA systems, interested service providers and system suppliers have embarked on standardization of radio interfaces for P-MP systems in all fixed service bands currently used or targeted for BWA applications. P-P radio interfaces are not specifically included at this time. Irrespective of the outcome, such standardization efforts promote a better understanding of the BWA requirements and will thereby contribute to the general progress of system development and service deployment.

The maximum shared capacity of existing P-MP systems in the bands above 20 GHz is 45 Mbit/s. IEEE 802.16 foresees a peak capacity of 155 Mbit/s, and aims at a standard that would allow scaling beyond that. The upper limit of existing P-P systems in some bands in the 20-40 GHz range is currently at 155 Mbit/s. Increasing it to 622 Mbit/s is feasible and can be expected in the next P-P system generation.

CHAPTER 9

FUTURE TECHNOLOGIES FOR FWA

9.1 Market and industry trends: fixed, mobile and broadcasting convergence

9.1.1 Introduction

Today the demand for mobility services is increasing to meet the needs of telephony subscribers as well as the needs of those asking for wireless access to E-mail and the Web utilizing portable computers. The amount of estimated telephony traffic to be carried over by mobile handsets is 50% or even higher. This traffic is often times established with a fixed connection at one end, or carried over "fixed" (wired and unwired) networks.

Broadcasting networks (both terrestrial and satellite based) are evolving from exclusive unidirectional transmissions of TV and sound to interactive communications. This interactivity makes broadband broadcasting networks also available for packet data transmissions, such as required for Internet Web type communications.

The future for FWA is promising. As the price of cellular systems and other wireless access systems approaches that of the fixed network, mobile traffic will increase. On the other hand, Internet Service Providers (ISPs), most of them based on "fixed" networks, will look to offer not only data communications but telephone traffic as well, at very low price compared to traditional fixed and mobile operators.

9.1.2 Convergence

The concept of convergence in the context of radio services refers to transforming existing heterogeneous facilities into a single platform with capacity of conveying multimedia (voice, data and images) services over a variety of seamless fixed, mobile and broadcasting networks. Differences between fixed, mobile and broadcasting are blurring and such distinctions might appear arbitrary as new applications are developed.

Such convergence allow users to access any one form of network infrastructure, which may lead to cost savings.

Convergence may also offer new opportunities for:

a) New entrant operators without network, due to potential savings from sharing resources and the flexibility of using fixed, mobile or broadcasting networks.

b) New brand of service providers, such as ISPs and the so-called virtual networks operators (VNO). These are companies offering direct access to mobile-handset telephones and PSTN via their own switches and Internet network platforms. Services offered typically include E-mail and Web access connection with flat rate for the subscriber in many countries, and the possibility of voice, fax and data services.

9.1.2.1 Fixed and mobile convergence

For ease, users may want to utilize a single telephone number, both for fixed and for mobile terminals.

As a result, several telecommunication operators in Europe (such as Deutsche Telecom, Tele Danmark and Telia) are conducting trials of new fixed and mobile convergence technologies as a way to maintain market share and increase revenue. This one form of convergence technology generally uses one telephone subscriber number to access both the fixed and mobile networks, including limited mobility in some cases.

9.1.2.2 Fixed and broadcasting convergence

Planned first generation broadband broadcasting networks will be delivering a range of services, including data and multimedia services to the general public. To allow interactivity and access control, a permanent return channel may be required that will provide an asymmetric distribution infrastructure.

In the future, multimedia services over heterogeneous networks with broadband access may be required. Broadband fixed and interactive broadcasting networks, operating across different frequency bands, may be configured to facilitate bandwidth-on-demand access and distribution with both symmetric or asymmetric bit data transmissions. A variety of bit rates (from a few 10th bits/s to 10 Mbit/s and even more) will be required to satisfy user needs.

9.1.3 Regulators and operators

Regulators and operators are seeking ways of breaking down obstacles in order to obtain a competitive telecommunications marketplace. One such approach is that administrations are mandating incumbent operators to open their local networks to new entrant operators. It is likely that mobile operators, will also be mandated offer mobile interconnection to public networks (such as PSTN and ISDN).

In order to satisfy users needs, operators need to be able to provide their services seamlessly over fixed, mobile or broadcasting networks.

As the mix of mobile and fixed traffic fluctuates, service providers may have to come up with novel solutions and services in order to retain market share and increase revenue.

9.1.4 Fixed wireless access applications

FWA were initially designed as radio systems capable of replacing wired access lines due to advantages in price and time of installation. FWA are considered as the wireless connection between end-user and core networks, such as PSTN, that not only fully supports wireline services, but can also provide generic requirements with complete transparency to end-users.

Fixed broadband wireless access (BWA) are providing full support for ISDN and other high-speed data services, including telecommunication management network (TMN) functions, and access to Internet and video services.

The integration and flexibility offered by FWA, including broadband, make it as the core application for convergence. Convergence of fixed, mobile and broadcasting networks might start from new FWA applications, such as the so-called high-density systems in the fixed service.

9.2 Technology trends

Systems are becoming more complex with consequent benefits, but expected cost increases are not being realized because of technological innovation and greater economies of scale. In many cases significant cost and performance benefits are already being realized through exploitation of advances in cellular mobile systems, due to the rapid growth in these volume markets.

Technological improvements are expected over the next decade in the following areas:

– Multipoint architectures. Most FWA systems are configured as P-MP systems. In the future, some of those systems may feature a multipoint-multipoint (MP-MP) architecture. These types of system have found some acceptance at lower frequencies, especially for military HF applications where route diversity has afforded great benefit in terms of network resilience and traffic flow flexibility.

– Adaptive antennas, sometimes termed SDMA (spatial domain multiple access). Most FWA systems do not employ such technology. Adaptive antenna systems have recently started to be employed in cellular mobile systems, and initially they use this functionality in one RF direction only. Some future systems (e.g. mobile cellular) will employ full adaptive antenna technology on both up and down links. It is possible with this technology to both null out interferers and/or attain additional diversity gain. There are a variety of antenna weighting algorithms available, and it is a significant challenge to choose the correct algorithm for the intended application.

– Software radios. As with other advances, this may benefit greatly from the proliferation of cellular mobile systems, especially at the semiconductor chip level. The transceiver may be reconfigured dynamically by software control for modulation scheme or even frequency, and in addition system-wide updates can be facilitated through network download.

– Components. A number of technologies are in existence or emerging for use in bands above 20 GHz. Recent developments, such as MMIC (Monolithic Microwave Integrated Circuits), have made these bands, particularly in the range 20 to 60 GHz, suitable for HDFS applications. Commercial components and devices are available in the market for mass production of affordable equipment.

– Frequency use techniques. To further increase spectral efficiency and service flexibility, advanced FWA (inc. HDFS/BWA) systems are increasingly likely to employ a range of techniques that may include different duplex technologies, and mixes of them, and dynamic allocation of bit rate, of modulation and of antenna beamwidth/pattern. Such systems will likely have the functional capability of variable or flexible channelization; this better facilitates transmission of symmetrical or asymmetrical services, based on need, an important factor in the growth of wireless services. In terms of FS deployment arrangements, the near future will see use of connected (ring) as well as conventional cascades ('daisy chain' or radio relay) for P-P schemes, and multipoint (MP) schemes will include MP-MP (mesh) structures as well as P-MP and hybrid arrangements of all these. The air-side concentration is a significant distinguishing feature in MP system usage as compared to conventional P-P systems. Some MP systems are already deployed to include in-band infrastructure support; but many more FS deployments are also needed simply as dedicated to network infrastructure support for the rapidly growing cellular mobile/nomadic widescale deployments i.e. these are not access but conventional infrastructure applications. It should be noted that even P-P systems used in this fairly conventional type of deployment (infrastructure) will benefit from these advances in systems design and in spectrum usage, including the use of block-based frequency arrangements rather than conventional channelization, and this will be influenced by the evolution in design of the MP, which are largely access, systems. It is foreseen that future access and infrastructure applications will to some extent converge, and this will demand more enlightened and flexible approaches to air-side systems architecture, and to spectrum engineering and frequency management processes and their administration.

ANNEX 1

Terminology and acronyms

1 Terminology and definitions

Air traffic slot	This term refers to one communication channel on the air interface.
Bearers	This term indicates the number of simultaneous radio channels that a base station can use.
Cell perimeter	A contour that defines the signal strength or path loss at a given threshold.
Central office	See local exchange.
Class 5 office	See local exchange.
Clutter	A general term describing reflections from obstacles such as trees, buildings, etc.
Coverage quality	The percentage of locations within the cell radius that statistically will have a signal strength that exceeds the minimum threshold value.
Effective antenna height	Usually applied to the base station, this takes account of the terrain variation along a path as well as the mast height. If, for example, the ground height at the base station is much greater than that at the subscriber's radio system then the base station mast height would not adequately describe the height difference between the two ends of the link.
Frequency reuse	The convention for describing frequency reuse is N, M where N: number of sites in reuse cluster, M: number of sectors in reuse cluster.
Fresnel zones	Approximation of the zone where wavelike interference can affect the propagation of the radio path. Fresnel zone ellipsoids have the specific property that the total path length via each ellipsoid is $n\lambda/2$ greater than the direct path. Thus the first Fresnel zone gives an indirect path that is $\lambda/2$ longer than the direct path. At the midpoint of the path the depth of this Fresnel zone is greatest. When an object penetrates inside the first Fresnel zone excess loss relative to free space path loss is consistently observed.
Local exchange	An exchange in which subscribers' lines terminate (ITU-T Rec. Q.9, Fig. 1/Q.9).
Lognormal distribution	The distribution of a positive variable whose logarithm has a normal (Gaussian) distribution. Typically implies that the variable is the result of many individually insignificant causes which combine multiplicatively.
Path loss	The ratio (dB) of received power to transmit power measured between antennas.

Primary rate	The transmission bit rate of 1 544 kbit/s or 2 048 kbit/s.
Quasi-smooth terrain	Terrain where the average level does not differ by more than 20 m. Additionally the interdecile height variation is less than 20 m with gentle ups and downs.
Radio link availability	A long term measurement that describes the percentage of time that the received signal strength is sufficient to provide a specified quality. Non-availability or outage can be caused by temporal fading and anomalous propagation conditions.
Rolling terrain	Terrain without "significant" hills or valleys. More exactly defined as terrain where the interdecile height variation over 10 km lies between 40 and 80 m.
Sector rotation	In a conventional sectored frequency plan the re-use cells (cells where frequencies are re-used) would all be orientated in the same direction. With sector rotation, the cell orientation is rotated, typically by ±120°, between the neighbouring re-use cells.
Server	The base station to which a subscriber's radio system is attached.
Shadow margin	If the link budget with no margins is used to calculate the cell radius then due to shadowing 50% of locations at the cell edge will have a median path loss below the link budget. This gives a low coverage quality over the whole cell. To increase the coverage quality to an acceptable level a margin needs to be added to the link budget. This has the effect of reducing the cell radius from the noise limited range. The margin is dependent on the coverage quality required.
Specular reflection	The reflection that occurs when a radiowave meets with the interface between two different media and the wavelength is small in comparison to the 'roughness' of the interface. In other words a "perfect", non-diffuse reflection.
Temporal fading	Fading experienced at a fixed location over time.
Temporal fade margin	The margin needed to be added to the link budget to ensure the required radio link availability in the presence of temporal fading.
Rayleigh distribution	The distribution of the signal envelope of a received signal which consists of a large number of randomly-phased components. Typically associated with multipath transmission when there is no significant direct path.
Rician distribution	The distribution of the signal envelope of a received signal that consists of a steady component together with random (Rayleigh) components. The characteristics of the distribution are dependent on the ratio of power in the steady components to the power in the random which is know as the *k*-factor. As the power in the steady component diminishes the distribution tends to the Rayleigh distribution. Typically associated with the reception of a direct path with some multipath scattering as well.

2 Acronyms

ADPCM:	adaptive differential pulse code modulation
agl:	above ground level
AMPS:	advanced mobile phone system
AN:	access network
ANSI:	American National Standards Institute
ATM	asynchronous transfer mode
BCF:	base common function
BER:	bit error ratio
BRAN	broadband radio access network
BS:	base station
BSC:	base station controller
BSS:	base station system
BTR	base station transceiver
BTS:	base transceiver station
BWA	broadband wireless access
C/I:	carrier-to-interference ratio
C/Ia:	carrier-to-adjacent channel interference ratio
C/Ic:	carrier-to-co channel interference ratio
CAI:	common air interface
CATV:	community antenna television
CBR	committed bit rate
CD:	code division
CDMA:	code division multiple access
CDPD:	cellular digital packet data
CE:	common equipment
Cellco:	cellular company
CELP:	code excited linear prediction
CEPT:	Conférence européenne des Administrations des postes et télécommunications
CIS:	CDMA interconnect subsystem
CLID:	calling line identification
COB:	chip on board
CSU:	channel service unit
CT:	cordless telephone
CTR	customer premises transceiver
D-AMPS:	digital advanced mobile phone system
dB:	decibel
DCA:	dynamic channel allocation
DCS:	digital cellular system
DECT:	digital enhanced cordless telecommunications
DLC:	digital line carrier
DOCSIS	data over cable system interface specification
DRU:	dual-mode radio unit
DSP:	digital signal processing
DSU:	data service unit
ETS:	European Telecommunications Standard
ETSI:	European Technical Standards Institute
FDD:	frequency division duplex

FDMA:	frequency division multiple access
FPLMTS:	Future Public Land Mobile Telecommunication Systems (see IMT)
FWA:	fixed wireless access
GMSK:	gaussian minimum shift keying
GOS:	grade of service
GPRS	general packet radio service
GPS:	global positioning system
GSM:	global system for mobility
HDFS	high density applications in the fixed service
HLR:	home location register
ICP:	intelligent cellular peripheral
IDT:	international digital trunk
IMT:	international mobile telecommunication
IN:	intelligent network
IP	internet protocol
ISDN:	integrated services digital network
LAN	local area network
LE:	local exchange
LMCS:	local multipoint communications system
LMDS:	local multipoint distribution system
LOS:	line-of-sight
LTB:	line termination box
MDS:	multipoint distribution system
MMDS	multichannel multipoint distribution services
MP-MP	multipoint-to-multipoint
MVDS	multipoint video distribution system
MSC:	mobile-service switching centre
MSC:	mobile switching centre
MTM:	maintenance trunk module
MTX	mobile telephone exchange
MWA	multimedia wireless access
N-AMPS:	narrow-advanced mobile phone system
NIU	network interface unit
NMT:	nordic mobile telephone
NLOS:	non line of sight
NNE	network node equipment
NSS:	network switching system
O&M:	operations and maintenance
OA&M:	operation, administration and maintenance
OAM&P:	operations, administration, maintenance and provisioning
OCP:	operations control point
P-P	point-to-point
PBX:	private branch exchange
PCM:	pulse code modulation
PCS:	personal communications service
PDA	personal data assistant
PDTC:	peripheral digital trunk controller
PHS:	personal handyphone system
P-MP	point-to-multipoint

PMP:	point to multipoint microwave radio
POTS:	plain old telephone service
PSTN:	public switched telephone network
PTM:	package trunk module
PTT:	postal, telephone and telegraph
QAM	quadrature amplitude modulation
RF:	radio frequency
RLL:	radio local loop
RLP	radio link protocol
RSU:	remote switch unit
RTTH:	radio to the home
SBS:	selector bank subsystem
SDMA	space division multiple access
SMS:	short message service
SNR:	signal to noise ratio
SOHO	small office home office
SRT	subscriber radio terminal
STM:	service trunk module
T1/E1:	primary rate transmission system
TAB:	tape automated bonding
TACS:	total access communications system
TCP	transmission control protocol
TDD:	time division duplex
TDMA:	time division multiple access
TFU:	timing frequency unit
TM:	trunk module
TMN	telecommunications management network
UPD	user datagram protocol
VLR:	visitor location register
VNO	virtual network operator
VPN:	virtual private network
W-LAN	wireless local area network
WAP	wireless application protocol
WBS:	wireless base station
WCTX:	wireless centrex
WKTS:	wireless key telephone system
WL:	wireless line
WLL:	wireless local loop
WPBX:	wireless private branch exchange
WT:	wireless terminal

ANNEX 2

SPECTRUM SHARING CONSIDERATIONS

FWA spectrum engineering and frequency management issues:
some considerations, including frequency plans

1 Introduction

This Annex discusses key spectrum engineering and frequency management issues associated with FWA usage. Most of the material is generic in nature, although the proposals for further work are to some extent specific to particular frequency bands. Most of the work described here has been undertaken within the framework of CEPT, as part of ongoing studies to support use of FWA systems within Region 1 and in support of work to promote wider harmonization and standardization in all Regions in cooperation with international and regional bodies. Material available in preliminary form has been tailored for ITU-R JRG 8A-9B as contained here, in the hope that it can assist in exploring several important issues. It is not supplied as a formal CEPT position paper, but rather as information and to promote more detailed study, particularly as related to frequency plans and compatibility with other systems and services.

Addressed here are terrestrial P-MP systems used for FWA. These systems generally feature air-side concentration and contiguous cellular (area) deployment arrangements, and it is necessary to take account of the several important similarities with, and differences between, these systems and both conventional P-P systems on the one hand and cellular mobile systems on the other hand.

Specific bands are not discussed in detail, and the material is qualitative rather than quantitative.

Some of the considerations within this document also relate to compatibility of FWA systems with systems in other services, and more sharing studies are underway in Region 1 for various bands and different scenarios.

1.1 Guidance on coordination and related issues

Guidance material has been identified as an important requirement for effective use of available spectrum, including intra-system, inter-system, inter-service issues. In due course this will contain information on interference calculation methodology, systems parameters, reference model results for model scenarios, and some information on interpretation (including sensitivities, identification of simplifying assumptions and other factors which may need to be considered). The following sections, Sections 2-5, present useful considerations on spectrum engineering issues, including frequency plans for geographical co-deployment of FWA systems.

2 Frequency allocation guidance

For co-deployment of FWA systems in the same geographical area, it is necessary to:

- Take account of Regional or other recommendations on preferred frequency bands for FWA systems.
- Allocate sufficient spectrum to enable operators to be competitive; sub-bands should not be too small to preserve spectrum efficiency since any guardbands must be included, and wherever possible co-sharing[1] should be encouraged.
- Take note that generally best spectrum efficiency is obtained by use of contiguous rather than non-contiguous arrangements, taking into consideration systems design and necessary frequency separation issues.
- Plan for traffic growth, and to remember that in general one needs contiguous spectrum, although some systems may assist planning in using non-contiguous spectrum.
- Take note that, whereas assigning spectrum to several potential operators across a band facilitates comparison of competitive schemes by these operators, it may be equally acceptable to facilitate competition by use of different bands.
- Take note that if too many operators are assigned spectrum in a band, this may be counter-productive in terms of spectrum efficiency.
- Incorporate suitable guardbands to mitigate interference, taking account of the different mix of technologies used, in order to attain an acceptable compromise between performance degradation and necessary protection/mitigation measures, including guardbands.
- Specify for FDD systems, a consistent plan for the forward (central station to terminal station) and reverse (terminal station to central station) sub-band frequencies. It may be assumed that generally the forward (down) link should be at the higher frequency, similar to accepted usage in most cellular and satellite systems, but exceptional cases may dictate the reverse. Account must be taken of the added complications where mixed up/down directions are used.
- Take account that for TDD systems the designation of forward and reverse link directions is no longer possible, and in this case additional interference scenarios need to be considered.
- Take account that when considering accommodation of P-MP with P-P systems in the same band, e.g. for the 24.5-26.5 GHz band, one attractive approach can be to make appropriate regional/national allocations for each FS type from opposite ends of the band, with the proportion of total band usage for each type perhaps determined by market or other needs.
- Take care when comparing different technologies and their spectrum usage, taking account that there is as yet no definitive guide to comparing spectrum efficiency in a simple manner; consideration needs to be taken of cluster size, consequences of mixed technologies according to these guidelines, quality and grade of service and other factors.
- Use actual/typical parameters, wherever possible, for the calculation of the compatibility factors, rather than just the minimum requirement limits from the corresponding standards, and take account of the sensitivity of the results to these parameters.

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[1] Equitable, efficient apportionment of the band between operators within the same region/area, not co-frequency sharing normally.

3 Frequency plans

3.1 General

For co-deployed FWA systems, it is necessary to:

- Take note that to date FS frequency plans have generally been prepared for P-P telecommunications systems featuring use of FDD, with symmetric channel/sub-band widths which may not be appropriate for all FWA systems.
- Take account that services with *variable* asymmetry are often needed, especially for broader band applications[2].
- Take account that asymmetry may be achieved by:
  - pairing narrower channels in one direction with wider channels in the other;
  - using different orders of modulation in one direction from that used in the other;
  - using multicarrier modulation;
  - using asymmetrical TDD within the paired spectrum.
- Take account that having narrower channels in one direction and wider in the other can accommodate traffic efficiently only where this traffic exhibits a *fixed* asymmetry matching the ratio of the channel/sub-band widths. Such a fixed sub-bands approach is inherently less efficient for *variably* asymmetric traffic which may exhibit *only over time* a general bias in the traffic in favour of the channel direction enjoying the wider band.
- Take note that it is possible in some cases to "pair" up and down links in widely separated bands, for example an up link within one band together with a narrower down link within a lower band to provide fixed asymmetry for certain wideband applications.
- Take note that some multimedia wireless systems, especially those derived in concept from broadcast/distribution type systems, may have a bidirectional rather than unidirectional "interactivity" channel/sub-band. All the guidance provided elsewhere in this document should apply to this situation.
- Take account that different orders of modulation may be used for the two traffic directions to offer a limited degree of asymmetry (and could result in different characteristics in terms of range/robustness of the up- and down-links) and that this may permit some *variable* asymmetry if the equipment can dynamically adapt the modulation scheme independently in the two directions.
- Take account that TDD with variable time allocated to up- and down-link directions can provide a manner of achieving applications having variable, asymmetrical traffic.
- Take account of the need to promote an equitable burden sharing in respect to guardbands. For example, for the first FWA operator in a band it would be prudent and fair to ensure that any guardband/s are included within the assigned sub-band.
- Note that in general a -1 dB interference criterion might be considered appropriate in interference calculations between FWA systems and, unless stated otherwise in ITU-R Recommendations, with other services.

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[2] As opposed to the type of fixed asymmetry needed by, for example, video surveillance type systems with wideband down-link capacity and narrow upstream capacity.

3.2 TDD assignments in bands with paired spectrum

3.2.1 General

In the case of TDD systems in bands with a frequency plan based on standard paired spectrum, it is necessary to:

- Ensure that the TDD assignment respects the channel plans for the FDD channel raster.
- Note that where part of the lower band is assigned to a TDD system then the corresponding part of the upper band should also be assigned to TDD, and *vice versa*.
- Note that for *fixed asymmetrical* applications based on FDD and operated with channel arrangements previously designed to be suitable for *symmetrical* FDD use (having equal channel widths in both upper and lower bands), it is possible for n channels of the lower sub-band to be paired with m channels of the upper sub-band. The "surplus" unpaired |m-n| channels could be usefully assigned to TDD services (including any necessary guardband allowance).
- Take account that in the latter case, and notwithstanding the availability of the m+n channels for fixed asymmetric FDD services, it is possible that these channels could be assigned to one or more TDD channels.
- Take into account the possibility of using the centre gap for TDD, provided the requirements of Section 2 are observed.

3.2.2 Implementation

In the case of TDD systems in bands with a frequency plan based on standard paired spectrum, it is necessary to:

- Note that there may be particular spectrum engineering issues (such as constraints on transmitter masks and the need for guardbands) associated with operating TDD systems in a band already accommodating FDD systems.
- Take note that polarization may be used as a system propagation discriminant, although less usefully at lower frequencies. This can be useful to mitigate interference.
- Note that additional parameters may be needed for the coexistence planning of TDD systems.
- Note that it has been asserted that the issue of verifying TDD compatibility with existing FDD systems is a larger task than checking compatibility of a FDD system with existing FDD system (with the same duplex spacing). But once compatibility in the lower (or upper) sub band has been demonstrated, compatibility in the other sub-band can be inferred.

4 Deployment

For co-deployment of FWA systems in the same geographical area, it is necessary to:

- Consider the benefits of encouraging cooperation between operators in order to minimize interference and consequent economic impact, and to seek to use the spectrum efficiently.
- Note that where central stations belonging to different operators are proposed to be sited relatively close, it may be preferable to co-locate these stations to minimize and better define the near/far effect. This may be especially appropriate in those cases where the directions of the forward and reverse frequency sub-bands are mixed or not designated e.g. where different duplex technologies/spacings are mixed.

- Note that where considering compatibility with P-P systems, CS and TS installations should wherever possible minimize P-MP antenna heights and judiciously use antenna angular discrimination, including nulls in the polar pattern, as additional mitigation and to minimize guardbands.
- Note that where considering compatibility with FSS systems, account should be taken of ITU-R Recommendations where available, including any guidelines covering the FSS and P-MP antenna heights, separation distances, allowable range of elevation view angles, additional diffraction or other mitigation measures.
- Note that where considering compatibility with the RAS, it is important to comply with the ITU-R Radio Regulations, taking account the aggregation effect of P-MP systems.
- Note that where considering compatibility with radiolocation/navigation systems in adjacent bands or in neighbouring countries, account should be taken of existing relevant ITU-R Recommendations. For radiolocation/navigation systems that may be in-band, account should be taken of ITU-R Recommendations where available, including any specific methodology needed to ensure compatibility for the particular technology and radar type/s.
- Take account of the need to plan and deploy CS and TS antennas which are no less directional than is required for the intended intra-system deployment and which are sited no higher than is necessary to ensure adequate performance margin.
- Ensure that any necessary synchronization and other measures to accommodate mixed technologies are implemented as appropriate.

5 Equipment design

For co-deployment of FWA systems in the same geographical area, it is necessary to:

- Take account of the importance of minimizing spurious and out of band emissions through appropriate equipment design.
- Take account of the importance of maximizing receive selectivity (and noting that relevant standards may be insufficiently detailed or stringent in all cases).
- Take account of the desirability, consistent with compliance with the required level of quality and grade of service, of incorporating measures to ensure adequate transmit power control, dynamic channel/frequency and/or other adaptive measures to enhance compatibility.

6 Check lists and guidelines

The considerations in the above three sections might form the basis of a useful check list in the further study of some FWA compatibility issues and in the formulation of guidelines that may be necessary for some co-deployment situations.

ANNEX 3

Criteria to assess fixed wireless access systems and technologies in relation to needs and requirements

1 General

This Annex provides planners and designers of fixed wireless access networks with guidelines and procedures to be followed during the design and implementation of the network. Important aspects of radio paths are reviewed in § 2. Since the planning of fixed wireless access networks is similar to that of mobile cellular networks, the main characteristics are compared in § 3. Generic radio network models are described in § 4 while in § 5 the concept of an idealized hexagonal grid is noted. The radio planning process is described in § 6 (top level), § 7 (business planning support), § 8 (cell planning), and § 9 (performance analysis and optimization). This annex concludes with a summary of radio planning considerations in § 10, including checklists that are useful in planning a wireless access system.

2 Radio planning fundamentals: radio paths

The path loss between a transmitter and a receiver is, at least to the first approximation, dependent upon the range and the degree of obstruction along the path. A radio path can be described as a free-space path, a line-of-sight path or an obstructed path depending on the degree of obstruction.

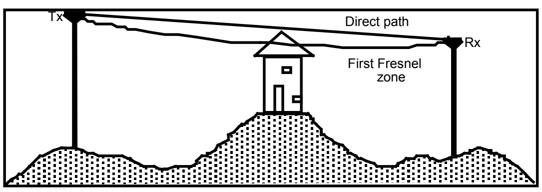
It is important to understand that some wireless access systems do not require line-of-sight paths to operate. The degree of obstruction that can be tolerated along the path is dependent on the link budget, the additional margins applied and the range one wishes to achieve. A line-of-sight path would only be a requirement if an operator wished to use the system at very long ranges, but even under these conditions path losses in excess of free-space loss will often be encountered.

The following figures attempt to illustrate the path types described. A free-space path is one in which there is a direct path between the transmitter and the receiver and there are no objects penetrating into the first Fresnel zone (for a discussion of Fresnel zones and related aspects refer to texts such as [Parsons and Gardiner, 1989; Calhoun, 1992; Boucher, 1995] or [HESS, 1993].

A line-of-sight path will include free-space paths, but also includes ones in which terrain features or obstacles penetrate inside the first Fresnel zone, whilst still allowing a direct path. This path will have up to 6 dB theoretical excess path loss relative to a free space path and is illustrated in Fig. 21.

FIGURE 21

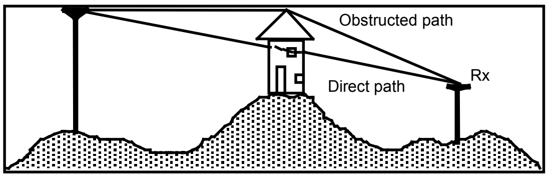
Line-of-sight path



An obstructed path is a path in which the objects such as terrain, buildings, trees and other clutter cause a definite obstruction of the direct path. In this instance the indirect path diffracts over the edge of the object. This path will typically have at least 10 dB extra path loss relative to a free space path and is illustrated in Fig. 22.

FIGURE 22

Obstructed path



2.1 Attenuation due to rainfall

The rainfall data may be calculated based on rainfall rate data presented in Recommendation ITU-R P.837-1 and its translation into an attenuation value as given in Recommendation ITU-R P.838 and Recommendation ITU-R P.530-5 § 2.4.1. Recommendation ITU-R P.837-1 divides the world into rain climatic zones and gives the rainfall intensity exceeded (in mm/h) for varying percentages of time. The maps show that most of South East Asia and parts of Central America are the areas with the highest rainfall intensity. The highest figure quoted by any of these figures is 250 mm/h which is exceeded for 0.001% of time in Zone P.

2.2 Propagation over water

If the path between the transmitter and receiver for a radio link is over, or in close vicinity to, large expanses of water, care must be exercised in the overall link design. Radiowave propagation over or in the vicinity of water differs from that over dry land. The difference in propagation occurs due to the following significant factors:

– Increase in the electrical conductivities for the surface propagating radiowaves results in relatively slower attenuation for the same distances. This means that reasonable signal strengths can be received at longer distances. Characteristically water surfaces present efficient reflecting planes for radiowaves. For suitable link geometries this may result in specular reflection (particularly of calm water surfaces) giving rise to multipath fading.
– The space wave propagation through the troposphere is also affected in terms of increased probability that the atmospheric conditions are conducive to "duct propagation". This phenomenon can result in the loss of signal over short to medium distances and interference due to propagation over long distances and beyond the radio horizon.

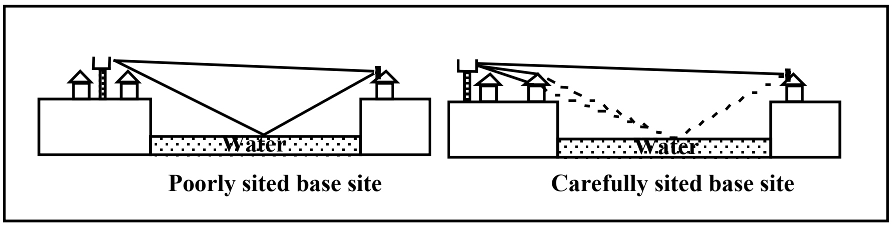
2.3 Avoiding fading due to reflections

In certain situations signal fading due to reflections can be avoided by taking simple precautions.

– If, for a problematic radio link, calculations show that the signal reflection is taking place at a known reflecting surface, such as flat land or particularly water, then siting one of the antennas to a new location should alleviate the problem. This can be particularly effective if the reflected signal is now shown to be obstructed. This is simplistically illustrated in Fig. 23 which shows how careful siting of a base station that is situated near an expanse of water (an estuary for example) can avoid potential multipath problems by ensuring the reflected path is obstructed.

FIGURE 23

Base site selection to avoid multipath problems



– By making the height of one of the antennas as high as possible and the other as low as possible the reflection point occurs closer to the lower antenna. This helps to reduce the uncertainty in the occurrence of reflection points introduced by the atmospheric changes. The fading effect is particularly mitigated if the reflection as a result of this measure happens on a less reflecting surface. For example, such a precaution is particularly useful if the reflection point for a link is moved from the water surface to the surrounding land.

– It should be ensured that the combination of transmitter and receiver antenna heights avoids attenuation due to the "vertical fading structure" caused by the summation of the direct and reflected paths. Standard ITU-R calculations can be used to design suitable heights.

2.4 Millimetre-wave propagation

In the bands between approximately 10 and 60 GHz, highly directional antennas (1-3 degree beamwidth) are used for the customer premises. The propagation model applied in this case is usually free-space, with a small additional fixed margin added for atmospheric absorption and a large temporal fade margin. Unlike propagation at lower frequencies, the temporal fade margin accounts not for time-varying multipath, but for rain losses, which are considerable and increase linearly in dB with range for a given availability. Most systems are designed only to work with line-of-sight conditions; however, some systems designed for residential access with very small cells and low customer premises antenna height may include a margin for light foliage loss. Material on foliage loss at millimetre-wave frequencies can be found in "Propagation losses due to foliage at various frequencies", J.E.J. Dalley, M.S. Smith & D.N. Adams, Proc. IEE Conference on Antennas & Propagation, Publ. No. 461, pp 267-270, March 31st - April 2nd 1999.

Because propagation is free-space, and base station antennas are generally mounted above other features in the environment, there is a high potential for base-to-base co-channel interference. Therefore, FWA systems either use FDD to eliminate base-to-base interference, or else if they use TDD, the base stations must be synchronized so that base stations are never receiving the transmissions of other base stations.

When antenna height is close to rooftop, and the system is designed for line-of-sight coverage, the cell size tends to be limited to less than 1.5 km by natural obstacles. Beyond this distance, the probability of any given customer premises with low antenna height having an optical line of sight to the base station becomes low. With antennas mounted on rooftops of multi-story businesses, larger cells, up to about 5 km radius, are possible.

3 Mobile cellular and fixed wireless access planning comparisons

In many ways planning a fixed radio network is similar to planning a mobile cellular network. In each case a cell plan detailing radio coverage and capacity must be produced. In addition a backhaul, transport and switching network must be provided to interconnect the base stations. However, the manner in which the network is required to grow may be radically different for mobile and fixed radio access networks.

The initial requirement for roll-out of a mobile cellular system is usually radio coverage. There is a critical mass in terms of radio coverage at which subscribers realize they can make calls from most of the locations they find themselves in. Only at this stage does the mobile network become attractive to customers. In contrast a FWA subscriber will not be concerned about coverage provided his own fixed location can be reached. Thus it is possible for FWA operators to gain revenue from a very limited coverage deployment. Figure 24 illustrates how an FWA operator can target coverage on areas of population whereas a mobile cellular operator must provide both broad area coverage together with high capacity in areas where users congregate.

FIGURE 24

Coverage comparison between FWA and mobile cellular

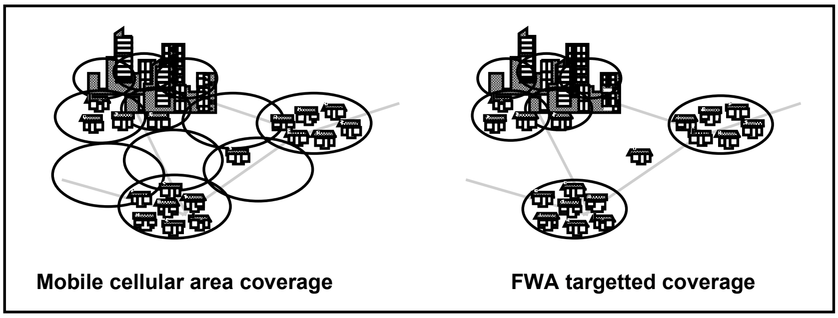


Table 3 gives a number of comparisons between a mobile cellular system and Fixed wireless access.

TABLE 3

FWA and mobile cellular comparisons

	Mobile cellular	**FWA**
Traffic generation	People on the move with mobile phones Dynamic scenario difficult to predict accurately	Static installations Mainly static scenario probably allows more accurate prediction and thus better traffic capacity match
RF propagation	Mainly indirect paths with Rayleigh fading Mobile antenna can be in a multitude of different environments, including indoors and moving at high speed. Antenna may be at an arbitrary polarization orientation Modelling less detailed due to more homogeneous multipath environment and mobility	Near line-of-sight paths with Rician fading and more optimal antenna siting Subscriber's radio system antenna is fixed, usually at a high level with respect to clutter. Antenna will be at a fixed polarization orientation Modelling more challenging due to less homogeneous environment. Paths vary from LOS to highly cluttered (> 60 dB excess loss over free space)

TABLE 3 (*continued*)

FWA and mobile cellular comparisons

	Mobile cellular	FWA
Link budget	Margins for handover and building penetration Explicit fading margin not required, as mobile assumed to be moving through fade structure (implicit margin built into Rx sensitivity)	No margins required for handover or building penetration Temporal fading margin required to account for non-stationary environment
Frequency reuse	Typical schemes: Omni cells with reuse of 12 Tri-sector cells with reuse of 4,12 (also sectorized 7,21 or 4,24) Polarization discrimination not applicable due to omni mobile antenna	Typical schemes: Omni cells with a reuse of 7 Tri-sector with reuse of 3,9 Sector rotation and polarization splitting used to reduce co-channel interference
Capacity growth planning	Sectors, split cells and add fill-ins as required	Requires early planning due to directional subscriber's radio system antenna and need to avoid large scale re-pointing
Cell planning	Omni mobile antenna thus orientation not important Mobile antenna typically fixed at 1.5 m agl	Directional subscriber's radio system antenna needs to have orientation controlled for *C/I* evaluation Subscriber's radio system antenna at a variable height related to house dimensions, operator installation preferences and local planning restrictions
Network planning	Planning of complex system of BSCs, MSCs, VLR and HLR required	Simplified backhaul planning

4 Generic radio network models

Wireless access systems can be deployed in a diverse range of markets and environments. This will result in network designs that fulfill a wide range of performance objectives. To discuss the appropriate radio planning parameters and constraints it is useful to group these into generic network models. Two generic radio network models have been identified. Each differs considerably from the other in the nature of the deployment and hence the margins that must be applied. The two models represent varying degrees of subscriber density; these will be discussed and their characteristics outlined.

4.1 "Standard" wireless access networks

Wireless access can be deployed to offer service in areas where the potential subscriber density could be described as low, medium or high. This is typical of most urban and suburban areas and also some of the rural areas of more densely populated countries. In this type of network the exact location of potential subscribers is not normally known at the time of planning and thus the aim of the radio planning is to provide a statistical estimation of the radio coverage. This type of network deployment has the following characteristics:

– The exact location of customers is not known in advance, so coverage and traffic are predicted to a small area (pixel) not to an exact location.

– Regulations, housing densities or economics prevent the use of tall masts at the subscribers premises to optimize the radio path.

– Subscriber equipment can only be mounted on or near the subscriber's premises.

– Radio paths are usually not line-of-sight and hence there will exist a significant degree of shadowing.

– Good area coverage is required to enable connection of customers anywhere within the designated service area.

– The network design requires flexible long term capacity extension capability.

– Design and control of interference is critical to achieving optimum network capacity.

4.2 Low density rural networks

In certain instances an operator may wish to offer service in sparsely populated rural areas with very low subscriber densities. This network type will normally require long range operation to ensure economic viability and hence the radio paths to subscribers are designed to optimize radio propagation conditions. This type of deployment has the following characteristics:

– Very low subscriber densities although traffic may be high relative to subscriber densities in some circumstances, for example teleworking.

– Locations where service is required are generally well defined.

– Service is provided to comparatively isolated subscribers or small groups of subscribers and requires long range operation.

– Locations of the base site and subscriber's radio system are chosen to optimize propagation, generally by obtaining a line-of-sight path.

– At the remote location the subscriber unit can be positioned to provide a good point-to-point radio path with the subscriber's radio system mounted on a mast if necessary.

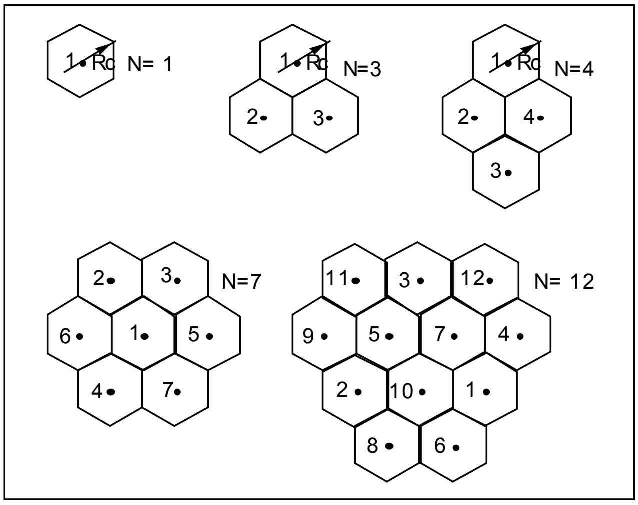
5 Idealized hexagonal coverage

To facilitate top level design and analysis of wireless access networks the concept of an idealized hexagonal grid is used. For radio planning purposes the area to be provided with radio coverage must be divided into cells in a regular fashion. This implies the representation of the cells by a regular polygon chosen such that the polygons will form clusters that tessellate (i.e. fit together without gaps). The hexagon is commonly used for this purpose and has the advantage that it closely resembles the idealized circular coverage of a cell.

Typical cell clusters used in wireless access planning are illustrated in Fig. 25. The "radius" of a centre fed hexagonal cell (Rc) is defined as the peak radial distance and the cell area is thus equal to $2.6Rc^2$.

FIGURE 25

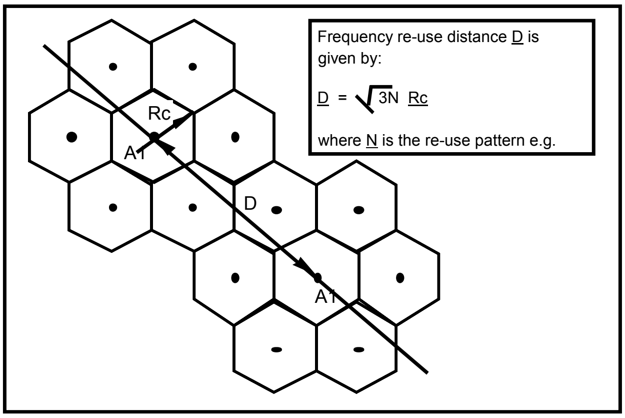
Typical cell clusters



An example of frequency re-use in a 7 cell cluster is shown in Fig. 26. A particular group of channels A1 is used in one cell with coverage radius Rc. These channels are re-used in another cell with the same coverage radius at a distance, *D*, away.

FIGURE 26

7 cell re-use example



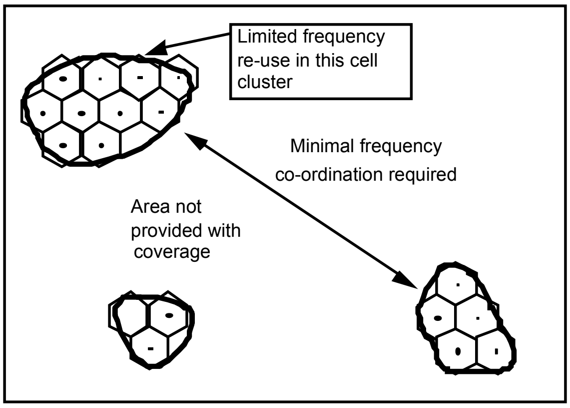
In general the requirement to provide continuous coverage over very large areas may be less prevalent in wireless access network design than in mobile cellular network design, as discussed in § 3. Two coverage conditions can therefore be described:

– multi-cell continuous coverage – involving extensive frequency re-use within the coverage area. As such the hexagonal grid can be considered to be infinite when interference calculations are being made. This condition may be representative of high capacity networks in large cities where a large number of small cells are employed;

– isolated selective coverage – coverage of small 'islands' such as key population centres with areas of limited service in between these coverage areas. A finite grid of cells can be considered when interference calculations are being made. This scenario is illustrated in Fig. 27.

FIGURE 27

Selective coverage scenario



Sectorization is employed in wireless access networks to reduce the number of cells in a frequency re-use cluster leading to an increase in the number of radio channels available per cell and hence increase the traffic. Sectorization can also be used in situations where extended range is required because sectored antennas have higher gain than omnidirectional antennas. Sectored sites can be arranged in two generic forms, centre-fed and corner-fed. One possible technique for reducing interference in wireless access networks is through the use of sector rotation. The fixed nature of wireless access, together with the use of directional subscriber antennas, makes this technique possible. The orientation of the sectors is rotated at the base station and this can increase the distance to interfering sectors. Refer to a text such as Boucher [1995] for details on sectorized cell plans.

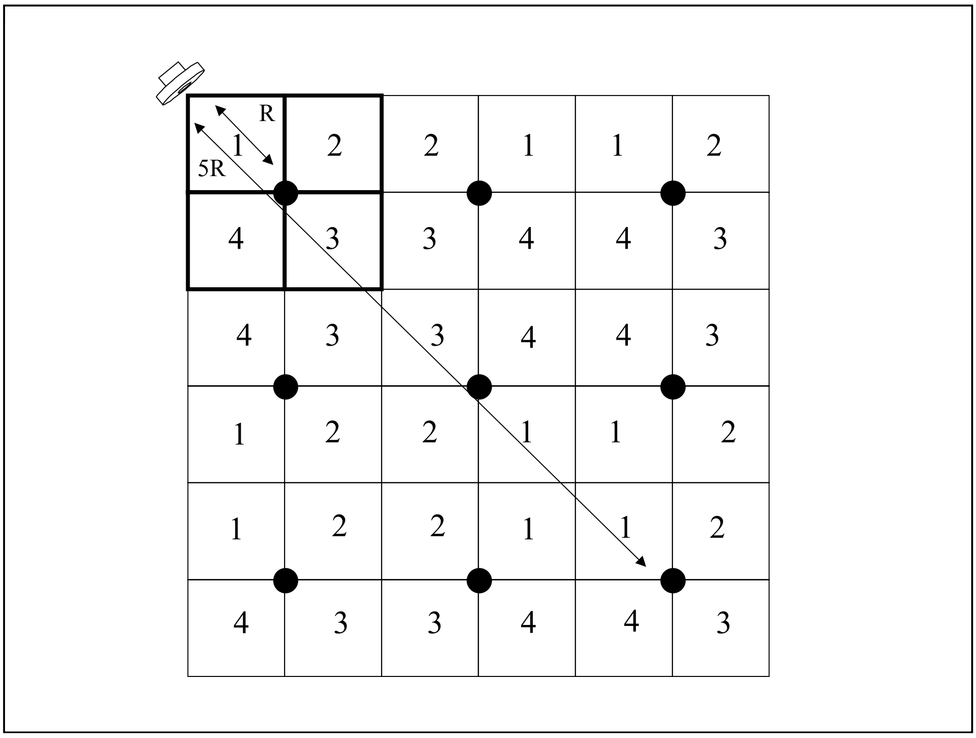
The convention *N*, *M* is used for describing frequency re-use, where *N* is the number of cell sites in the re-use cluster and *M* is the number of sectors in the re-use cluster. In reality a number of factors such as difficult terrain and antenna height may limit the re-use distance.

5.1 Broadband cell planning

Reflecting that intensive frequency reuse is possible in BWA systems, because the antenna at the CPE is highly directional and dispersion minimal, square grids, rather than hexagonal, are common. Generally, all frequencies can be reused at least once in each cell; i.e. the base reuse factor is 1. A common scheme is 1,4 using 4-sectored square cells with mirroring of the re-use pattern between cells, as shown in the figure below.

FIGURE 28

A common reuse pattern for 4-sectoral square cells



The black dots represent the base station locations. The boundaries of a single cell, with 4 sectors, is shown by the heavy lines in the upper left portion of the figure. With this scheme, the available spectrum is divided into four groups. All groups are used once per cell. The same frequency is reused in the adjacent sector of the adjacent cell; however, the CPEs in each sector face away from the sector re-using the frequency; therefore, C/Ic ratio is related to the front-to-back ratio of the CPE antenna. Good CPE antenna sidelobe and backlobe suppression is therefore required; especially when differential rain fading is considered.

The nearest co-channel codirectional re-use occurs in a sector located five cell radii away. For example, a CPE in the upper left corner sector sees a co-channel, codirectional base station located at the lower right corner. The C/Ic ratio with free space propagation is 14 dB in this case; however, there are frequently other factors present which help to further reduce this, such as the low probability of line-of-sight from low CPE antennas at this distance.

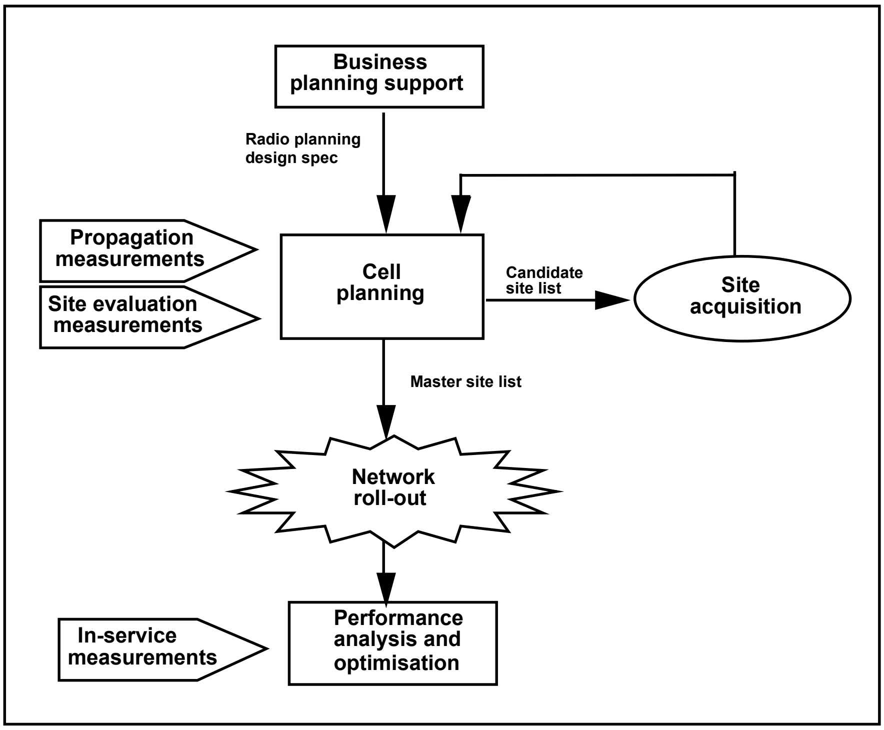
The use of both vertical and horizontal polarization may allow more intensive frequency re-use. This is not always desirable, however, as horizontal polarization is associated with decreased range due to higher rain loss, and polarization isolation requirements become stringent.

6 The top level radio planning process

Radio planning forms a substantial activity within the overall network engineering process. This handbook uses the model shown in Fig. 29 as a basic model of radio planning. The process consists of three main activities, business planning support, cell planning, and performance analysis and optimization. A number of support activities together with the main deliverables from each stage are shown. Whilst the different phases are described separately there will be in reality a degree of overlap as the network design progresses from inception through roll-out to optimization.

FIGURE 29

Top level radio planning process



The individual stages of the process are described:

6.1 Business planning support

Business planning covers a wide spectrum of issues but this Handbook only describes the support activities that require radio planning inputs. Business planning support involves evaluating/generating key aspects of the operator's business plan based on simple rules for analysis of population data, expected traffic, radio cell sizes, costs, marketing targets, revenue etc. Radio propagation is only considered in terms of top level radio planning rules. The planning rules will be based upon idealized hexagonal cells, generic frequency plans and statistical propagation models that assume "quasi-smooth" or "rolling terrain".

The outputs from the business planning process are typically an estimate of the number of base stations and amount of backhaul required to cover the country or area, a definition of the areas to be covered, a capacity growth plan, an order or roll-out plan, network costs and a business plan.

6.2 Cell planning

Cell planning covers the placement of cell sites and detailed modelling of cell coverage and capacity. An early objective is to produce a candidate site list giving full details of all site locations and configurations. This will enable site acquisition teams to start work and transmission planning groups to assess and plan the backhaul and switching networks before detailed planning is completed. Fine tuning of propagation models may be required to optimize models to specific national and regional environments. Additional support for site acquisition may involve measurements at specific problematic or marginal sites. The output from this phase is an approved cell/network design with verified performance (in planning tool) against coverage and capacity objectives together with a master site list.

6.3 Performance analysis and optimization

The objective of network performance analysis and optimization is to extract the optimum performance from the wireless access network at any given phase in the lifecycle of the network. Activities in this phase will include coverage and interference verification and management of growth plans. This activity will be supported by in-service measurements using both survey equipment and the diagnostic and measurement capabilities of the network itself.

6.4 Traffic estimation and calculation of spectrum requirements

The methodology in Recommendation ITU-R M.1390 may be used to estimate the FWA traffic and the corresponding spectrum requirements.

7 Business planning support

A complete description of a business planning process is beyond the scope of this Handbook. This section only describes the radio planning inputs to the process.

Business planning will typically occur at the bid stage of contract negotiations. It may then subsequently be repeated once the contract has been awarded to further refine the top level network design and confirm before detailed network design begins that the operator's objectives have not changed. The radio aspects of the business planning activity will always require confirmation before cell planning can begin.

The objective of business planning support is to produce key inputs for the operator's business plan based on simple rules for analysis of population data, traffic, radio cell sizes, costs and operator service targets. This input will enable the operator to evaluate the economic feasibility of the network in terms of market conditions, revenue potential and system cost.

Business planning is usually completed using spreadsheet models of the network. These incorporate simple models for subscriber density and traffic, equipment cost and idealized hexagon radio coverage.

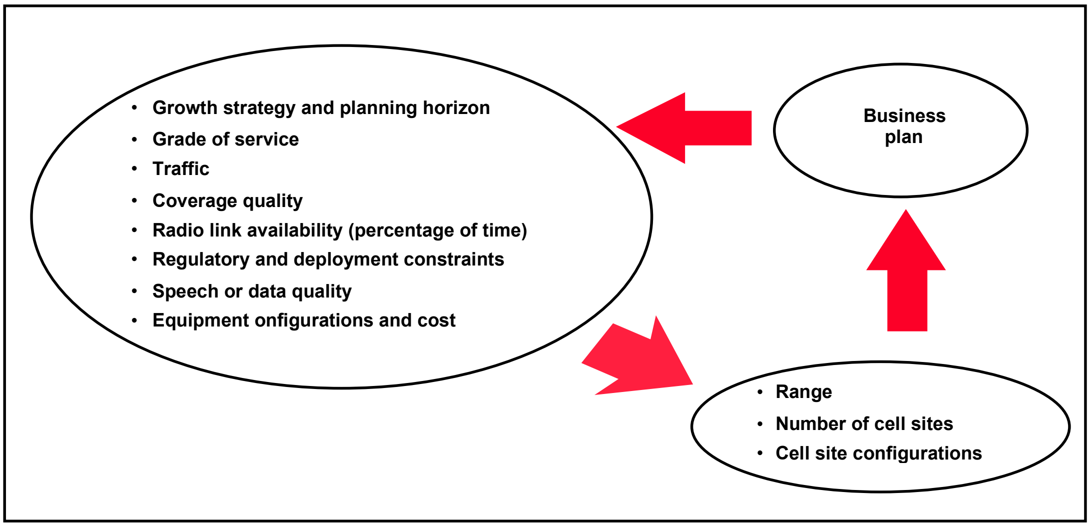
Radio propagation is only considered in terms of top level radio planning rules. The planning rules will be based upon idealized hexagonal cells, generic frequency plans and statistical propagation models that assume "quasi-smooth" or "rolling terrain". To determine radio ranges to be used in business planning a number of network design objectives must be considered.

7.1 Key inputs to business planning support

Radio coverage and penetration is of major strategic importance to business planning. A high percentage of the total network infrastructure capital cost is required to support the delivery of the radio coverage. Thus the achievement of the optimal cost/performance balance within a wireless access network is extremely important. As part of the business planning process the network operator has to make a number of key choices on radio network design objectives as illustrated in Fig. 30. These choices will directly affect the number of base station sites and their configuration.

FIGURE 30

Key operator choices



– Grade of service: this is defined as the busy hour call blocking probability.

– Speech or data quality: defined in the link budget in terms of BER.

– Coverage: definitions of areas or zones and coverage objectives such as coverage quality. Coverage quality is defined as the percentage of locations within the cell radius that statistically will have a BER better than the minimum threshold value.

– Radio link availability: the percentage of time that the received signal strength exceeds a minimum threshold value (threshold determined by speech or data objectives).

– Traffic: offered traffic per subscriber in Erlang per subscriber, voice/data split (POTS/fax or data), subscriber densities and target growth.

– Growth strategy and planning horizon: does the network design have a growth path, can it accommodate changes to the business plan?

– Terrain and ground cover (clutter): different markets will present markedly varying propagation environments. For example, under some specific circumstances, propagation conditions may allow long-range rural networks to be considered. In most circumstances the business planning models described in this handbook will be applicable and the process described in the following section will provide typical ranges.

– Regulatory and deployment restraints: licence requirements or limitations, spectrum availability, constraints on size or locations of masts, subscriber antenna heights, etc.

– Acceptable percentage of cell area affected by interference: tight frequency re-use schemes allow high capacity networks to be designed but a small percentage of the cell will be susceptible to interference. The acceptable limit will determine the re-use scheme and hence capacity achievable from the network.

– Equipment configurations and cost: equipment types, sector/omni, mast costs, etc.

7.2 Key outputs of business planning support

The outputs from the business planning support phase are typically an estimate of the number of base stations and the amount of backhaul required to cover the country or area, a definition of the zones to be covered, a capacity growth plan, an order or roll-out plan and quantified network costs.

7.3 Measurements associated with business planning support

Propagation measurements may be required during the business planning phase for fine-tuning of statistical propagation models in specific or "unusual" environments. "Unusual" can be interpreted to mean environments or deployments which deviate from the validity conditions stated for the models, for example very high base station heights or dense tropical vegetation. Measurements may also be required to support example or trial sites.

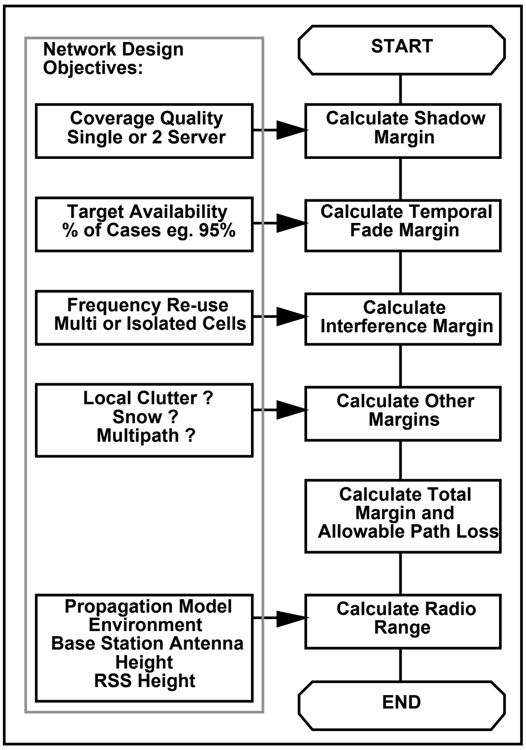
7.4 Calculating radio range for "Standard" wireless access networks

Radio range is calculated by applying a propagation model to the allowable path loss budget. The allowable path loss is generated from the link budget calculations with appropriate margins. Note that the range calculated in this way is based on certain terrain assumptions. In a real deployment which includes large terrain or clutter features, the range in any direction may be significantly more or less than this value. Hence the need for detailed planning prior to deployment.

Figure 31 illustrates the steps required to calculate the radio range appropriate to the network design objectives provided.

FIGURE 31

Calculating radio range for "Standard" wireless access networks

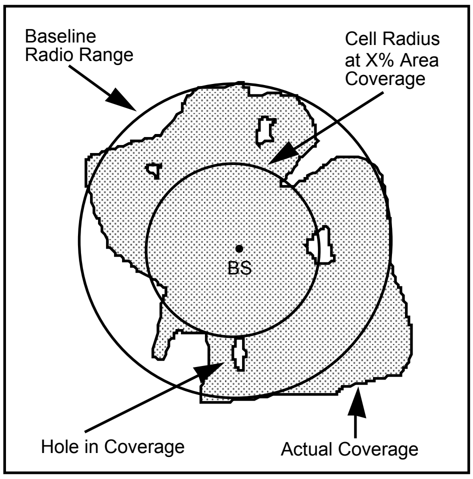


7.5 Shadow margin and coverage quality

Wireless access networks, just like other radio systems, will encounter "shadowing" due to terrain undulations and other obstacles such as buildings, foliage etc. Thus a percentage of locations within the cell may have a median signal strength that falls below the receiver sensitivity. Coverage quality is defined as the percentage of locations within the cell radius that statistically will have a signal strength that exceeds the minimum threshold value. To increase the coverage quality within a cell a shadow margin is added to the link budget. This has the effect of reducing the cell radius down from the noise limited range. This is illustrated in Fig. 32, where the coverage quality within the reduced cell radius is higher than the coverage quality within the radius defined by the noise limited range. The coverage quality acceptable to an operator usually ranges between 75% and 99%, and the requirement may be different for urban and rural areas.

FIGURE 32

Coverage prediction over uneven terrain



To calculate the shadow margin requires knowledge of the variation in local median signal strength. This will vary according to environment. The variation of the local median signal strength has been found to be log-normally distributed in many practical environments such as rolling terrain. However a degree of caution is required, for example in mountainous terrain it clearly would not apply.

In calculating coverage quality it is important to include the improvement that can be obtained by considering base site diversity. The installer of the subscriber unit can possibly assign the subscriber unit to one of a controlled choice of host base stations when the installation is made. In this way the probability of achieving a radio path above threshold is increased.

7.6 Temporal fade margin

The two-way wireless access radio link between a subscriber's radio system and base station will be subject to short term fluctuations in the signal level over time. These "temporal" fades will manifest themselves as a degradation in the resultant system BER as compared to the non-fading environment. A margin is introduced to the link budget to reduce the probability of fading below the sensitivity level, which can be expressed as a radio link availability. Radio link availability is defined as a long term measurement that describes the percentage of time that the signal strength is sufficient to provide a specified quality.

BWA systems operating over line of sight paths at frequencies above 10 GHz typically experience severe temporal fading due to rainfall. The fade margin is a function of the desired availability and the statistics of rainfall occurrence and severity for the geographic region. At lower frequencies, temporal fading is mainly due to time-varying multipath fading which occurs as objects in the environment move.

7.7 Interference margin

A margin is required to account for sensitivity degradation due to co-channel and adjacent-channel interference. The precise value required will depend upon the particular deployment and may not be the same for the uplink and the downlink.

BWA systems are typically engineered for very high availability (99.9% – 99.99%), as each link typically provides service to a large number of end users, frequently for mission-critical business applications. Interference margins are typically 0.5 – 1 dB, which means that interference must be kept several dB below the thermal noise floor of the receiver. In some regions there may be regulatory requirements for a 3 dB reserve to allow for future implementations.

7.8 Other link budget margins

Link budget margins may be required in addition to the shadowing, temporal and interference margins described in previous sections. These margins are to make an allowance for the following:

– Local clutter around the subscriber's radio system – for example if local foliage is expected close to or in the radio path this could be included as a margin.

– Falling snow has no appreciable loss but if accumulation of snow on the face of the subscriber's radio system or base station antenna occurs for extended periods then a margin may be appropriate.

– Paths over large exposed areas of water.

– Multipath propagation – In some specific installations specular reflections from tall buildings, mountains etc. could cause multipath to occur with delays comparable to symbol lengths. The directional subscriber's radio system antenna will usually introduce a significant attenuation into the delayed signals relative to the direct signal. The most severe problems of multipath will occur where specular reflections are present in the main beam when the subscriber's radio system antenna is pointing towards the base station. Precautions such as avoiding omni antennas in the vicinity of large buildings should be employed where possible.

7.8.1 Sample BWA link budget

The range of typical BWA systems varies between 1.5 and 5 km, depending mainly on the temporal fade margin. This is a function of the frequency, polarization, rain region, and desired availability. Vertical polarization is preferred. Link budgets for BWA systems are usually downstream-limited (base station to CPE direction). This arises because the downstream channel is usually much wider than the upstream channel, and in addition, multiple downstream carriers may be combined in the same PA, requiring a substantial power back-off to preserve PA linearity. A example of a possible downstream link budget is shown in the table below.

Item	Value	Comments
Frequency	28 GHz	
Rain Region	K	ITU rain region designation
Polarization	Vertical	
Modulation	16-QAM	Affects power back-off and receiver threshold
Channel bandwidth	20 MHz	
Number of channels combined	2	
Transmitter:		
PA saturated power	24 dBm	1 dB compression point, referred to antenna flange
Power back-off for linearity	7 dB	Related to modulation, number of carriers, PA intermodulation performance, and spurious emissions requirements
Total transmitted power	17 dBm	
Net transmitted power per carrier	14 dBm	
Transmitter antenna gain	18 dBi	90 degree sector, 4 degree vertical beamwidth
Net Effective Isotropic Radiated Power	32 dBm	
Receiver:		
Thermal noise	-174 dBm/Hz	
Noise Figure	7 dB	referred to antenna flange
Noise bandwidth	72 dBHz (16 MHz)	25% roll off assumed
Required C/N	16 dB	depends on modulation, forward error correction (FEC) scheme, and target bit error ratio (BER)
Modem implementation margin	1.5 dB	depends on modem quality
Margin for interference	1 dB	for 1 dB margin, interference must be 6 dB below the thermal noise floor plus noise figure
Net received signal level threshold	-76.5 dBm	
Receiver antenna gain	36 dBi	approximately 30 cm parabola
Total system gain	144.5 dB	e.i.r.p.-receiver threshold+receiver antenna gain
Range	3.9 km	
Free space path loss	133.2 dB	
Atmospheric gaseous losses	0.4 dB	
Temporal fade margin	10.9 dB	
Availability	99.95%	

7.9 Calculating range for low density rural networks

For long range rural networks as described in § 4 above, margins are required for diffraction loss, multipath fading and possibly dispersion under anomalous atmospheric conditions. Calculation of these margins is highly dependent on environmental factors.

7.10 Radio capacity vs. range

The maximum radius of a cell will be limited by one of two factors – capacity (which is dependent on subscriber density) or the range for a given coverage quality and availability (i.e., the maximum ranges).

7.11 Top level frequency planning

Wireless access, similar to mobile cellular radio systems, relies on the re-use of frequencies to provide large scale coverage. Each base station is assigned a block of frequencies and these remain allocated to the base station even at times when no calls are being made. The frequency can be re-used by another base station when the distance between the two base stations is sufficient to prevent interference. Interference due to the common use of the same channel is called co-channel interference and is the major concern in the design of frequency re-use schemes.

7.12 Radio growth strategies

Radio growth strategy is concerned with the provision of additional capacity as an operator's business grows. The growth strategy for a wireless access system is substantially different to cellular systems because of the subscriber's radio system directional antenna and the use of polarization discrimination. Since the system is optimized for fixed subscribers there is no handover between base stations. Thus if during network growth it is desired to re-assign a subscriber to a new or different base station the operator must re-visit the subscriber's radio system and physically re-point it and repeat the subscriber's radio system attachment and registration. In some cases it may be necessary to "re-install" the subscriber's radio system in a different position where the direction to the new base station is heavily obstructed from the current subscriber's radio system location. The use of polarization and directional subscriber's radio system antennas for discrimination between interfering cells achieves tighter frequency re-use than is traditionally possible with cellular technology. However, this has to be designed from the start if re-visits to subscriber to change polarization are to be avoided.

Cell splitting is used to provide additional capacity in the radio network. When the number of radio channels in each cell cannot provide enough capacity then the original cell can be split into smaller cells. Cell splitting options include:

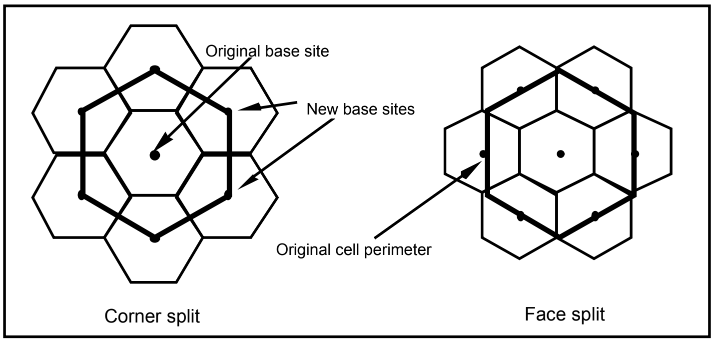
– *Corner splitting* – In this scheme new sites are established at the corners of the original cell. The ratio of cell radii for corner splitting schemes is $\sqrt{3}$ (square root of 3), thus 3 times the original number of sites are required. The split cell has an area 1/3 the area of the original cell and thus if the frequency re-use remained constant a 3 times increase in capacity per unit area would result. It also follows that if the subscribers were uniformly distributed then approximately 66% would need to be re-pointed to new base stations after corner splitting was completed.

– *Face splitting* – In this scheme new sites are established at the mid-point of the faces of the original cell. The ratio of cell radii for corner splitting schemes is 2, thus 4 times the original number of sites are required. The split cell has an area 1/4 the area of the original cell and thus if the frequency re-use remained constant a 4 times increase in capacity per unit area would result. It also follows that 75% of the original subscribers would require repointing after face splitting.

Corner and face splitting schemes are illustrated in Fig. 33.

FIGURE 33

Corner and face split centre fed cells



8 Cell planning

The cell planning phase involves the modelling of cell coverage and capacity in detail. The objective is to produce a candidate site list at the earliest opportunity. This gives initial placement details of all site locations and configurations and will enable site acquisition teams to start work and transmission planning groups to assess and plan the backhaul and switching networks. Support to site acquisition teams continues as sites are evaluated for suitability and the network plan continuously updated. Site evaluation measurements may be undertaken at problematic or marginal sites. The output from the cell planning phase is an approved cell/network design with performance verified in the planning tool against coverage and capacity objectives.

The radio planning team must supply the candidate site list together with search areas and marked-up maps to the site-finding teams. Radio planning resource must be available to provide consultation on critical sites where specific problems or non-ideal locations are found. This will involve site visits, site evaluations using measurement equipment and modelling within the planning tool.

It is not possible to describe a definitive process for cell planning in this Handbook because planning groups will have their own methodology and "style". A generic wireless access cell planning process is presented and used to highlight wireless access specific planning considerations. Typical inputs and outputs of the process are described and items with specific relevance to wireless access planning highlighted.

Figure 34 illustrates the typical cell planning process. The following is a brief summary of the key points:

– Signal strength thresholds – Thresholds have to be set for coverage assessment. These will be based on the link budgets with additional margins to account for lognormal shadowing. In addition the decision threshold targets for lost business and failed surveys will assign Yes/No/Maybe responses to signal strengths.

– Cell placement – Once signal strength thresholds are set, a suitable set of idealized hexagon sizes can be determined. These can be used for initial cell placement and give a very rough indication of coverage.

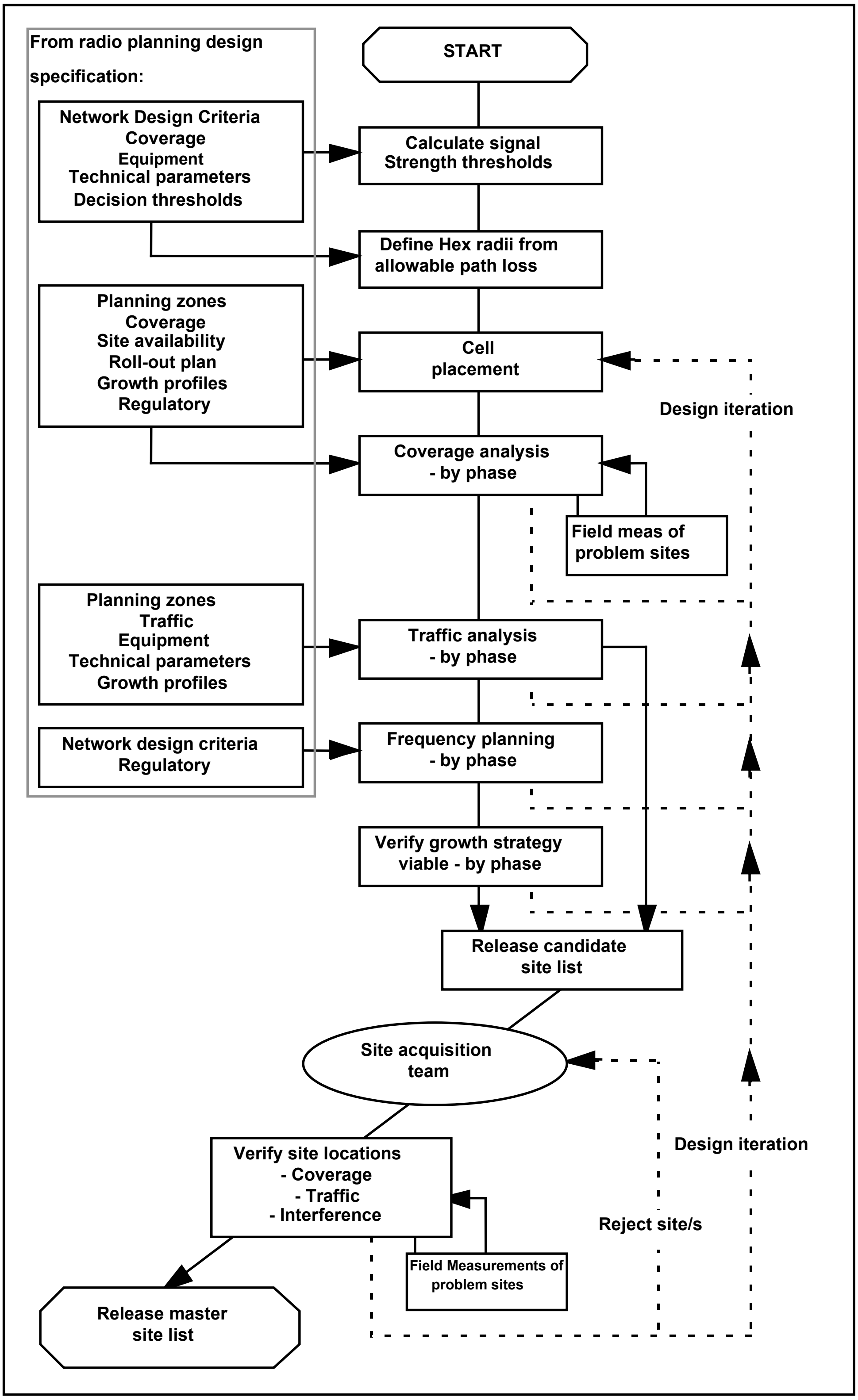
– Coverage analysis – Coverage is analysed for the cells and overall coverage within a zone can be determined. This will need to be determined for each phase of network deployment.

– Traffic analysis – Traffic analysis has to model the fixed nature of the subscriber's radio system attachment. Once a subscriber's radio system has been installed and attached to a base station, unless re-pointing and re-attachment occurs, the subscriber's radio system will always generate traffic on a single base station even if an additional base station is added. This situation is mimicked in the planning tool by using fixed and incremental layers of traffic for each phase.

– Frequency planning – Frequency planning for wireless access is similar to cellular frequency planning. Verifying site locations encompasses the following activities:
  – screen the site for suitability and position;
  – evaluate the actual position coverage and interference as against the ideal position. Re-engineer plans to accommodate non-ideal positions whilst still meeting network design objectives;
  – verify access and utilities available;
  – support to transmission planning;
  – assess site-specific frequency licensing issues.

FIGURE 34

Cell planning process



9 Network performance analysis and optimization

The objective of network performance analysis and optimization is to extract the optimum performance from the wireless access network at any given phase in the life cycle of the network. All radio networks have an element of continuous change, with new cell sites being introduced, old sites being enhanced and assigned additional frequencies, omnidirectional sites being sectorized, new frequency plans being implemented in different regions, etc. In short, there is no such thing as a final system design, but rather a continuous evolution process. Throughout this evolution, the performance of the radio network must remain optimum and, hence, the need for fine-tuning and the optimization process. Activities in this phase will include the management of growth plans, coverage and interference verification. This activity will be supported by in-service measurements.

The following is a summary of the activities required in this phase:

– Traffic data collection and analysis, blocking levels, dropped calls

– Management of growth, number of bearers, frequency plan modifications, cell splitting, additional sites etc.

– Evaluate and resolve network quality problems.

Radio network acceptance, with many turn-key type contract radio surveys may form part of the overall system acceptance testing.

The capability of the wireless access network to measure and collect large amounts of data on the radio performance of the network will provide opportunities for analysis and optimization of specific network performance metrics.

10 Summary of radio planning considerations

This section contains checklists that are useful in planning a wireless access system:

Radio planning design specification

Typical contents of the design specification are given in Table 4.

Candidate site list

Typical contents of the candidate site list are given in Table 5.

Master site list

Table 6 shows the typical content of a site master list.

Cell planning report

Table 7 gives details of typical information that should be documented once a cell plan is completed. This information should provide a concise view of the network plan, and detail all assumptions/parameters used to allow future optimization and iteration of the network plan.

TABLE 4

Radio planning design specification

Type of information	Parameters
Planning zones/areas	Polygon definitions of zones/clusters/towns Assumptions of environment by zone Prioritized order of planning zones (including prioritized towns/clusters within zones)
Coverage	Coverage objectives by planning zone and environment Coverage quality Special coverage requirements/areas
Traffic	Grade of Service (GOS) Subscriber profiles (mErl/sub) Call mix (fax/phone/modem) Average lines per subscriber Subscriber densities by zone/area Target traffic growth Target penetration Initial network capacity at launch
Equipment	Base station configurations Subscriber configurations Equipment costs Backhaul requirement for each configuration Masts Base station capacity
Other network design criteria	Radio link availability Speech quality BER for data Percentage of cell area lost due to interference
Regulatory	Licence requirements Spectrum availability or constraints Planning - constraints on size/location of masts etc.
Technical parameters	A summary of the technical parameters used/assumed in the design: – Propagation model version (Business planning) – Propagation model version/s (Cell planning) – Link budget – Traffic model – Temporal fading margin – Shadow margin – Other margins
Roll-out plan	Number of base sites per planning zone (at roll-out and growth intervals) Configuration of base sites (at roll-out and growth intervals)
Growth profiles	Coverage growth by year or planning increment Traffic growth or market penetration by year or planning increment Growth strategies for above Planning horizon
Site availability	Known planning difficulties Operators' existing sites Friendly sites
Mapping data	Specification and availability of: – Terrain data – Clutter data – Vector data (optional)

TABLE 5

Candidate site list

Type of information	**Parameters**
Candidate site list (by phase)	Site ID Site name Latitude/Longitude Ground height Phase Configuration (e.g. omni/tri, vert/horiz) Base station configuration Number of bearers Power levels antenna type, height, orientation, tilt, polarization
Maps	Search area Marked-up maps

TABLE 6

Site master list

Type of information	**Parameters**
Master site list (by phase)	Site ID Site name Latitude/Longitude Ground height Phase Configuration (e.g. Omni/Tri, Vert/Horiz) Base station configuration Number of bearers Power levels antenna type, height, orientation, tilt, polarization Site information from site finders: – Owner(s) – Location – Detail location maps – Pictures – Site survey report – Site measurement result (if appropriate)

TABLE 7

Cell planning report content

Type of information	Parameters
Roll-out plan	Total number of sites by phase Number of base sites per planning zone by phase Installation and roll-out documentation
Radio network costs	Zone costs by phase Site costs (including equipment, provisioning, site costs)
Planning zones/areas	Polygon definitions of zones/clusters/towns Zone changes with phase
Coverage results (by phase)	Coverage maps Coverage statistics
Interference analysis (by phase)	*C/Ic* maps *C/Ia* maps *C/Ic* statistics *C/Ia* statistics
Traffic analysis	Total capacity by zone Number of subscribers by zone Traffic maps
Frequency plan	Frequency groups Frequency assignments Polarization
Growth plan	Capacity growth plan Coverage growth plan Sites by phase
Design requirements (as per radio planning design specification)	Coverage Traffic Equipment Other criteria Regulatory Technical parameters Roll-out plan Growth profile
Technical parameters	A summary of the technical parameters used/assumed in the design: – Propagation model version/s (cell planning) – Model tuning details – Propagation measurement data – Link budget – Traffic model – Temporal fading margin – Shadow margin – Other margins – Antenna patterns – Terrain data – Clutter data – Vector data

ANNEX 4

Detailed descriptions: systems based on existing radio interface standards

The following sections describe each system based on existing mobile radio interface standards in more detail. The purpose is to provide a fundamental understanding of the system in terms of technology/architecture/configuration, features of each system, some key advantages, and some typical applications.

In general, these wireless access systems employ: a standard style telephone set which resides in the subscriber's home or business. However, instead of being plugged into a jack that connects it through traditional twisted pair copper wire to the local telephone switch, the telephone connects to the switch via radio. When the subscriber places or receives a call, the control and voice signal is transmitted via radio link to or from the nearest radio site, which then transmits or receives the signal via digital trunk to a switching centre in the network. The call is then routed via the traditional, land-based public telecommunications network to its destination. An incoming call is routed and transmitted the same way – by land-based wires from the public wired network to the switching centre to the appropriate radio site, and then by radio link to the subscriber's telephone.

1 D-AMPS/TDMA-based wireless access systems

1.1 General

These are digital wireless access systems based on TDMA technology which are fully compliant with IS-54/IS-136 standards. These systems offer digital voice quality and conversation security, and may be configured to operate in 450 MHz and/or 800 MHz spectrum. In addition to voice services, fax and data services are also supported. This additional capability set is available on an optional basis whenever the market need arises.

1.2 Technology, architecture and configurations

Given that the D-AMPS/TDMA-based system is based on non-proprietary technology and is compliant with world-recognized IS-54/IS-136 common air interface standards, wireless subscriber units may be purchased from a variety of vendors on the open market. Likewise, further product technology advancements will continue to be made and will become available, in line with the standards, as they evolve. For example, refer to Table 2 of Recommendation ITU-R M.1073 for a detailed analysis of capacity improvements in the various evolution stages.

1.2.1 Radio interface characteristics (800 MHz band)

Class of emission:	
– traffic channels	40K0G7WDT
– control channels	40K0G1D
Access method	TDMA
Transmit frequency bands (MHz):	
– base stations	869-894
– mobile stations	824-849

Duplex separation (MHz)	45
RF carrier spacing (kHz)	30
Total number of RF duplex channels	832
Modulation	π/4 DQPSK (roll-off = 0.35)
Transmission rate (kbit/s)	48.6

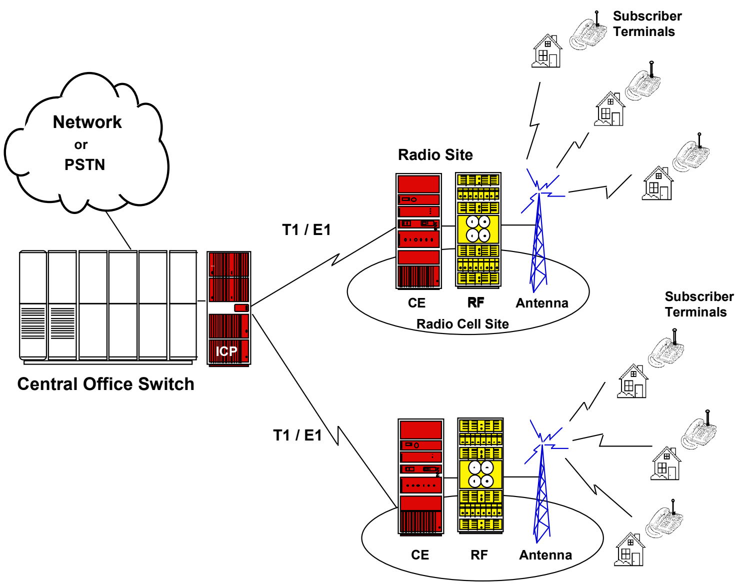
1.2.2 Network configuration

In a typical configuration, these wireless access systems simply connect to a local or toll exchange via standard or proprietary interfaces and functions as an intelligent remote unit. Both macrocells and microcells are supported and as a result these systems have the intrinsic ability to cost-effectively handle both low density and high density applications. This simplifies network planning, and minimizes maintenance and training costs due to deployment of one, single and simplified product line. Likewise, the system may grow modularly to provide service to millions of subscribers.

The basic architecture is shown in Fig. 35. The wireless access system comprises switching and radio site equipment. A basic system would include the controller and a digital radio site including one common equipment (CE) bay, and a radio frequency (RF) bay. The radio cell site is typically located at some distance from the Central Office Switch, typically in cells where the subscribers are located. A number of such similar cell sites are then connected to the central office as shown above. The cell site also contains the antennas.

FIGURE 35

D-AMPS/TDMA-based wireless system architecture



The functions of each and every component as shown in the system architecture are:

Central Office Switch

The central office switch provides the call processing features that will be used by the proximity terminals transparently through the Radio Site equipment. The connectivity between the central office and the radio site may be based on the concentration or non-concentration concept. In case, if concentration is provided the particular voice channel between the central office and the radio site can be used for any call to and from a user terminal. On the other hand, in non-concentration case, the voice channels are pre-allocated to particular terminals.

The central office switch may be configured as follows:

– may support combined fixed/mobile networks;

– may support unique wireless features such as cellular digital packet data (CDPD) and short message services (SMS);

– may be available in different sizes depending on market size and traffic capacity.

The peripherals in the central office switch provide the link to the outside world. They interface with the central processor of the switch and the lines, trunks, and RF channels it serves. In a typical configuration, the peripheral modules consist of intelligent cellular peripherals (ICPs), international digital trunk controllers (IDTCs and PDTCs), maintenance trunk modules (MTMs), package trunk modules (PTMs) and service trunk modules (STMs). The peripherals interface the switching network to digital carrier lines, analogue facilities and/or test circuits. Using microprocessors for control, they perform call supervision, dial pulse timing, multi-frequency and dual tone multi-frequency digit transmission and reception, and analogue to digital conversion. They also establish answer supervision through audio tone detections when a hardware answer signal is not received from the controlling office.

Radio site equipment

The radio cell site equipment converts baseband voice signals to frequency-modulated 450 or 800 MHz RF signals. It is the intelligent interface between the central office switch and the telephone subscribers served by the system. Typical equipment is modular, easy to install, easy to maintain, and houses the dual-mode radio units (DRUs). Various cell site configurations (simplex with no redundancies, duplex with load sharing mode, etc.) are available for different applications. Cell Equipment Manager is used to configure the radio sites and provides the state information and alarms on the radio sites. The Cell Equipment Manager is Usually co-located with the central office switch.

Dual-mode radio unit

The DRU supports both the D-AMPS as well as the AMPS systems.

Subscriber equipment

Several options are possible for the subscriber equipment. The most user-friendly option is a standard residential or business telephone set enhanced with radio transmit and receive capability (see Fig. 36). As an option, this telephone set may include a standard RJ-11 interface jack to allow connection of several conventional telephone sets as extensions, a fax machine or computer modem.

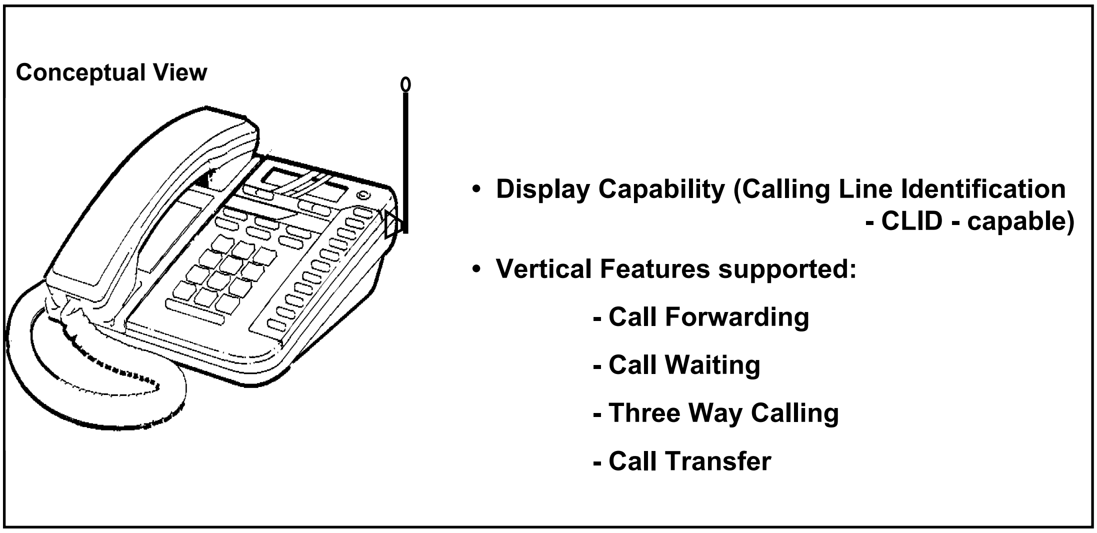
Another alternative is a conversion terminal unit with a standard interface for conventional telephones which provides the conversion link between the subscriber's standard telephone set and the wireless access system. Such conversion terminals offer multiple connections per terminal to allow for extension telephones, fax machines, computer modems, payphones, and public call office phones.

In order to maintain the same service as the wireline subscriber, the user terminal provides the dial tone and ringing as part of the basic telephone service.

All subscriber equipment options include battery back-up and are available from several vendors.

FIGURE 36

Terminals - Key features



1.3 Summary of capabilities

In summary, the North American TDMA-based wireless access systems offer the following key attributes:

Features/Highlights

– Support all important subscriber features such as call forwarding, call transfer, calling number plus advanced wireless features such as short message services.
– Provide feature transparency from the host switch.
– Advanced Operations, Administration and Maintenance systems allow troubleshooting the entire system including subscriber terminals.
– Provides a platform for evolution to CDPD, a wireless packet data service.
– Fully IS-54 standards compliant.
– Wide range of subscriber terminal options.
– Digital control channel for future additional advanced services.

Prime advantages

– Quick and cost effective deployment.
– Multiple switch platforms.
– Economical alternative to copper-based local access systems.
– Simplifies network planning by reducing lead times for installation and service activation.
– Savings in operations costs due to reduced maintenance.

– Provides a wide range of services such as standard telephone service, pay phones, data and fax on a common hardware platform.

– Supports both macrocell and microcell configurations.

Applications

– Suburban, urban and rural.

– Low to high densities.

2 CDMA-based wireless access systems

2.1 General

CDMA-based wireless access systems are based on the IS-95 standard and use a CDMA digital wireless access system which incorporates proven switching and networking technologies. The wireless access system comprises switching and radio site equipment. Two basic configurations are possible, depending on whether the Fixed Wireless Access (FWA) functionality is provided from a Wireless Switch (MSC), or whether the FWA functionality is provided from a Class 5 Local Exchange/Local End Office/PSTN Access Network without the need for an MSC. The characteristics of the radio system are the same in both configurations.

A basic system would include mobile switching centre (MSC), base station controller (BSC), and base transceiver stations (BTS). Each BSC is connected to one MSC. The MSC interfaces with both the Signalling System No. 7 network and the public switched telephone network (PSTN).

The BSC interfaces with the MSC at one end, and with multiple cell sites containing BTSs at the other. The BTSs support the establishment of IS-95 over-the-air CDMA connections with subscriber stations. Depending on the desired cell configuration, multiple BTSs may be deployed at each cell site.

The number of subscribers supported by any one cell site is variable. Unlike AMPS and N-AMPS, which use frequency division multiple access (FDMA) to divide the available bandwidth into 30 kHz channels, where each portion of the radio spectrum is allocated to a subscriber unit on demand, or D-AMPS, which uses frequency division and then subdivides each frequency into 3 time-division multiplexed channels, CDMA technology does not assign any given subscriber a specific portion of either radio frequency or time. All subscriber units transmit and receive at the same time employing different codes, over the same frequencies, using the whole 1.25 MHz bandwidth assigned to the carrier.

The CDMA-based wireless access systems offer the benefits of CDMA technology, and are specifically designed for the access network environment, with the full benefits of proven digital switching technology.

– With CDMA, the air link is planned to support up to 56 active calls per sector per 1.25 MHz, with flexibility for growth.

– Unlike other systems, the sector capacity of a CDMA-based system is not hard limited. During abnormally high usage hours, the system can automatically allocate dynamic resources to accommodate the increased load with minimum loss of voice quality.

– Each cell is planned to support a maximum range of 52 km under good propagation conditions.

– With the base station equipment at the switching centre, the antennas and associated radio equipment can optionally be located at a remote location to create a decentralized system. Point-to-point microwave can be used for signal transport.

– Because the same frequency band is used by each base station, no frequency planning or coordination is required between individual cells. This important feature facilitates maintenance, and allows for growth.

– CDMA reduces unwanted background noise through a variable rate vocoding scheme implemented in the system. Referred to as code excited linear prediction (CELP) technology, it offers wireline voice quality that has been confirmed in tests conducted in the voice quality assessment laboratories.

2.2 Technology, architecture and configurations

2.2.1 Radio interface characteristics

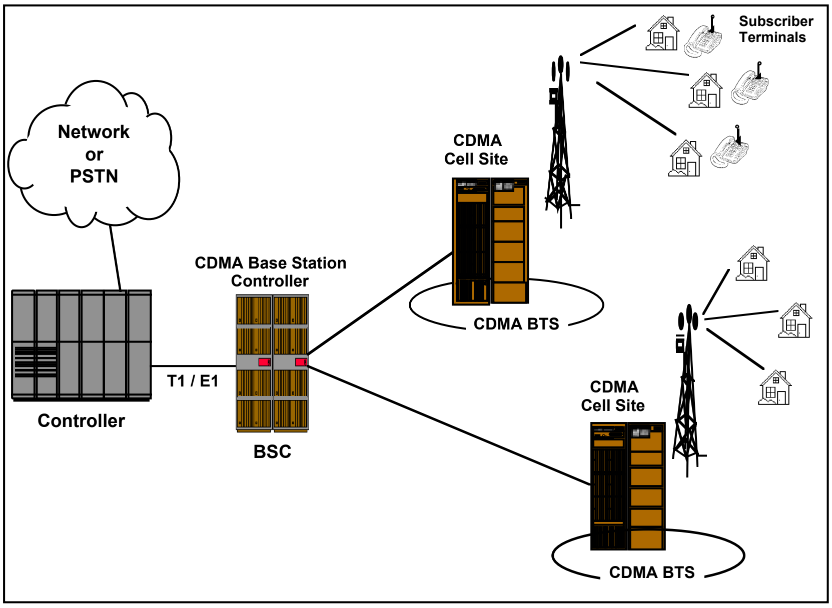
Class of Emission:	
– traffic channels	1250K0B1W
– control channels	1250K0B1W
Access method	CDMA
Transmit frequency bands for 800 MHz (MHz):	
– base stations	869-894
– mobile stations	824-849
Transmit frequency bands for 1 900 MHz (MHz):	
– base stations	1 850-1 910
– mobile stations	1 930-1 990
Duplex separation (MHz)	45 for 800 MHz and 80 for 1 900 MHz
RF carrier spacing (kHz)	1 250
Maximum number of users per sector (3 sector isolated cell)	56
Modulation	QPSK (spreading)
	64-ary orthogonal (inbound)
Transmission rate (bit/s)	9 600 per channel for 8 kbit/s vocoder, 14 400 per channel for 13 kbit/s vocoder

2.2.2 Network configuration

The basic architecture is shown in Fig. 37.

FIGURE 37

CDMA-based system architecture



The functions of each and every component as shown in the system architecture are:

MSC

The MSC is at the heart of the CDMA system and may be part of a family of digital switching systems. This family of switching systems may use a common hardware and software platform with the addition of specific software to cover the entire range of operator applications. The MSC may be available in different capacities.

Peripherals

Peripherals provide the link to the outside world. They interface between the MSC itself and the lines, trunks, and RF channels it serves. The peripheral modules consist of international digital trunk MSCs (IDTCs) and peripheral digital trunk MSCs (PDTCs), trunk modules (TMs), maintenance trunk modules (MTMs), package trunk modules (PTMs) and service trunk modules (STMs). Peripherals interface the switching network to digital carrier lines, analogue facilities and/or test circuits. Using microprocessors for control, they perform call supervision, dial pulse timing, multi-frequency and dual tone multi-frequency digit transmission and reception, and analogue-to-digital conversion. They also establish answer supervision through audio tone detections when a hardware answer signal is not received from the controlling office.

Base station controller

An outstanding aspect of the BSC is its inherent modularity. Each element of the BSC is directly scaled with the size of the system. The BSC contains the controlling elements and interface resources that provide a channel between the BTS and the switch. The primary function of the BSC is executed by three subsystems: the CDMA interconnect subsystem (CIS), the selector bank subsystem (SBS), and the base station manager (BSM). There are also other supporting subsystems include the timing frequency unit (TFU), the global positioning system (GPS), and the channel service unit/data service unit (CSU/DSU).

Base transceiver station

The BTS is the link between the subscriber units and the BSC. Located at the BTS are the antennas, transmitter, receivers, power amplifiers, and interface hardware to support the link to the MSC. The BTS provides the common air interface to the subscriber units according to the CDMA standard. For example, data from the subscriber unit is converted to packets by the BTS, and these packets plus additional control information are passed on to the Base Station Controller (BSC) for further processing. Specific functions of the BTS are:

– Over-the-air RF IS-95 and IS-95+ interface with the subscriber unit.
– Additional over-the-air functions such as pilot, sync, paging, and access channels.
– Call processing functions to control the subscriber unit operation over the paging and access channels, including short message services.
– Communication of subscriber information.
– Control and management of BTS resources.
– Control and management of communication between the BTS and other base station subsystems.
– Monitoring and configuration functions.

Subscriber equipment

Some CDMA-based wireless access system implementations allow several options for subscriber equipment. The most user-friendly option is a terminal with a standard interface for conventional telephones (Figure 38). When the subscriber plugs it into a standard AC outlet, this unit provides the link between the subscriber's standard telephone set and the CDMA-based wireless access system. Such terminals offer multiple telephone connections per terminal, battery back-up, and is available from several vendors.

FIGURE 38
Example of a user Terminal

2.3 Summary of capabilities

In summary, the CDMA-based wireless access systems offer the following key attributes:

Features/Highlights

– Based on Qualcomm's QCELP/13 kbit/s vocoder.
– Provides high capacity wireless communications.
– Supports multiple subscriber features including call forwarding, conference call and voice mail.
– Supports switched data and fax (Future packet switched data and fax).
– Innovative use of packet technology allows efficient backhaul of voice and data traffic from cell site.

Prime advantages

– Cost-effective alternative to copper based local access systems.
– Flexibility in network planning due to reduced lead times for installation and service activation.
– Savings in operations costs due to reduced maintenance and trouble reports.
– Rapid deployment.
– Provides a wide range of services such as standard telephone service, pay phones, data and fax on a common hardware platform.

Applications

– High density.
– Efficient operations.
– Evolving technology.

Service provisioning

– New entrants in de-regulating but developed markets.
– Operators and prospective operators in developing/modernizing markets.
– Non-established operators in developing markets.
– Fixed Wireless Access peripherals
– Residential Features
– Group ringing
– Cellular hotline
– Time of day routing
– Call forwarding/call forwarding ring splash
– Call waiting/cancel call waiting
– Calling number identification
– Message waiting notification

- Distinctive ringing
- Over-the-air activation
- Enhanced Variable Rate Codec
- Denied origination
- Denied termination
- Network toll denied
- Toll denied
- Toll denied operator assistance
- Malicious call trace
- Metering support
- CDMA payphone support
- Features for small business markets
- Account code billing
- Real-time billing
- Credit card calling
- Two-stage dialing
- Call transfer
- Three way calling
- Call hold
- Calling name

3 GSM-based fixed wireless access systems

3.1 General

The wireless access systems based on GSM technology generally operate in the 900 MHz, 1 800 MHz or 1 900 MHz frequency range. They are capable of providing voice, data and message services to subscribers.

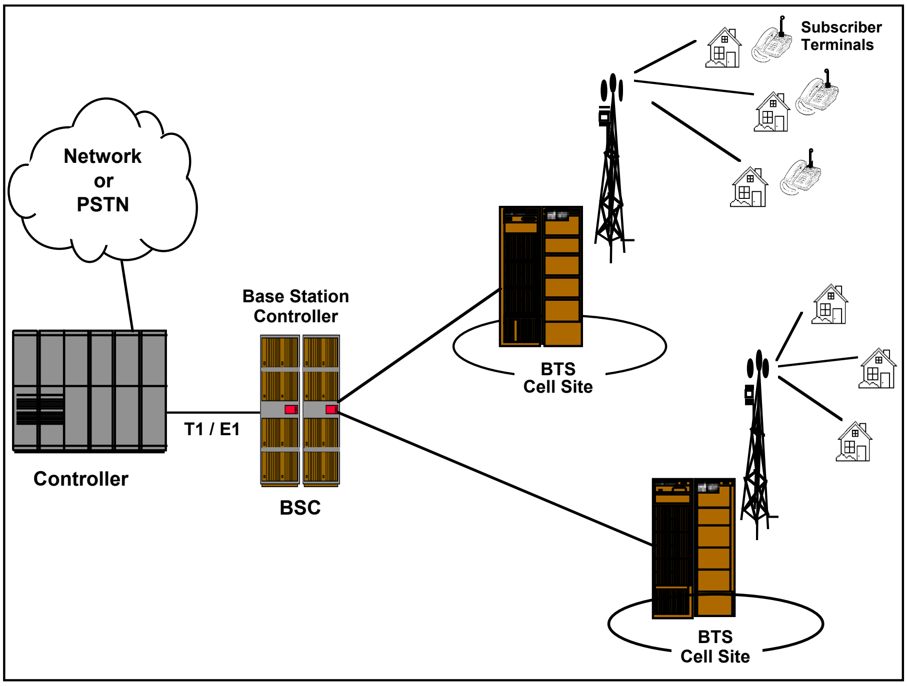
Some specific systems include an extremely "feature rich" offering with services such as Centrex and Virtual Private Network (VPN), which have allowed second operators to generate market share and differentiate themselves against established competition.

These services generate revenue in a number of different ways, such as:

- The offering of additional capabilities, such as personal screening profiles, on a pay-per-use or subscription basis.
- Services, such as voicemail notification, which encourage traffic on the network.
- The availability of services, such as corporate network interlinking and tariffing, which give access to lucrative market segments.
- The development of added value capabilities, such as short message based traffic or weather information, which allow the development of new revenue streams.

FIGURE 39

GSM-based wireless access system architecture



3.2 Technology, architecture and configurations

3.2.1 Radio interface characteristics

Class of emission:	
– traffic channels	271KF7W
– control channels	271KF7W
Access method	TDMA
Transmit frequency bands (MHz):	
– base stations	935-960 (GSM) 1 805-1 880 (DCS) 1 930-1 990 (PCS)
– mobile stations	890-915 (GSM) 1 710-1 785 (DCS) 1 850-1 910 (PCS)
Duplex separation (MHz)	45 (GSM) 95 (DCS 1 800) 80 (PCS 1 900)
RF carrier spacing (kHz)	200
Total number of RF duplex channels	124 (GSM 374 (DCS) 299 (PCS)
Modulation	GMSK (BT=0.3)
Transmission rate (bit/s)	270 833

3.2.2 Network configuration

The basic architecture is shown in Fig. 39.

The network switching system (NSS) includes the main switching element, the databases needed for subscriber data and the ancillary server database to provide additional services such as short messages and voice messaging. The main roles of the NSS are to manage the communications between the GSM subscriber and other telecommunications network users and to act as a platform for the generation of services revenue. Within the NSS, the basic switching function is provided by the mobile services switching centre (MSC), whose main function is to co-ordinate the setting-up of calls to and from GSM users. The NSS also contains various databases which hold subscriber information relevant to the provision of telecommunication services.

The functions of each component as shown in the system architecture:

Controller

The switch is at the heart of the GSM system. Several versions offering several sizes and configurations are possible, which may include a common hardware and software platform with the addition of specific software to cover the entire range of operator applications.

Peripherals

Peripherals provide the link to the outside world. They interface between the controller itself and the lines, trunks, and RF channels it serves. The peripheral modules consist of IDTCs and PDTCs, TMs, MTMs, PTMs, and STMs. Peripherals interface the switching network to digital carrier lines, analogue facilities and/or test circuits. Using microprocessors for control, they perform call supervision, dial pulse timing, multi-frequency and dual tone multi-frequency digit transmission and reception, and analogue-to-digital conversion. They also establish answer supervision through audio tone detections when a hardware answer signal is not received from the controlling office.

Base station system

The base station system (BSS) includes two types of devices: the BTS, in contact with the subscriber terminals through the radio interface, and the BSC, in contact with the switches of the NSS.

Base station controller

The BSC is GSM compliant and therefore meets all the BSS control requirements. The BSC can be deployed either co-sited with the MSC or remotely to gain transmission savings through utilizing the traffic concentration capabilities of the BSC.

The main functions of the BSC are:

– Radio resource management: The BSC manages the radio resources, including allocation of channels to particular mobile stations (MSs), control of the broadcast power of the radio channels, etc., and it manages the handover requirements within the cells it serves. The BSC also controls the radio characteristics of the MS using signalling which is transparent to the BTS. This signalling instructs the MS on which channel and time-slot to tune to, what transmit power to use, etc.
– Operations & Maintenance Management: The BSC provides O&M management control over the radio sites in its coverage area. This includes configuration and status management, storage of software loads for the BTS equipment, collection of statistical data from the BTSs, and it acts as a sub-network O&M entry point to the greater network management.

– Remote transcoder management: The BSC controls the remote transcoders, which are usually located at the switching site. The remote transcoders enable the multiplexing of 4 traffic channels (13 kbit/s) on to the same PCM 30 slot (64 kbit/s) which leads to transmission cost reductions.

– Traffic grooming: The grooming of traffic is realized through a modular, non-blocking 64 kbit/s switching matrix. A secondary matrix, capable of switching at 16 kbit/s and 8 kbit/s, also non-blocking, is associated with the main matrix. The second matrix allows implementation of the intra-BSC handover function by permitting sub-slot traffic switching. Use of the 16 kbit/s channels is optimized by multiplexing to 64 kbit/s, thereby reducing the required number of PCM links and remote transcoders.

Base transceiver station (BTS)

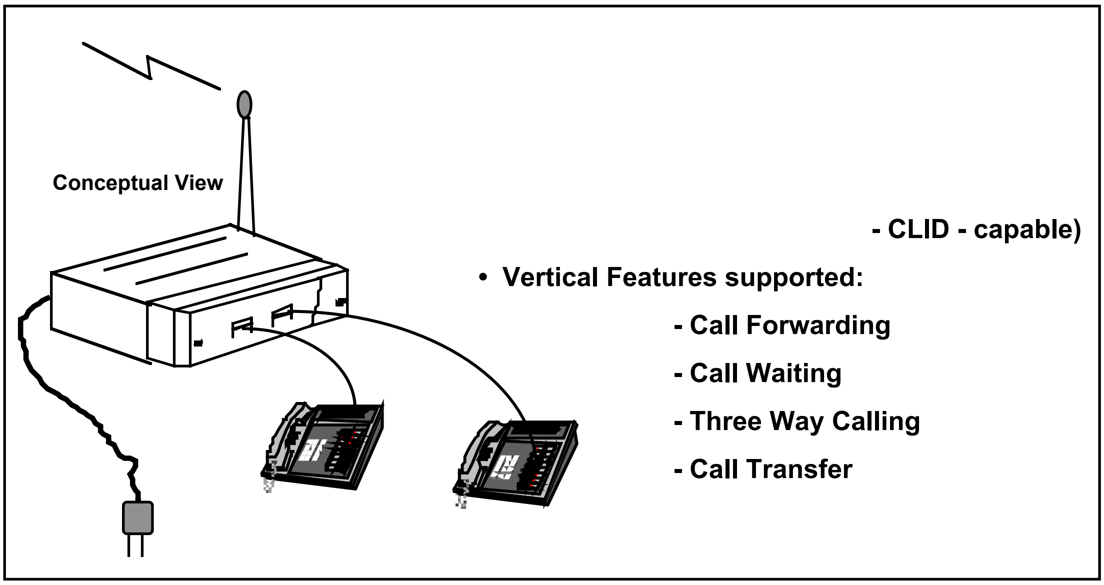
The BTS is the link between the subscriber units and the BSC. Located at the BTS are the antennas, transmitter, receivers, power amplifiers, and interface hardware to support the link to the controller. The BTS comprises two main elements: common site equipment handling multiple cells/sectors, labelled the base common function (BCF); and the radio equipment related to each cell (TRX equipment).

Subscriber equipment

Several options are possible for subscriber equipment. The most user-friendly option is a conversion terminal with a standard interface for conventional telephones (Figure 40). When the subscriber plugs it into a standard AC outlet, this unit provides the conversion link between the subscriber's standard telephone set and the wireless access system. Such conversion terminals offer multiple telephone connections per terminal, battery back-up, and will be available from several vendors.

FIGURE 40

Terminals - Key features



3.3 Summary of capabilities

In summary, the GSM-based wireless access systems have the following key attributes:

Features/Highlights

– Supports ETSI GSM standard for digital cellular.
– European and worldwide deployment.
– Leverage existing GSM infrastructure.
– Innovative RF engineering (i.e.: frequency hopping).

Prime advantages

– Economical alternative to traditional copper based land line systems.
– Flexibility in network planning due to reduced lead times for installation and service activation.
– Savings in operations costs due to reduced maintenance and trouble reports.
– Significant savings in up-front capital expenditures over traditional copper based systems.
– Speedy deployment.
– Provides a wide range of services such as standard telephone service, pay phones, data and fax on a common hardware platform.

Applications

– Medium to high densities.
– Large networks from 25 000 subscribers.
– Multiple terminal and base station suppliers.

Service provisioning

– Existing or new GSM cellular providers.
– Established or new PCS operators.
– Established DCS service providers.
– New entrants in de-regulating but developed markets.

4 PHS-FWA (Fixed Wireless Access) system

4.1 General

PHS-FWA is designed for PSTN/ISDN(BRI)/Leased line which utilizes PHS basic technologies described in Recommendation ITU-R M.1033. PHS-FWA uses most of the existing network facilities. Since PHS uses a TDMA scheme capable of 32 kbit/s user bit rate, PHS-FWA is capable of supporting high-speed data. PHS-FWA is suitable for high traffic areas such as urban and suburban areas as well as rural areas with the adoption of micro-cell structure. Therefore, PHS-FWA provides a way to construct telecommunication infrastructure at low cost and in a short time for developed as well as developing countries.

Since this PHS-FWA retains the mobility function, which is not necessary for fixed telephone access, PHS-FWA allows telephone terminals to move in a limited area, so it is also referred to as a limited mobile telephone system.

4.2 Technology, architecture and configurations

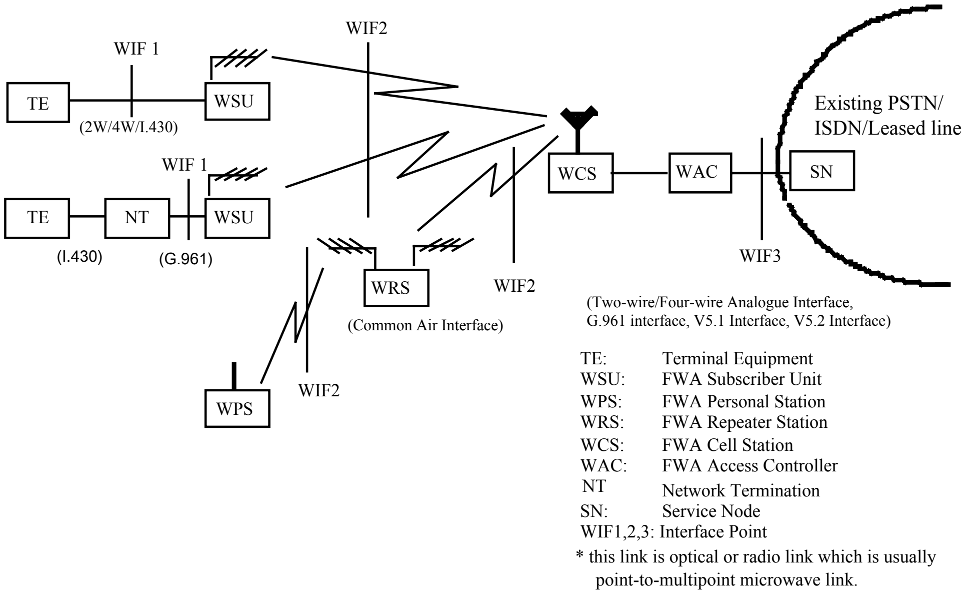
4.2.1 Radio interface characteristics

Class of emission:	
– traffic channels	288KG7WDT
– control channels	288KG7DDT
Access method	TDMA/TDD
Transmit frequency bands (MHz):	
– base stations	1893.5-1919.6
– mobile stations	1893.5-1919.6
Duplex separation (MHz)	Not applicable
RF carrier spacing (kHz)	300
Total number of RF channels	87
Modulation	π/4 shift QPSK
Transmission rate (kbit/s)	384

4.2.2 Network configuration

FIGURE 41

PHS-FWA architecture



The service node (SN) which corresponds to the local exchange accommodates subscribers and processes originating/terminating calls (Fig. 41). PHS-FWA model consists of the following components: FWA access controller (WAC), FWA cell station (WCS), FWA personal station (WPS) and FWA subscriber unit (WSU). WAC is located between the SN and the WCS, and its functions are to implement line concentration, authentication, etc. The air interface between WCS and WSU is standardized as the PHS air interface in RCR STD-28, which is described in

Recommendation ITU-R M.1033. WCS is usually installed outdoors in locations such as at the pole tops. By using a high-power WCS with more than 100 mW (average) output power and an external antenna equipped with the WSU, it is capable of supporting subscribers 1 000 to 5 000 m away from the WCS. The indoor type WSU is installed in the customer's premises and is connected to the telephone terminals. The antennas are mounted on the roof or wall. The outdoor type WSU is installed on the pole near the house and is connected to the module in the house. WRS can be placed in regions whose geographies make reception difficult. The WPS is a PHS terminal which is equivalent to a telephone terminal with WSU functions.

The definition of the interfaces follows:

1) WIF1 is a two-wire/four-wire analogue interface, ITU-T Recommendation G.961 or I.430/Q.921/Q.931 interfaces, between TE (Terminal Equipment) and WSU (FWA Subscriber Unit), or NT and WSU as recommended in the C-IF1.00 series of PHS Memorandum of Understanding (MoU) documents.

2) WIF2 is a radio interface between WSU or WPS and WCS and so on is recommended in C-IF2.00 series of PHS MoU documents (Common Air Interface Based on ARIB standard RCR STD-28).

3) WIF3 is a two-wire/four-wire analogue interface, ITU-T Recommendation G.961/ Q.921/Q.931 interfaces, ITU-T Recommendation G.964:V5.1 interface, ITU-T Recommendation G.965:V5.2 interface, or Bellcore GR-303 between WAC and SN as recommended in C-IF3.00 series of PHS MoU documents.

The functions of the components shown in the system architecture are as follows:

TE : terminal equipment

TE, which is the same as customer premises equipment, is a user terminal such as a telephone terminal.

WPS : FWA personal station

WPS, which is a mobile subscriber communication terminal, communicates with WCS using PHS based air interface (RCR STD-28).

WCS : FWA cell station

WCS, which is a radio communication equipment, communicates with WPS or WSU using PHS based air interface (RCR STD-28).

WAC : FWA access controller

The WAC controls call connection and performs authentication.

SN : service node

SN which is same as local exchange, or telephone network, terminates the subscriber line signal and network signal.

WSU : FWA subscriber unit

WSU, which has a two wire analogue interface for TE, converts signals between TE and WCS.

NT: network termination

NT, which terminate network and connect to terminal equipment (TE).

Typical configuration

There are two types of network topology. One is all wireless system. The other is the combination of optical and wireless.

1) All wireless

One possible application of PHS is as a complement to a backhaul/distribution point-to-multipoint TDMA system. The point-to-multipoint TDMA system is used for the connection between WCS and WAC to realize a complete fixed wireless access from switch to subscribers. An example of a radio frequency band for the TDMA radio system is 1.5 GHz or 2.4 GHz. A distance of 1 000 to 3 000 m between WSU and WCS is supported with the PHS air interface.2) Optical and wireless

2) Optical and wireless

Optical and wireless configuration is the combination of optical entrance link and wireless approach link using PHS radio interface. Optical link, which is matured technology, is used for the connection between WCS and WAC to realize a high reliability and high traffic access from switch to WCS. Network topology is Single-Star (point-to-point) configuration. The length of optical link using 1.3µm single mode optical fibre is up to 20 km from WAC to WCS.

4.3 Summary of capabilities

In summary, PHS-FWA offers the following key attributes:

Features/Highlights

– PSTN, ISDN(BRI), Leased line.
– High voice quality.
– Multi-frequency (MF) tone sending for accessing various services.
– Flash signal sending.
– Authentication.
– Encryption.

Prime advantages

– Telecommunications facilities can be constructed in a short time.
– Initial investment for facility installation is relatively small.
– Adequate traffic handling capacity.
– Use most of the existing network facilities.

Applications

– Urban and suburban area.
– High traffic rate.

Service provisioning

– New operator is able to deploy quick and economic telephone service without constructing a local cable network.
– Economical voice and data service to the high density and/or business area.
– Temporary telephone service such as restoration of failed wired network and urgent establishment of temporary circuits at disaster area or at exhibition/event sites.
– Limited mobility with WPS.

5 NMT-based wireless access systems

5.1 General

The Nordic Mobile Telephone (NMT) standard is an analogue cellular network which originated in the Nordic countries (Denmark, Finland, Norway and Sweden). The NMT 450 system permits, because of the good propagation characteristics in the 450 MHz frequency band, coverage of wide areas with relatively large radio cells, when the subscriber terminals have high power transmission capabilities, due to transmission over long distances. With the advent of NMT 900, an additional 1 000 radio channels were made available which effectively increased the system capacity by decreasing the cell size. The propagation characteristics at 900 MHz are not as good as in the 450 MHz band, and the increase in the number of voice channels by "interleaving" which can add as many as 1 999 available voice channels. The architecture of NMT 450 and NMT 900 cellular systems is simple with just two components (apart from the mobile phones themselves): A mobile telephone exchange (MTX) and base stations (BS) along with some interconnect hardware to the PSTN. Both wireless access systems are supported by modularly designed, digital switching centres which can be supported by a mobile operation support system (OSS) network management and a home location register (HLR) to meet market requirements for advanced services. These services, such as intelligent network (IN), number translations services (universal access numbers), time-dependent call-forwarding and closed user groups (which allows mobile telephones to be included within a company's internal numbering plan), are currently available.

There are two basic concepts for the radio-based access. One is a true "copper replacer" for the access network, connecting the MTX to the PSTN and the other is a "mixed" cellular solution, which provides a complete cellular network, including switches, IN nodes, base stations, but is designed to serve either fixed cellular subscribers only (fixed cellular) or a mixture of normal cellular mobile and fixed cellular (mixed cellular). Currently, there are advanced radio access systems based on analogue NMT base stations, which enables operators to boost the capacity and coverage capability without the need for physical wires between the local exchange and the subscriber.

NMT-based wireless access systems serve as an alternative or a complement to copper wire and offers service equivalence with respect to numbering, charging, etc., all with considerable savings in cost and time to the service operator. New subscribers can be added quickly, installation costs are low, and the benefit to the operator is that they can provide coverage to wide areas using this radio technology.

5.2 Technology, architecture and configurations

The NMT-based wireless access systems have four basic components: the switch interface module (SIM), the translator interface module (TIM), the BS and the subscriber radio terminal (SRT).

The SIM provides the interface between the wireless access system and the local exchange, using 2 Mbit/s PCM links conforming to ITU-T Recommendations G.703 and G.704. Each 2 Mbit/s link serves 30 subscribers; and analogue line interfaces are available. With minor modifications, the SIM can be connected to virtually any type of local exchange. The SIM acts as a traffic concentrator towards the radio parts of the system, which are controlled by the TIM. The TIM allocates radio channels for calls, and also encrypts the radio signals to prevent eavesdropping. Each TIM can support up to 90 radio channels. With normal residential and small business traffic loading, a single radio channel can support up to 10 subscribers with an acceptable grade of service; this means that the TIM has an effective capacity of around 900 subscribers. A single SIM can control multiple TIMs, and the TIMs can be located remotely form the SIMs (usually, they are co-located with the BSs).

BS are available in a variety of sizes, serving from 8 to 32 radio channels. These are exactly the same as used in conventional cellular networks. The BSs use either 2 x 5 MHz in the range 380-500 MHz, or up to 2 x 25 MHz in the range of 800-1 000 MHz, depending on the local availability of radio frequencies. Generally speaking, the lower frequency band provides longer-range transmission and the higher frequency bands are better suited for areas of high subscriber density.

The final component is the SRT. An indoor antenna connects directly to the SRT; alternatively, an outdoor, directional antenna can be used to improve reception in marginal areas. Telephones, fax machines and/or modems can be plugged into the SRT exactly as into a normal phone socket, and subscribers can make and receive calls in the usual way using pulse or DTMF dialling. Meter pulses can be carried by the system, allowing coin-box telephones and private meters to be used as well. Multi-line SRTs, for apartment buildings or office blocks, are also available.

5.3 Summary of capabilities

In summary, the NMT-based wireless access system offers the following key attributes:

Features/Highlights

– Transparent to POTS, Fax group III, Voice band data (ITU-T Recommendations V.21, V.22, V.22bis, and V.32), DTMF (ITU-T Recommendation Q.23).
– Metering capability (12/16 kHz pulses and/or polarity reversals are supported).
– Voice privacy for voice, data, fax and DTMF.
– Remote operation and maintenance function with alarms presented for SIM/TIM/RBS.
– Digital interface V5.1 (ITU-T Recommendation G.964) to any local exchange.
– Analogue 2-wire connection to any local exchange.
– Traffic statistics available.
– PSTN numbering plan not affected.

Prime advantages

– Quick and cost effective.
– High quality voice.
– Large range of system configurations.

Applications

– Both low to medium density and high density systems.
– Rural, suburban and urban.

6 DECT-based wireless access systems

6.1 General

Digital Enhanced Cordless Telecommunications (DECT)-based systems use a combination of time division multiple access (TDMA) and time division duplex (TDD). This obviates the need for expensive RF filtering, enabling compact, lightweight and low-cost handsets to be developed. DECT operates in 20 MHz of spectrum, which is designated throughout Europe, namely 1 880-1 900 MHz. The spectrum is divided into 10 carriers, each with 12 TDMA time slots, providing a total of 120 voice channels. Speech is coded at 32 kbit/s, twice the rate used for GSM and providing effective toll quality. Maximum peak power for both base stations and handsets is 250 mW. However, because this is peak power (i.e., only present for the duration of the transmitted time slot), average transmitted power is 10 mW or less resulting in a significantly extended battery life compared to cellular handsets or conventional analogue cordless telephones.

DECT provides voice and data ISDN compatibility, full encryption and seamless handover. Time slots can be combined to provide high capacity data transmission (up to 552 kbit/s). Dynamic channel allocation removes the need for any radio planning of the network and there are no dedicated control panels. In operation the system continually scans and selects the best available RF channel.

DECT has defined an enhanced modulation scheme which enables net data rates of 2 Mbit/s. DECT has a capacity of around 10 000 Erlangs/km^2, or around 100 times that of the current cellular networks.

6.2 Technology, architecture and configurations

A full set of ETSI Standards define the characteristics of the system. They can be divided into sets of:

- basic standards;
- Public (radio local loop access profile: RAP) and generic access profiles (GAP);
- DECT authentication module;
- DECT profiles;
- Test specifications and;
- Regulatory documents.

These standards are accepted in an increasing number of countries. To facilitate the introduction of DECT in non-European countries where the basic DECT frequencies 1 880-1 900 MHz are not available, the radio parameters have been defined for the frequency range 1 880-1 937 MHz.

6.2.1 Radio interface characteristics (1 880-1 900 MHz)

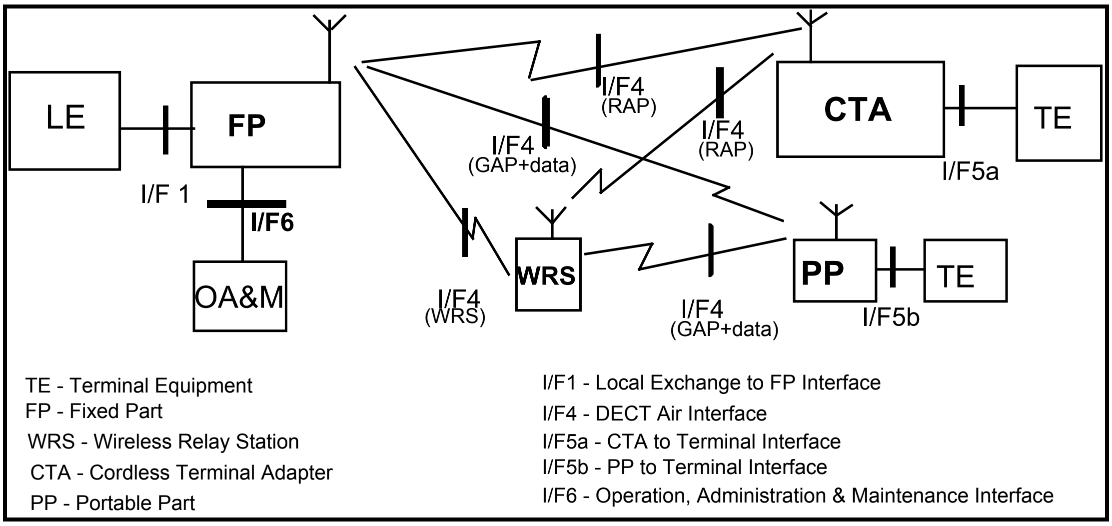
Class of emission	1M73F7W
Access method	TDMA
TDD transmit/receive frequency band (MHz)	1 880-1 900 MHz
Duplex separation	not applicable (TDD)
RF carrier spacing (MHz)	1 728
Total number of RF TDD channels	120
Modulation	GMSK
Transmission rate (kbit/s)	1 152

6.2.2 Network configuration

The reference model for DECT wireless access local loop systems is presented in Fig. 42. This reference model is provided for the purpose of demonstrating the DECT wireless access local loop services, facilities and configurations.

FIGURE 42

DECT RLL reference model



6.2.3 The DECT interoperability air interface approach

Being derived from a mobile technology, DECT wireless access local loop employs an interoperability profile standard – which in principle means that the fixed part (base station) may be manufactured by one manufacturer, the equipment at the subscribers' premises by another, and perhaps wireless relay stations by another whilst still being able to offer a useful level of service to the user. The advantage of multi-vendor sourcing for the operator is apparent and allows the manufacturers to choose to specialize in one segment of the network.

6.2.4 Range, traffic capacity and efficiency issues

With the DECT technology, in line-of-sight propagation conditions, ranges of up to 5 km are shown to be feasible using 12 dBi antennas at both ends of the link and with reasonable antenna heights. A single hop Wireless Relay Station (WRS) could extend this range by a further 5 km in a particular direction. By special antenna arrangements and the advance timing Cordless Terminal Adapter (CTA) option, the range may be increased beyond 5 km.

Support of 40-60 E (equivalent speech duplex bearers) average traffic at 1% grade of service is realistic for a DECT wireless access local loop site with sectorized gain antennas. Such a site will be equipped with about 6-12 DECT radios and can support 400-600 POTS or ISDN subscribers with 100 mE average traffic each.

A single radio CTA can provide 1 to 12 lines (trunks) at the interface. It should be noted that even if 12 lines are provided, the corresponding bearers on the air interface are only set up if there is a call on the line. These lines (trunks) can have an analogue 2-wire IF/5a interface, or the D/A conversion in the CTA is deleted, whereby 4-wire digital 64 kbit/s PCM lines (I/F5a) are provided. This is suitable when interfacing to digital PABXs and for CENTREX services. By using narrow angle sectorised antennas, especially in line-of-sight conditions, a large number of such trunks can be effectively provided for an office.

The DECT ISDN service monitors the ISDN layer 3 information, and allocates DECT bearers resources only when and as required by the specific instant ISDN services. For packet data, transmission over the D channel is much more spectrum efficient and, on average, loads the radio devices much less than any modem service or ISDN service.

6.3 Summary of capabilities

In summary, the DECT-based wireless access systems have the following key attributes:

Features/Highlights

– Using the dynamic channel allocation (DCA) in the whole 20 MHz band there is no need for frequency planning.
– The DCA selects the best radio channel, during the call, according to the signal quality.
– The 32 kbit/s ADPCM coding according to ITU-T Recommendation G.721 provides a grade of service equivalent to that of the public network.
– Pulse dialling and DTMF signalling protocols are supported.
– ISDN subscriber interface available.
– Location registration of the subscriber, ciphering and authentication are provided.
– Use of any type of telephone set, including DECT mobile handsets.

Prime advantages

– Widely accepted standard in a multivendor environment.
– High traffic loading capability.
– Connection to PSTN and ISDN.

Applications

– High, medium and low density systems.
– Urban, suburban and rural.

7 AMPS-based wireless access systems

7.1 General

AMPS-based wireless access systems are analogue systems based upon FDMA technology and are compliant with EIA/TIA 553 standard. AMPS systems were among the first cellular systems deployed in the world, offering high quality voice and are available in 400 and 800 MHz frequency bands. In addition to voice, these systems support inband fax and data services

7.2 Technology, architecture and configurations

AMPS wireless systems utilize FDMA technology in line with EIA/TIA 553 standards. Since these systems are based upon non-proprietary technology, and were among the first cellular systems in North America (and the world), there is an abundant supply of low-cost subscriber units available from many sources. Furthermore, the development of IS-54 and IS-136 digital standards allow for a graceful evolution of the analogue system to digital without impacting the existing subscriber base.

7.2.1 Radio interface characteristics

Class of emission:	
– voice channel	30KOF3E
– control channel	26KOF1D
Access method	FDMA
Transmit frequency (MHz):	
– base	869-894
– mobiles	824-849

Duplex separation (MHz)	45
RF carrier spacing (kHz)	30
Total number of RF duplex channels	832
Modulation:	
– voice	FM ± 12 kHz deviation
– signalling	Binary FSK ± 8 kHz deviation

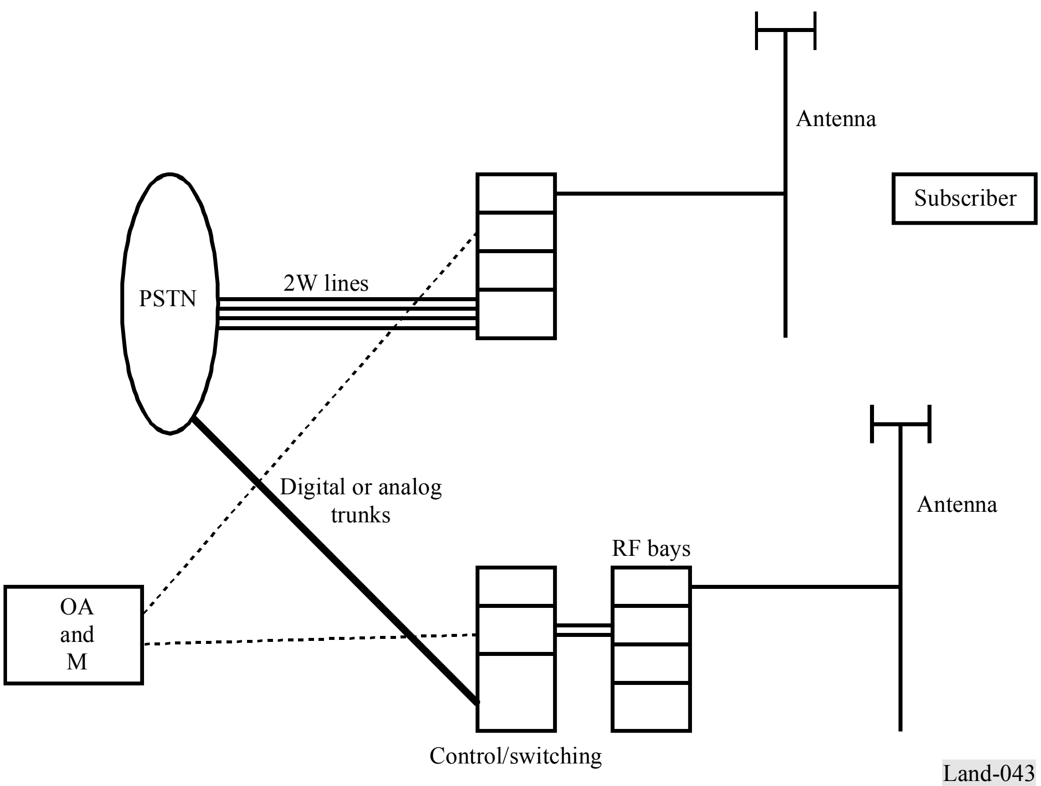
7.2.2 Network configuration

In their simplest configurations, AMPS systems can consist of a few voice channels and some interface hardware connected directly to the local PSTN via two wire subscriber lines. In larger configurations, these systems can support sites in excess of 50 RF channels connected to the PSTN via analogue or digital trunks. Normal configurations consist of macro-cells although micro-cells can be supported. These systems are generally designed to support low to medium density applications. Due to the maturity of the hardware, these systems can be a low-cost solution in many cases.

The basic architecture is shown in Fig. 43. The wireless access system comprises switching and radio site equipment. A small system would consist of a half-height cabinet that contains radio, control and switching equipment. The only outside connections required are power, antenna and two wire lines. Larger systems consist of separate bays of radio equipment, control and switching equipment.

FIGURE 43

AMPS-based system architecture



Controller

In general, the controller is responsible for management of radio resources and for providing the appropriate interfaces to the PSTN. In simple configurations this function connects a two wire telephone connection to a wireless subscriber using an available radio channel. In more complex configurations, the controller provides advanced network management, mobility management, billing and subscriber management capabilities. Available in differing sizes/configurations depending on overall capacity and features of system.

Peripherals

Apart from PSTN connection options (lines, trunks, analogue, digital, etc.), the only significant peripheral is the OA&M subsystem. This system is optional depending on the size and capacity of the installed equipment. It can be connected via dedicated or dial-up means. On small networks, this subsystem could consist of a portable computer that is used only in serious fault or major reconfiguration circumstances.

Radio site equipment

The radio cell site equipment converts analogue voice to frequency modulated 400 MHz or 800 MHz signals. It is the intelligent interface between the controller and the subscribers served by the system. Typically it is modular and easy to install and maintain.

Subscriber equipment

Several options are available for the subscriber equipment. The most common is a mobile unit converted to a fixed station through the addition of power sources, packaging and RJ-11 telephone interfaces. A number of suppliers provide this type of unit. These fixed stations are also available without the RJ-11 interface and can be used directly with their own handsets.

7.3 Summary of capabilities

In summary, the AMPS-based wireless access systems offer the following key attributes.

Features/Highlights

– Support basic subscriber phone service.
– High quality voice.
– Provide feature transparency for basic fax and data services (in-band).
– Large range of OA&M capability.
– Provide a platform for evolution to CDPD.
– Full EIA/TIA 553 compliant.
– Many sources of inexpensive subscriber terminal equipment.
– Evolution path to IS-54/IS-136 digital systems.

Prime advantages

– Quick and cost-effective.
– Multiple switch platforms.
– Large range of system configurations (3 channel sites to 60 + channel sites).
– High quality voice.
– Supports in-band fax and data services.

Applications

– Low to medium density systems.
– Rural, suburban, urban.

8 TACS-based wireless access systems

8.1 General

TACS-based wireless access systems are analogue systems are analogue systems based upon FDMA technology and are compliant with United Kingdom Total Access Communications System Compatibility Specification, Issue 4. These systems offer high quality voice and are available in the 400 and 800 MHz frequency bands. In addition to voice, these systems support in-band fax and data services.

8.2 Technology, architecture and configurations

These wireless systems utilize FDMA technology in line with United Kingdom Total Access Communications System Compatibility Specification, Issue 4. Because these systems are based upon non-proprietary technology, there is an abundant supply of low-cost subscriber units available from many sources.

8.2.1 Radio interface characteristics

Class of emission:	
– voice channel	25KOF3E
– data channel	23KOF1D
Access method	FDMA
Transmit frequency (MHz)	
– base	917-950
– mobiles	872-905
Duplex separation (MHz)	45
RF carrier spacing (kHz)	25
Total number of RF duplex channels	1 320
Modulation:	
– voice	FM ± 9.5 kHz deviation
– signalling	Binary FSK ± 6.4 kHz deviation

8.2.2 Network configuration

System configurations are identical to the AMPS systems described in the previous section.

8.3 Summary of capabilities

Capabilities, advantages and applications are for the most part identical to the previously described AMPS systems with the exception of two key items, one being positive and one being negative.

On the positive side, the 25 kHz channel spacing provides more system capacity in the same bandwidth. On the negative side, there is no simple, economic upgrade path to digital technologies (no equivalent IS-54 or IS-136).

ANNEX 5

Detailed descriptions: systems based on proprietary radio interface technologies

1 Nortel Networks Internet Fixed Wireless Access System

1.1 General

The Nortel Networks Internet Fixed Wireless Access System is a fully digital fixed wireless access system designed as an alternative to the long term deployment of traditional copper line access. Nortel Networks Internet FWA System is a new brand-name, announced in April 2000, for what was previously known as the Nortel Networks Proximity II FWA System. The system has been designed to offer the same quality and service transparency as wireline access with the additional benefit of "always on" faster-than-modem Internet access data rates becoming available as an important upgrade in 2001.

The system easily integrates in networks of mixed access technologies with little impact on the network infrastructure. The product has many advantages over other access methods. Compared to copper it offers the same service transparency and quality but is much faster to deploy. Compared to other radio access systems it is easier to integrate into existing access infrastructure needing only a handful of digital links into the local switch that provides dial tone, billing and other services offered by the service provider. Finally, the product will provide high quality "always on" Internet access at air interface rates of up to 96 kbit/s (uncompressed) using packet data transmission, beginning in 2001.

The Nortel Networks Internet FWA System operates using a 3 500 MHz radio link between base station and customer premises equipment. The spectrum is available in most parts of the world and being unsuitable for mobile use, has proven ideal for fixed applications. Use of this frequency band requires near line-of-sight operation between the remote antenna at the user's premises and the base station, using spatial diversity to minimize the effects of multi path and fading.

The signalling protocol used between the base station and user equipment has been derived from existing mobile standards but has been optimized for this fixed application removing signalling overheads and quality limitations of mobile systems. The system uses FDD and TDMA techniques to maximize spectral efficiency.

In traditional wireline networks a local exchange or remote line concentrator would be deployed in an area and wired to street cabinets ready to provide connection to users. With the Nortel Networks Internet FWA System the base station replaces the remote and radiates radio signals over the area of a cell that would be designed to cover the user community. A contiguous cell structure can be designed to cover complete communities.

The base station is directly connected to a switch via a number of 2 Mbit/s links, compliant with ITU-T Recommendation G.703 (E1 links), which may be delivered over the appropriate transmission medium such as fibre or line-of-sight radio. The Nortel Networks Internet FWA System provides telecommunications service from any host network switch, providing toll quality voice, data, and fax services over these links and also uses the ETSI open signalling standard V5.2 to minimize the number of links required. Packet data networking features interface using Internet Engineering Task Force (IETF) protocol standards through the base station E1 links.

The Nortel Networks Internet FWA System base stations operate over a cell radius from 200 m to 40 km. They are scaleable from 30 simultaneous calls to 180 simply by adding radio carriers in-groups of 3 and can be dimensioned for rural, suburban and urban applications. Approximately three quarters of the cost resides in the user premise equipment. Consequently the operator only makes the majority of the network capital investment when a new customer is recruited.

The user premises radio terminal has 2 PSTN line interfaces for 2 independent connections. Internet access via packet data will be provided via USB or RS-232 data ports on the terminal. The PSTN lines may be assigned to one user or split between two users, each provided with their own power unit.

1.2 Technology, architecture and configurations

NOTE – The following section describes the Voice-Band Service specifications of the Nortel Networks Internet Fixed Wireless Access System which are currently available. Additional enhanced Internet access packet data capability specifications are under development and will be available in 2001.

1.2.1 Radio interface characteristics

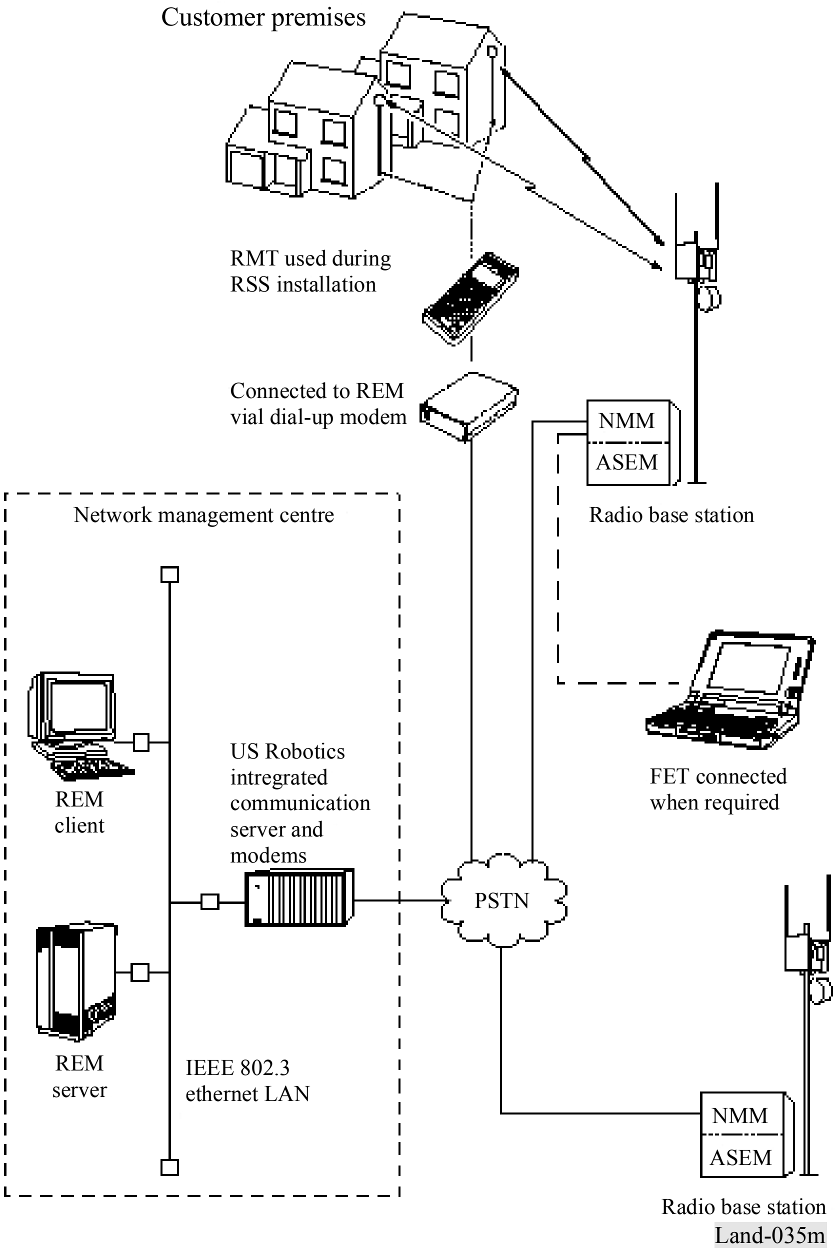
Class of emission:	
– traffic channels per bearer	10
– traffic channel bandwidth	32 kbit/s
– voice coding	32 kbit/s ADPCM
– voice band data	64 kbit/s PCM
Access method	TDMA
Duplex	FDD+TDD
Transmit frequency bands (Hz): 50 000 000 duplex	
– downlink	3 475 968 000 + (n x 307 200)
– uplink	3 425 280 000 + (n x 307 200)
Transmit frequency bands: 100 MHz duplex	
Uplink to base station	
Band A	3402.8544 + (n x 0.3072) MHz
Band B	3428.8944 + (n x 0.3072) MHz
Band C	3450.7776 + (n x 0.3072) MHz
Band D	3475.6608 + (n x 0.3072) MHz
Downlink from base station	
Band E	3502.6944 + (n x 0.3072) MHz
Band F	3525.7344 + (n x 0.3072) MHz
Band G	3550.6176 + (n x 0.3072) MHz
Band H	3575.5008 + (n x 0.3072) MHz
Duplex separation (Hz)	50 668 000
RF channel spacing (Hz)	307 200
Total number of RF duplex channels	54
Modulation	π/4-DQPSK
Gross bit rate (kbit/s)	512
Net bit rate per traffic slot (kbit/s)	32

1.2.2 Network configuration

The basic architecture is shown in Fig. 45. The Nortel Networks Internet FWA System is comprised of switching and radio site equipment. A basic system would include a central office switch, a network of base stations, residential user equipment which is installed at the customers' premises providing the radio connection to the base station and the Nortel Networks Internet FWA System is comprised of operation and maintenance equipment.

FIGURE 45

Nortel Networks Internet FWA System Configuration
(Voice-Band service)



The functions of system components are as follows:

The central office switch

The local exchange/central office switch is a standard Class 5 switch as would commonly be deployed in switching networks. It interconnects with one or more of the public networks other central switching offices and also with each of the radio sites. There is no specific equipment required in the network between the base station and central office switch.

The base station equipment emulates the operation of a normal wireline remote connected to the central office switch. Users are provisioned and billed from the switch in the same way as for wireline connections.

The base station implements the following signalling systems for connection to the switch:

– **2 Wire**. The base station backhauls using unconcentrated 2 Mbit/s channel associated signalling and would require a central office terminal (comprising a modified street mux) located at the central office to convert to 2 wire line interfaces for connection into normal subscriber line interfaces in the switch.
– **CAS**. Unconcentrated 2 Mbit/s signalling can be provided utilising either Nortel Network's open signalling specification or custom signalling to suit a specific switch implementation.
– **DMSX**. Nortel Networks's proprietary concentrating interface signalling for connection to any of Nortel's family of DMS switches. Alternatively inexpensive base station controller equipment can be provided by Nortel Networks to allow conversion of this signalling to national trunk side signalling and connection to existing switches over the PSTN trunk.
– **V5.2**. Nortel Networks has implemented the ETSI open access signalling standard V5.2. A signalling specification is available that allows connection to any class 5 switch that can implement V5.2.

Remote service system

The remote service system (RSS) is the equipment located at the users's premises and provides up to two independent telephone lines per antenna. The RSS has an indoor unit for power and line termination and an outdoor unit that contains an integral antenna (Fig. 46):

– Remote transceiver unit (RTU). This unit contains all active electronics except for the power source. The electronics, comprising radio transceiver, processor and 2 line interfaces are mounted behind an octagonal directional antenna, measuring 30 cm across the flats. This unit would be mounted outdoors on the upper part of the user's premises with close to line-of-sight visibility of the base station.
– Remote power and connection unit (RPCU). This unit provides 48 V DC power from the mains supply to the premises. 220 V and 110 V units are available together with options for solar power. The unit also houses a battery to provide service during power outages and two RJ11 sockets.

The standard RSS provides access to up to 3 of the 32 kbit/s traffic carrying slots. In the case of a single voice call one slot is used and voice is encoded using 32 kbit/s ADPCM. For 2 simultaneous voice calls 2 slots are used. If one of the calls is being used to transmit voice-band data then 3 slots are used and the data is encoded using 64 kbit/s.

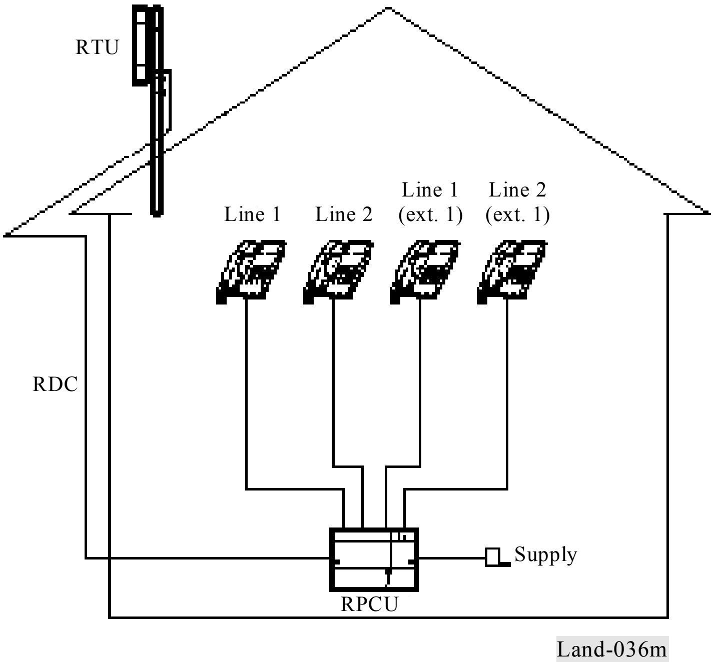
The ISDN unit allocates two slots for each B channel in use. Two RTUs are required for a full 2B+D service.

User terminals

The RSS provides connection for two standard telephones and data/fax equipment. This is an important feature of the product, allowing the use of existing equipment without modification.

FIGURE 46

Nortel networks internet FWA system user equipment (voice-band-service)



Base station

A variety of base station can be engineered to fulfil a wide range of all deployment situations, from sparsely populated rural to urban.

Have extended range to 40 km.The base station has a modular design allowing a low traffic handling system to be installed and subsequently expanded for greater capacity as demand grows. Base stations can be provided with either omnidirectional or sectored antennas. The standard building block for a base station is 3 bearers providing 3 independent frequency channels and 30 traffic channels. A 3 bearer base station can provide service to approximately 320 lines. The base station capacity is 27 bearers, which can provide service to over 2 000 lines.

The base station equipment consists of radio transceivers, control electronics, power supplies, interface to the central office switch and the antenna. The power system would normally include battery back up to provide service in case of power loss. The backhaul to the central office uses standard G.703/G.704 connection using either fibre, twisted pair copper wires or microwave links.

The signalling link interface can be 2 wire, CAS, DMSX or V5.2.

OAM&P

Operation, administration, maintenance and provisioning (OAM&P) of the I-Series product has been designed to be easily integrated with existing access networks. Standard billing and subscriber management facilities are largely unaffected by adding Nortel Networks Internet FWA System access networks.

The following equipment is provided:

– Radio element manager (REM). This is software residing on a UNIX workstation that provides management of the Nortel Networks Internet FWA System access network. It also enables software downloads and control of base station configurations. The system communicates with base stations over a communications channel and is suitable for interfacing with umbrella network management systems. The REM would normally be situated in the network management centre.
– Remote installation system (RIS). This is a handheld computer used by the service technician during installation of RSS equipment at user's premises.
– Field engineering terminal (FET). The FET is a laptop computer that connects to a base station and allows a service technician to commission a base station.

In addition, Nortel Networks provides support for network and cell planning with a variety of manuals and planning tools.

1.3 Summary of capabilities

In summary, the Nortel Networks Internet FWA System has the following key attributes:

Features/Highlights

– Provides service transparency to value added switch features for users in residential and small business market segments.
– Users can connect existing standard telephone sets and modem equipment.
– Provides a 64 kbit/s PCM connection to support full rate voice-band data automatically.
– High quality speech and service transparency provides long term alternative to wire.
– 200 m to 40 km range from base station.
– RPCU power unit uses mains current and optional battery back-up to provide 12 h standby and 30 min of talk time.
– Designed to be integrated into existing networks with other access systems.
– Can interwork with existing support systems.

Prime advantages

– Economical alternative to copper based local access systems.
– Simplifies network planning by reducing lead times for installation and service activation.
– Low "Cost Per Premise Passed" very much less than other access methods.
– Low infrastructure costs provide high cash efficiency, investment is not made until subscriber is connected and revenue can be generated.
– Modular growth provides low start-up costs and investment tailored to subscriber growth.
– Rapid deployment.
– Provides a wide range of services such as standard telephone service, pay phones, data and fax on a common hardware platform.

Applications

– Alternative operators, providing cost-efficient alternative to existing wireline operators.
– Network expansion, providing cost-effective and scaleable access suitable for business subscribers.

– Voice, data and fax services.

– All subscriber densities.

– Switch independent, supports all host network switch subscriber features.

Service provisioning

– New entrants in de-regulating but developed markets.

– Operators and prospective operators in developing/modernizing markets.

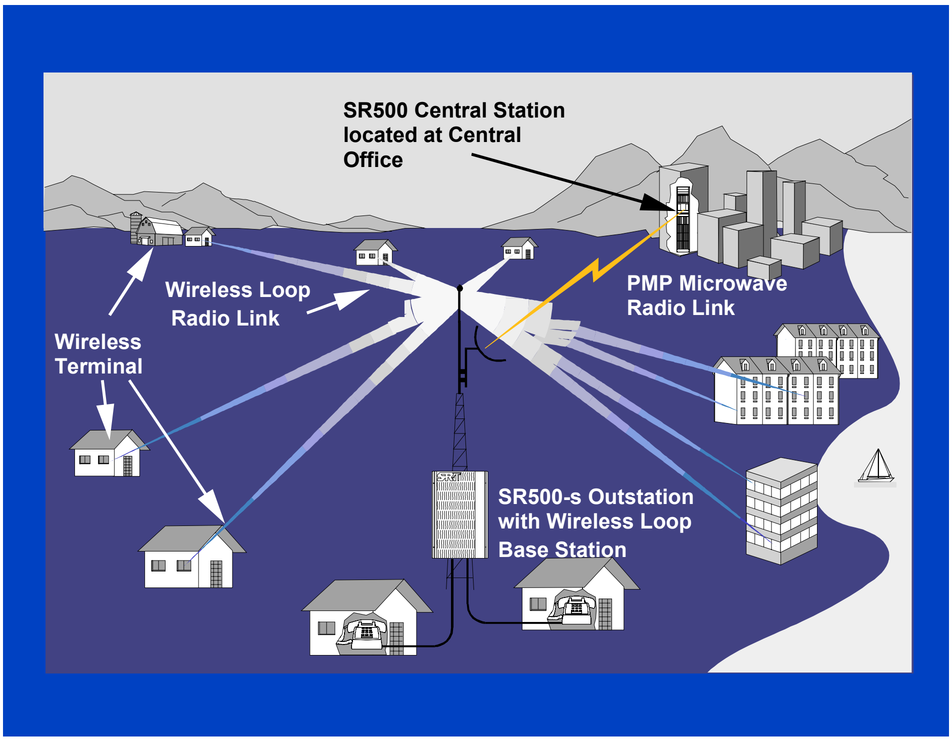
2 SR Telecom SR500-s wireless access subsystem

2.1 General

The wireless access subsystem of SR Telecom point-to-multipoint SR500-s closes the gap between the central office and the subscriber premises by completing the concept of radio to the home (RTTH). The wireless access replaces the last leg of the access – i.e., the drop wire to the home, with a radio link. In either rural, suburban or urban regions this alternative to cable provides the telephone operating company with the option to rely entirely on wireless links for the access or use wireless in the portions of the network where it is preferred over a cabled solution. Figure 47 illustrates a wireless access subsystem in a point-to-multipoint (PMP) microwave radio application.

FIGURE 47

A fixed wireless access system



2.2 Technology, architecture and configurations

2.2.1 Radio interface characteristics

Class of emission:	
– traffic channels per bearer	5
– traffic channel bandwidth	32 kbit/s
– voice coding	32 kbit/s ADPCM
– voice band data	28 8000 bit/s
Access method	TDMA
Duplex	TDD
Transmit frequency bands (MHz):	
– downlink	340-380 or 1 850-1 990
– uplink	340-380 or 1 850-1 990
Duplex separation (MHz)	Not applicable
RF channel spacing (kHz)	600
Total number of RF duplex channels	32
Modulation	GMSK
Modulation rate (kbit/s)	576
Net bit rate per traffic slot (kbit/s)	32

SR500-s Point-to-Multipoint (PMP) System

SR Telecom wireless access is a subsystem of the SR500-s point-to-multipoint (PMP) microwave radio system. The SR500-s provides the backhaul capacity from the wireless access to the existing telephone network, the PSTN interface connection into the telephone network and the OA&M interface.

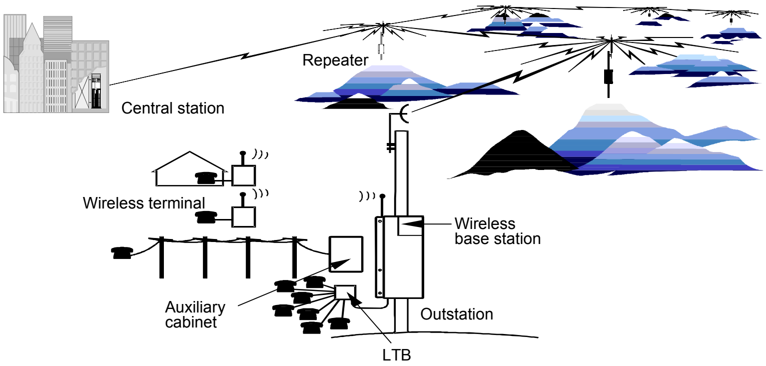
The SR500-s is a PMP system and therefore provides coverage over an area of hundreds of kms using microwave radio transmission. This provides a very effective backhaul capability allowing the wireless access to be deployed cost effectively in either a rural, suburban or urban application.

As illustrated in Fig. 48, the central station of the SR500-s provides the PSTN interface to the central office of the telephone network, via standard 2 wire or 2 Mbit/s (ITU-T Recommendation G.703 compliant) interfaces. The central station also provides all OA&M capabilities for both the PMP system and the wireless access subsystem from a common interface.

From the central station the SR500-s communicates to the outstations located remotely in the rural villages directly or via a repeater. At the outstation the subscriber can be connected to the network either via cable or via a wireless access subsystem.

FIGURE 48

System diagram



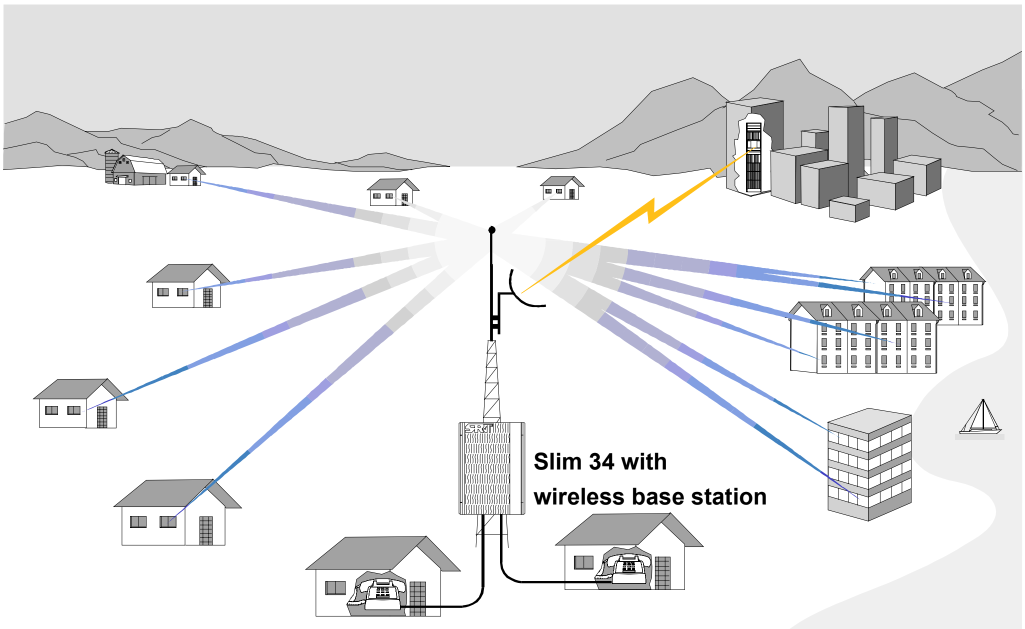
Wireless access subsystem description

The wireless access subsystem connects to the SR500-s system at an outstation eliminating the need for distribution cable and drop wire over this last leg of the local access. The wireless access subsystem consists of two units, the Wireless Base Station (WBS) and the Wireless Terminal (WT). The WBS is installed inside the outstation cabinet while the WT mounts on the outside of the subscriber premise and connects to the subscriber's telephone.

The two units communicate via a TDMA radio link using a single TDD frequency for both the transmit and receive signals. The wireless access subsystem operates in either the 340-380 MHz or 1 850-1 990 MHz band. Other bands are also available. The system is capable of operating with a hop length up to 10 km for line-of-sight (LOS) operation and 5 km for non-line-of-sight (NLOS) operation. With NLOS operation it is possible to shoot the radio signal through trees and over the tops of subscriber premises, simplifying installation and reducing the need for high towers. Figure 49 illustrates the coverage area for the wireless access subsystem.

FIGURE 49

Wireless access subsystem coverage area



Wireless base station

Each WBS consists of a 4 W (+36 dBm) wireless base station transceiver and a wireless base station controller. Each wireless base station provides 5 trunks which are shared among all wireless terminals. Using Erlang B traffic tables, 5 trunks will support 1.36 Erlangs of traffic with a grade of service (GOS) of 1% blocking. Assuming typical subscriber traffic levels of 0.07 Erlangs per subscriber each wireless base station will support 20 wireless terminals.

A maximum of 2 wireless base stations (2 slots each) can be installed in a Slim 34 Outstation or a Slim Auxiliary Cabinet. In this configuration the 2 wireless base stations communicate with each other allowing the 2 sets of 5 trunks (10 in total) to be dynamically channel allocated providing a total traffic capacity of 4.46 Erlangs which translates into 64 subscribers at 0.07 Erlangs per subscriber.

Wireless terminal

The wireless terminal is externally mounted on the side of the subscriber premise (see Fig. 48). It consists of the radio transceiver, the line interface circuitry and a connection point for both the telephone tip/ring and the power supply connection. The unit is designed for fixed applications under all environmental conditions.

A fixed plane directional antenna is connected to this unit and is extended via a coaxial cable to the rooftop for improved performance. The wireless terminal operates from a +12 V DC voltage which can be supplied from an optional AC converter or directly from solar or wind generators. In the case of AC powered systems the AC converter can be installed indoors or inside of the wireless terminal. Battery back-up is also provided in the wireless terminal for up to 12 h of standby operation.

Subscriber interface

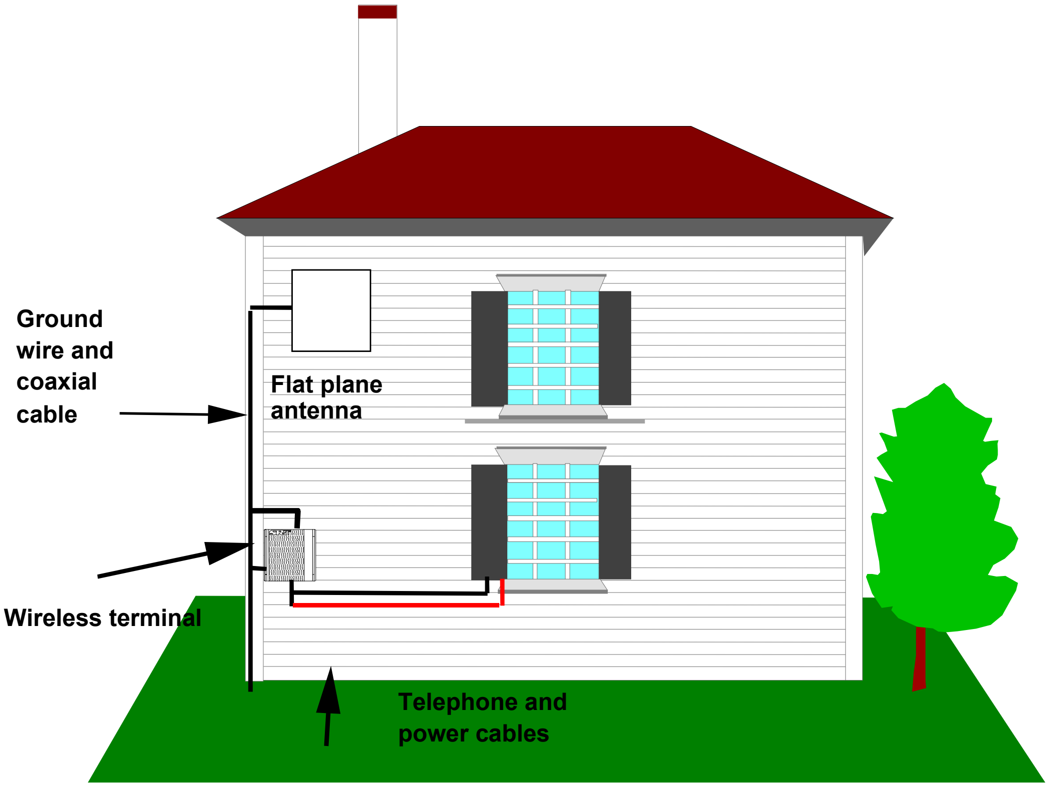
The wireless terminal provides connection to the telephone network for a single subscriber via a two wire plug. Voice, 12 or 16 kHz payphones and voiceband data devices (modems and faxes) up to 28 800 bit/s are supported. Future enhancements will include 64 kbit/s and ISDN (144 kbit/s).

Installation characteristics

Figure 50 illustrates a typical wireless terminal installation on the side of a subscriber premise. The preferred antenna is a flat plane directional antenna mounted near the rooftop facing towards the wireless base station. At the wireless base station either a directional flat plane antenna or an omnidirectional antenna can be used dependent upon the coverage area.

FIGURE 50

Wireless terminal installation



Feature transparency

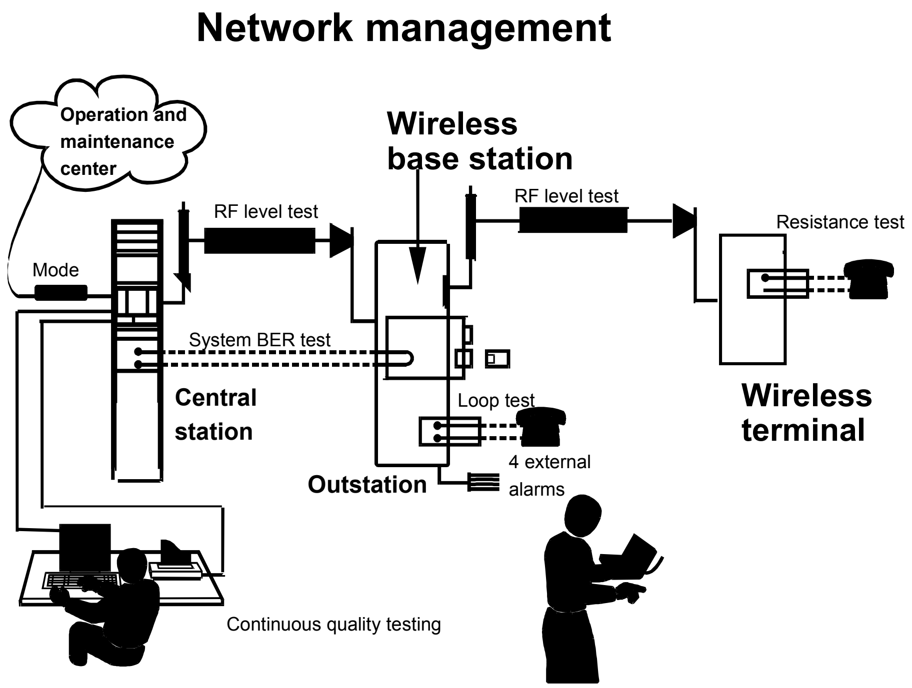
SR Telecom's wireless access subsystem provides transparent operation for fixed service applications. This includes, dialling transparency, support of all vertical services such as calling line identification and toll quality speech using 32 kbit/s ADPCM voice encoding. Other features include intracall, dedicated and priority trunks, as well as security and authentication for all conversations.

Operation, Administration and Maintenance (OA&M)

The SR500-s OA&M system extends its capabilities to include the wireless access. Alarms, traffic reports, RF level tests, individual circuit diagnostics and programmable parameter settings are provided for the wireless access subsystem via the OA&M system as shown in Fig. 51. Remote software downloading is also supported for the wireless access subsystem.

FIGURE 51

Maintenance and operation connections



2.3 Summary of capabilities

SR Telecom's wireless access subsystem offers the telephone operating company a cost-effective alternative to cabled systems that can be quickly deployed in modular increments to provide timely response to service requests.

Features/Highlights

– Transparent operation for all vertical services.
– Supports standard telephones, payphones and voice band data equipment.
– Supports fax and data transmission up to 28 800 bit/s.
– Planned support for ISDN.
– Low power consumption allowing solar power operation with 12 hours of battery back-up.

Prime advantages

– Operates up to 5 km over a NLOS (obstructed) path reducing tower height.
– Cost-effective alternative to cabled local access.
– Integrated backhaul to existing PSTN provided via SR500-s PMP.
– Supports all standard PSTN interfaces.
– Integral OA&M system provided via SR500-s including remote software download.
– No path planning required.
– Designed for outdoor operation.

Applications

– Network extension in rural areas.

– Network overlay to expand or enhance services in regions currently served with cable.

– Alternative operators providing service option with existing operators.

– Wireless replacement of cabled areas in need of cable upgrade or replacement.

3 TRT/Lucent Technologies IRT Modular System for wireless local access

3.1 General

The IRT Modular System is a point-to-multipoint system designed mainly to connect isolated subscribers to a telephone network. The main system characteristics include:

Service features:

– connection of telephone (wireline or wireless), telegraphic, and data transmission subscribers,

– ISDN compatibility,

– grade of service compatible with that provided by exchanges,

– network and equipment can be rolled out quickly and with great flexibility,

– easy operation and maintenance.

Technical features:

– coding of the VF channel using 64 kbit/s PCM (pulse code modulation) for the backhaul part of the network,

– DECT technology at 32 kbit/s with ADPCM encoding for the last segment of the connection to the subscriber premises,

– microwave radio transmission,

– use of TDMA.

The IRT system is adapted for a wide range of different applications, including rural telecommunication systems, dedicated urban data-transmission networks, ISDN, connection and supervision of offshore platforms, the transmission infrastructure of mobile radio networks and supervision networks.

The IRT system combines extensive connection capacity with a wide geographical coverage zone.

The system is available in two configurations (depending on the capacity):

– IRT 2000: maximum number of subscribers which can be connected: 480,

– IRT 4000: maximum number of subscribers which can be connected: 1 920.

These subscribers can be connected without appreciable limit (up to 1 600 km).

3.2 Technology, architecture and configurations

3.2.1 Radio interface characteristics

Class of emission:	2M00G7W
– traffic channels per bearer	30
– traffic channel bit rate (kbit/s)	64
– voice coding	PCM

Access method	TDMA
Duplex	According to the ITU-R channel arrangements
Frequency bands (MHz)	1 350-1 375 paired with 1 492-1 517
	1 375-1 400 paired with 1 427-1 452
	2 300-2 500 and 2 520-2 670
RF channel spacing (MHz)	2
Total number of RF duplex channels	according to the relevant channel arrangement
Modulation	QPSK
Modulation rate (Mbit/s)	2.304

3.2.2 Network functions, organisation and structure

Network functions

The IRT system offers the following main functions:

– concentration of telephone traffic on n x 30 x 64 kbit/s PCM circuits (n = 1, 2, 3 or 4, where n is the number of concentration units (CU) in an IRT system),

– radio transmission of traffic between the exchange and the different subscriber stations.

The IRT system is connected:

– at one end: to the main distribution frame at the entrance to the telephone exchange, and,

– at the other end: directly to subscriber lines.

The system provides subscriber access to all the services offered by the most up-to-date telecommunications networks, with transparency for the user.

Organization

The IRT system is based on a central station which is connected to other stations in the system by radio relay.

The central station is connected to the exchange by analogue or 2 Mbit/s digital links.

Each subscriber is connected (see Fig. 52):

– either to a remote station (near to the subscriber site) by wire line, or

– a subscriber terminal known as a CTA (at the subscriber site) which is then connected to a remote station by DECT radio extension.

Subscriber connection

In some cases, the geographical location of subscribers may require the implementation of repeater stations to provide radio links. These repeater stations can also be used to connect subscribers.

To simplify the system, an architecture with three levels is used (see Fig. 53):

– level 1: backbone repeater (BR),

– level 2: remote stations,

– level 3: DECT subscriber terminals (CTAs).

A type of radio link is associated to each level:

– backbone repeater (BR): backbone radio link,
– remote stations (RS): TDMA radio link,
– DECT subscriber terminals: DECT radio link.

Network configuration

An IRT system is made up of:

– a central station (CS) which is connected to the main distribution frame of the exchange;
– backbone repeater (BR) (IRT 4000 configuration only);
– remote stations (RS);
– RFP radio terminals and CTA subscriber terminals (radio DECT extension if wireless subscribers are connected).

Subscribers are connected to a remote station by wire line or DECT radio link.

There are two types of remote station: terminal or repeater (with or without subscribers) depending on the network architecture.

The IRT 2000 configuration manages one concentration unit (CU) which can handle 30 PCM circuits.

The IRT 4000 configuration includes n CU (where $n = 2$, 3 or 4) with each CU handling 30 circuits.

A CU manages the RSs and in some cases the DECT radio equipment (RFP and CTA).

Remote stations which are managed by the same CU can be grouped together or split within the network.

The CS and radio subunits

The CS can include between one and four CUs. The station is connected to the exchange by an analogue or digital link:

– analogue link: one pair for each subscriber,
– digital link: one pair for 30 subscribers (2.048 Mbit/s (V5-1 or V5-2)).

The IRT system uses microwave transmission to link stations in the network to the central station.

These are managed by the CS processer(s) which act as the heart of the system.

The CS TDMA radio subunit can be remotely located if this is a requirement of the network topology. In this case the CS is split into two parts:

– telephone equipment at the host exchange,
– remote radio station (RRS) at the distant network side.

These two units can be linked by standard 2.048 Mbit/s (ITU-T Recommendation G.703) cable or radio link.

Backbone stations

There are three types of backbone repeater (BR):

– TTH station (trunk through repeater).
– TDI station (trunk drop-insert repeater).
– TEB station (trunk end of backbone).

TTH station.

A TTH station only provides radio-relay facilities. Subscribers cannot be connected to this station.

A TTH station can relay up to 4 backbone streams (one backbone link per CU).

The number of TTH stations in an IRT network varies according to the network configuration.

TDI station

TDI stations act as nodes between levels 1 and 2 in the network. They are used to:

– connect up to 3 CUs to the backbone;
– connect subscribers.

A TDI station uses two types of radio link within the network (backbone radio link and TDMA radio link.

TDI stations can be used to relay 2, 3 or 4 backbone streams at 2.304 Mbit/s (for either 2, 3 or 4 backbone repeaters).

TEB station

A TEB station is used to terminate the network backbone.

This station is used to:

– connect up to 4 CUs to the backbone;
– connect subscribers.

A TEB station provides transmission/reception of 2, 3 or 4 backbone radio streams.

Remote stations

Level 2 in the system architecture is provided by RSs, which may be either repeater or terminal. There are two types of RSs:

– ERS remote station (repeater or terminal);
– microstation (terminal only).

A repeater station uses two types of TDMA radio links to communicate with the rest of the network (see Fig. 53):

– a link set up in the direction of the CS by an "upstream" radio link.
– another link set up towards further stations by a "downstream" radio link.

A terminal station is therefore able to communicate with the CS by radio link, which in some systems is relayed by one or more repeater and backbone repeaters.

Radio equipment in RSs

The DECT radio extension provides the third level in the system architecture (see Annex 4, § 8).

The various stations of the IRT Modular System are compatible with stations used by the former IRT networks (first generation RSs and mini-stations).

Types of network structures

Station modularity together with the flexibility of the IRT system allows the system architecture to be easily adapted to accommodate the different configurations encountered in the field:

– star-network configuration;
– tree configuration;
– linear configuration.

This enables networks to be deployed in deserts, plains or mountainous areas, and urban, suburban or maritime environments.

Diagrams showing examples of network structure

The use of radio equipment, including radio relay stations, allows extensive geographical areas to be covered and services to be provided in locations which are several hundreds of kilometres from the upstream station.

FIGURE 52

IRT modular system functionalities

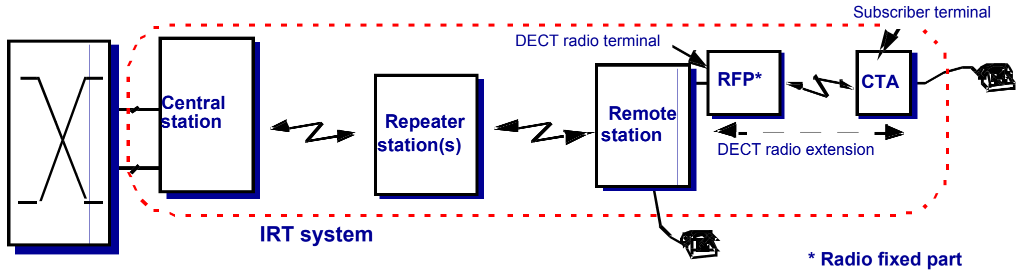
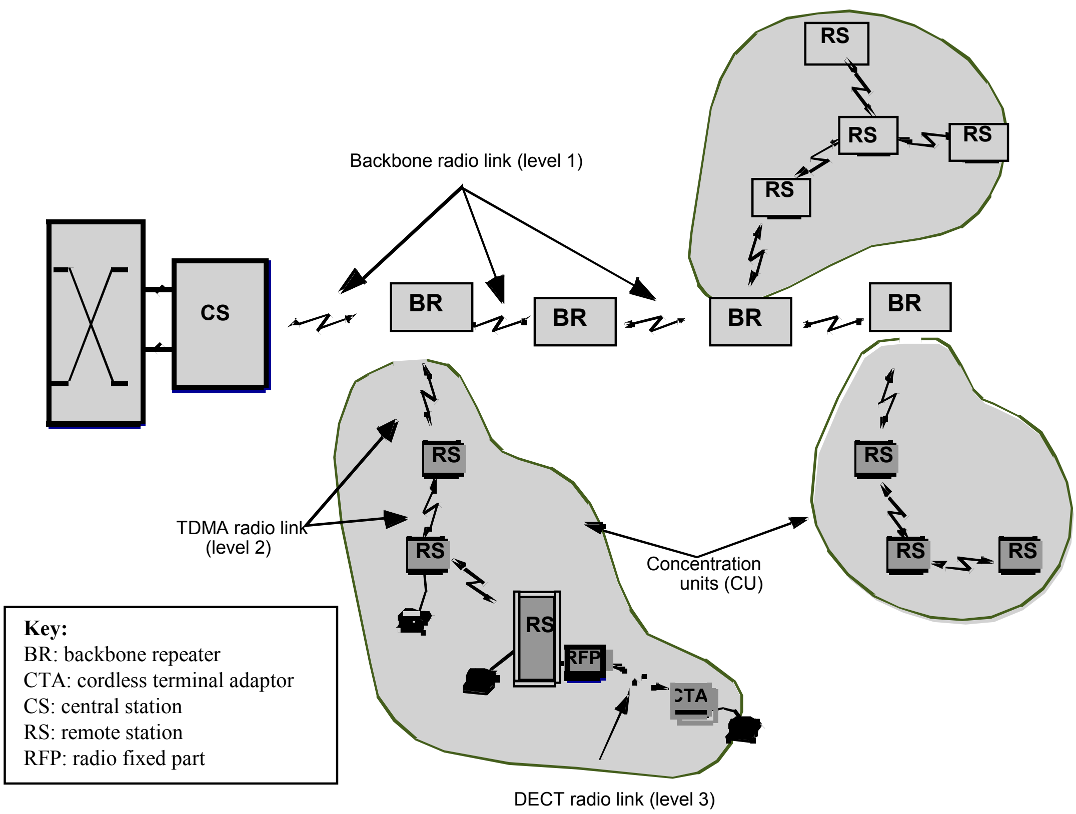


FIGURE 53

IRT Modular System network configuration



ANNEX 6

BWA systems deployment considerations

1 Introduction

This Annex supplements Chapter 8 with additional detail that developing countries may need in their planning and deployment of BWA systems.

2 Spectrum sharing considerations

The recommended methodology for the identification of possible bands for FWA, in general (see Recommendation ITU-R F.1400), prominently includes the identification of sharing and regulatory constraints. Of the six basic methodology steps, three address frequency band sharing. These considerations cause the longest delays in the identification of frequency bands for FWA in general and BWA deployment in particular.

3 WRC-2000 decisions relating to HDFS

3.1 Introduction

The World Radiocommunication Conference held in Istanbul (Turkey) from 8 May to 2 June, 2000 (WRC-2000) considered issues on allocations and regulatory aspects related to the use of frequency bands above 30 GHz for High-Density systems in the Fixed Service (HDFS) (agenda item 1.4), with due regard to the requirements of existing and future radio services systems operating in the relevant frequency bands.

High-density applications, particularly above 20 GHz, are generally characterized as follows:

- operate on a P-P or P-MP basis, or a combination of both;
- flexible and rapid deployment;
- high degree of frequency reuse due to propagation conditions;
- decreased antenna and terminal size with increased frequency;
- no necessity of major cost implications due to the to the need to include mitigation techniques to solve inter-service sharing problems;
- ubiquitous deployment of HDFS stations; and
- a wider range of antenna elevation angles than is found at lower bands.

The term HDFS does not refer to a particular application, sub-service or band in the FS, but does describe the phenomenon of maximized deployment density, spectral efficiency and frequency reuse in the FS. Often concentrated deployment density, spectrum reuse and spectral efficiency factors become more pronounced in the higher bands due to correspondingly more favorable propagation conditions. Use of the term "high density" can also be applied in the same way to any radio service that may be widely utilized for commercial or other purposes.

HDFS includes several applications of the fixed service amongst them BWA, see Section 6.3.2 for more detailed information.

3.2 Applications for HDFS

Due to propagation characteristics of frequency bands above 30, line-of sight and short range connections are required. Nevertheless, high population of FS systems can be achieved and consequently the systems in these bands are well suited to increase infrastructure in concentrated population areas. Transmission bit rates up to 310 Mbit/s and above are anticipated. Main applications include:

- Deployment of mobile network infrastructure for existing and new systems.
- Fixed wireless access (FWA):
  - accommodate new telecommunication operators in competitive markets;
  - provide alternate technologies for upgrade of existing telephone infrastructure;
  - provide greater access and service choices for residential and commercial users for telephony, data and multimedia services.
- Applications requiring no individual frequency assignments possibly in the bands around 60 GHz.

3.3 Results of WRC-2000

WRC-2000 designated several GHz of spectrum for HDFS applications above 30 GHz intended to provide a global solution for its deployment. Decisions taken are contained in the ITU Radio Regulations (RR) in the form of footnotes to article S5 and associated Resolutions that provide the regulatory provisions to be observed when deploying HDFS in these bands. Furthermore, in the Table S21-4 of the RR power flux-density (pfd) limits were provisionally added for space services operating in the relevant bands to protect HDFS systems. Particularly, major results concerning HDFS applications are included in two footnotes (S5.547 and new S5.551AA), two Resolutions (Resolutions 75 and 84) and additions of provisional pfd limits for space services (Table S21-4) in the frequency bands shared with HDFS systems.

ANNEX 7

Descriptions of broadband wireless access systems

1 Nortel Networks Reunion™ Broadband Wireless Access System

1.1 General

The Nortel Networks Reunion system provides digital broadband wireless access using a point-to-multipoint radio architecture. Reunion operates in a variety of frequency bands, mainly between 24 and 40 GHz. Cell sites are sectorized, each sector generally covering between 15 and 90 degrees of arc. Subscriber sites use highly directional antennas, similar to point-to-point radios.

The Reunion system allows the network operator to mix FDMA and TDMA upstream traffic on the same base station in order to optimally serve a mix of small and medium sized subscriber sites. TDMA tends to be optimal for serving small subscriber sites in which traffic demand is bursty or average traffic is less than about 2 Mbit/s upstream. FDMA tends to be optimal for serving larger sites (medium-sized enterprises or the aggregate traffic of multi-tenant buildings) in which there is enough steady traffic to justify a dedicated upstream channel. In addition, Reunion offers a choice of ATM or IP network interfaces, recognizing that both technologies have their place in the market.

A typical subscriber site might be provided with one or more DS-1 or E1 connections, similar to wireline leased lines. A DS-1 or E1 would then be connected to, for example, a PBX, for a large business customer, or to an operator-owned line concentrator, such as Nortel Networks' AccessNode Express™ which would then distribute individual access lines to end customers in the building. In addition, the CPE provides a 10baseT or 100BaseT port for providing a LAN bridging or routing function for data traffic within the building. Other applications include backhaul of land mobile radio cell-site traffic.

Traffic is carried over the air as ATM cells or IP packets with appropriate error control. In the downstream direction (base station to CPE), one or more broadband modulated signals at several tens of megabits per second is broadcast to all CPEs in a sector. This signal is a continuous time division multiplex stream of cells or packets intended for a number of CPEs. In the upstream direction, both FDMA and TDMA channels can be provided. Customer sites with high traffic throughput requirements can efficiently make use of dedicated channels using FDMA. The channel bandwidth is programmable in order to efficiently tailor spectrum usage to site requirements. In addition to programmable bandwidth, the modulation level is also programmable, offering a choice of 4-, 16- or 64-QAM. Downstream rates in excess of 50 Mbit/s can be offered. Customer sites with low throughput requirements, generally less than one or two DS-1s or E1s, can most efficiently time-share upstream TDMA channels. The TDMA upstream channel can be time-shared on a demand basis, with no fixed time slots assigned to any particular user. The media access control protocol is based on the MCNS DOCSIS protocol, which is also standardized in Recommendation ITU-R F.1499 and ITU-T Recommendations J.112 and J.116. It makes use of a scheduling algorithm at the base station. The scheduler processes bandwidth requests from CPEs in the upstream channel and grants time slots dynamically using a broadcast time-map sent periodically in the downstream channel.

Both FDMA and TDMA channels use forward error correction (FEC) as well as adaptive equalization, which is necessary to cope with channel errors and a dispersive radio channel.

The Reunion system uses frequency-division duplex (FDD) technology to separate upstream and downstream signals, and to provide for robust operation in a deployment scenario involving coexistence with other systems.

Links are typically engineered to provide 99.9 to 99.999% availability using cells of 1.5-5 km radius.

1.2 Technology, architecture and configurations

1.2.1 Radio interface characteristics

Class of emission	5-50MD7W downstream
	2-10MD7W upstream
Multiple access scheme	TDM downstream
	FDMA or TDMA upstream
Duplex type	FDD
Typical transmit frequency band (GHz)	Various bands 10-60 GHz
Typical RF channel spacing (MHz)	5-50 downstream
	2-10 upstream
Gross bit rate per carrier (Mbit/s)	8-150 downstream
	2-30 upstream
Modulation	4-QAM, 16-QAM or 64-QAM

1.2.2 Network configuration

The network architecture which allows any pairing of FDMA or TDMA access with ATM or IP networking is shown in Figure 44 below. The Reunion system comprises:

– the base station indoor equipment, or Network Node Equipment (NNE);

– the outdoor Base Station Transceiver (BTR);

– the outdoor Customer Premises Transceiver (CTR);

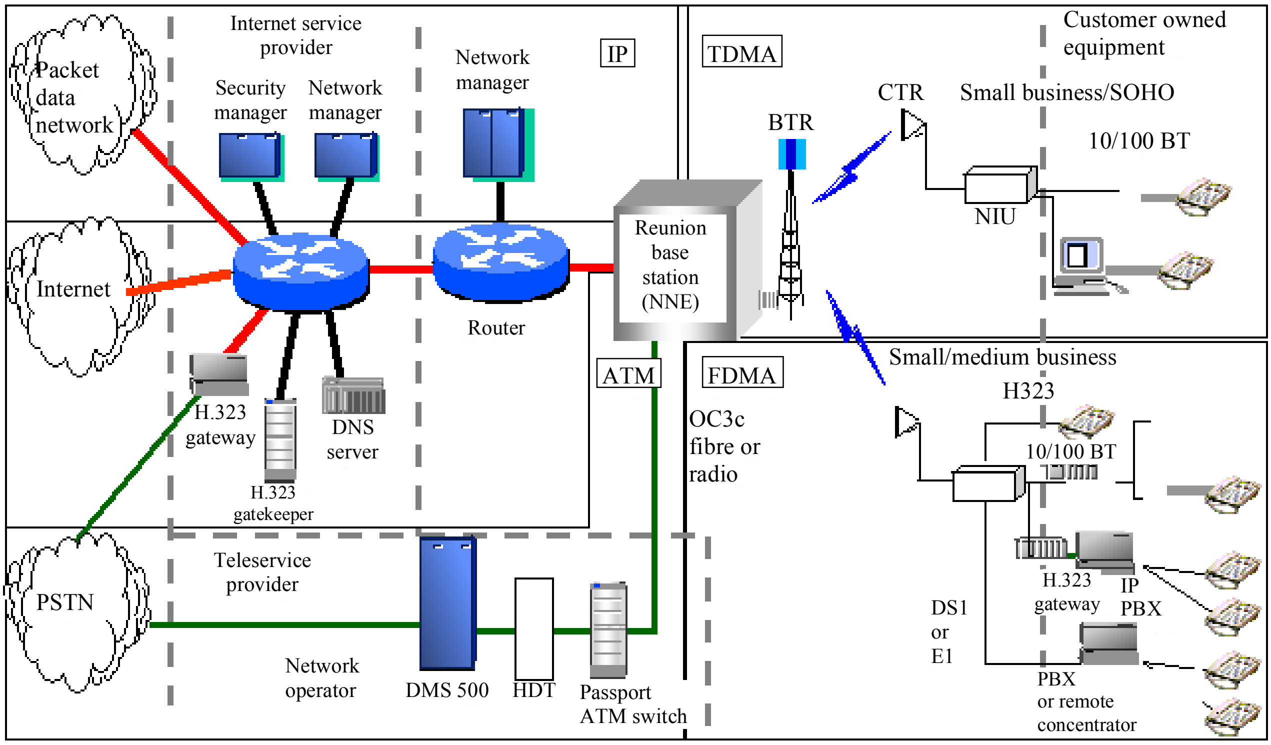
– the indoor customer premises Network Interface Unit (NIU); and

– associated network management equipment and tools.

External to the BWA system at the customer site are the customer owned equipment connected to the NIU, such as concentrators, H.323 IP gateways, PBXs, and LAN hubs. External to the Reunion system on the network infrastructure side are the backhaul media from the base stations (OC3c/STM-1 fibre or radio), the ATM switch or IP router, and network gateways. The Reunion system provides integration into the Internet service provider (ISP) and application service provider (ASP) customer-care system and operation support system (OSS).

FIGURE 54

Network architecture



Land-044m

The functions of the system components are as follows:

Network node equipment (NNE)

The NNE comprises base station modems, channel combining and redundancy switching matrix, and backhaul interface. The downstream channels are continuous TDM carriers. FDMA and/or TDMA upstream channels are supported, and with FDMA, a mix of narrowband and wideband upstream channels can be associated with each downstream channel.

Traffic is carried as ATM cells or IP packets, with support for quality-of-service (QoS). ATM CBR circuit emulation service supports both structured and unstructured DS-1 or E1 traffic.

Reunion uses broadband linear amplification technology, so that the multiple downstream channels are combined into each radio. A channel combining and redundancy switching matrix allows combining of several carriers into each millimetre-wave radio, and has the ability to switch spare modems into sectors as required for fault recovery.

A variety of broadband backhaul interfaces, including OC3c fibre or point-to-point radio, may be employed, and redundant backhaul is supported.

Base station transceiver (BTR)

The BTR converts a wide band of intermediate frequency transmit and receive signals from the NNE modems to millimetre-wave frequencies, and provides amplification. The BTR is remotely powered from the NNE via the IF cabling. Normally, a pair of BTRs are co-sited in each sector for 1:1 redundancy. A variety of sector antennas can be attached to the BTR, to provide coverage from 15 to 90 degrees with either horizontal or vertical polarization. Alarm and status supervision messaging from the BTR to the NNE is also provided.

Customer premises transceiver (CTR)

The CTR provides the same frequency-conversion and amplification functions as the BTR, but is optimized for single-channel operation and low cost. Like the BTR, the CTR is remotely powered via the IF cabling. A parabolic antenna is directly attached to the radio, providing high gain with high sidelobe and backlobe rejection, essential for intensive frequency re-use.

Network interface unit (NIU)

The NIU contains the modem for the customer premises side of the link and also provides a variety of interfaces to support a wide range of end-user services. The typical NIU provides one or more DS-1 or E1 ports plus a 10baseT port, all in a single integrated package. Each port is independently configurable to support several virtual circuits.

1.3 Summary of capabilities

The Reunion system offers the following key attributes:

Features/Highlights

– Broadband access (1 or more DS-1 or E1 lines and/or 10/100baseT)

– ATM or IP networking

Prime advantages

– Competitive alternative to wireline leased line facilities

– Rapid deployment

– Modular growth; scaleable solution

– Integrated voice, video, data solution

– Optimized for wide range of traffic, through mixing of FDMA and TDMA channels

– Choice of ATM or IP networking

Applications

– Structured or Unstructured DS-1 or E1 access

– "Last mile" connectivity for service providers

– High speed access in districts underserved by fibre, coax or copper leased line facilities

– High availability links

Service Provisioning

– Competitive local exchange carriers (CLECs)

– Internet service providers (ISPs)

– Cellular and PCS Operators with wireless backhaul requirements

2 TSR broadband fixed wireless access system

2.1 Introduction

This has been developed by the Swedish company Time Space Radio, TSR, and some of its salient features are the use of a unique time and space multiplexing, to achieve high capacity combined with efficient spectrum usage. It is designed to operate in the 10.5 GHz and 3.5 GHz bands.

2.2 Description

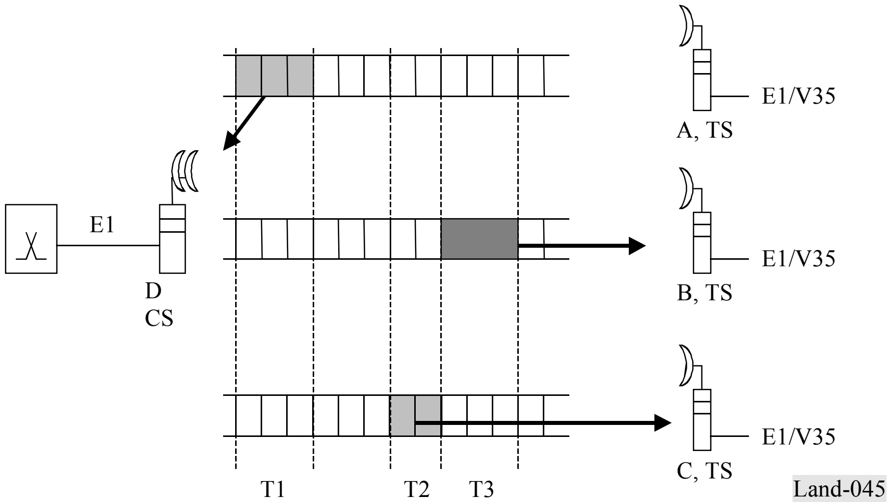
SDMA/TDMA is used to send or receive information, via narrow (5′) radio beams, in a specific direction during a specific period of time. The system allows a single station to communicate with one or more stations by rapidly changing the direction of antenna during transmission or reception to a station designed for that purpose. This allows for a very efficient utilisation of the frequency spectrum.

In transmissions between two specific TSR stations, the product TSR 34-10 thus functions as a conventional radio link. A single station can receive information one moment and retransmit it the following moment – so-called repetition. Significantly, a TSR radio network can consist of a combination of star, tree and link structures and it may be appropriate to avoid use here of the normal terms central/base and terminal /user stations and use the term "node". The latter term conveys better the notion that the stations serve several functions in an integrated manner ("master/slave" for example, is a term that might also be employed.)

The system uses Time Division Duplex (TDD), i.e. the same frequency is used for reception and transmission, which allows faster asymmetric traffic on TSR's networks.

FIGURE 55

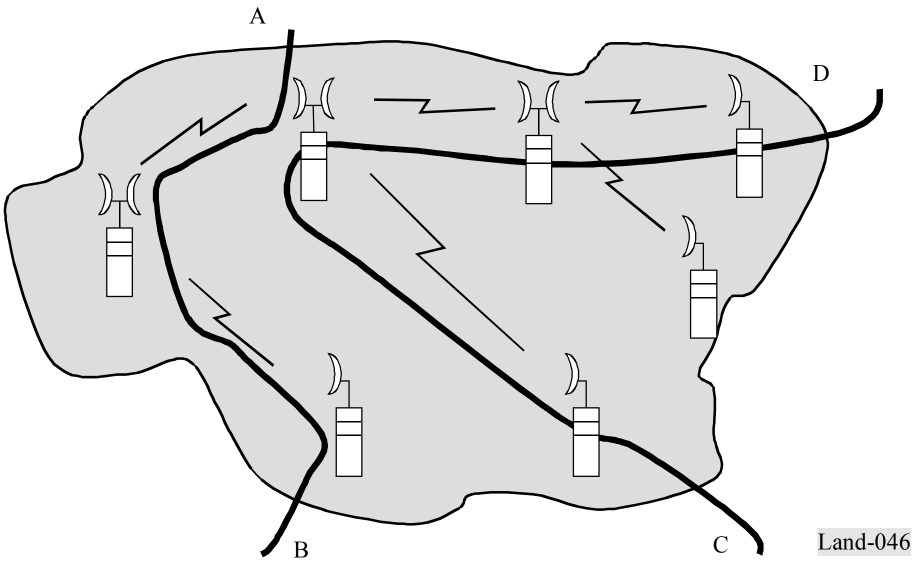
TSR 34-10 uses TDMA and TDD. A set number of Time Slots are used for communication between two stations. During T1 station A transmits information to station D. Station D retransmits - "repeats" - this information to station C during time period T2, after which, during T3, D transmits information to B. The radio link thus uses a single frequency for both transmission and reception.



A key function of TSR stations is their capacity for parallel repetition of traffic to another station and drop/insert of local traffic.

FIGURE 56

A TSR network may comprise any combination of star, tree and link structures. In a logical link between A and B traffic through the net is transparent. Each node in a TSR network constitutes a resource of 34 Mbit/s. Provided that the flow of traffic through each node does not exceed 34 Mbit/s, the C-D and A-B links can be used concurrently.



Design parameters

The design of a radio network consisting of TSR nodes should take into account the following parameters:

1) The number of interfaces per node.

2) Link distance.

3) Total bandwidth through a node.

4) Bandwidth for each direction.

TSR 34-10

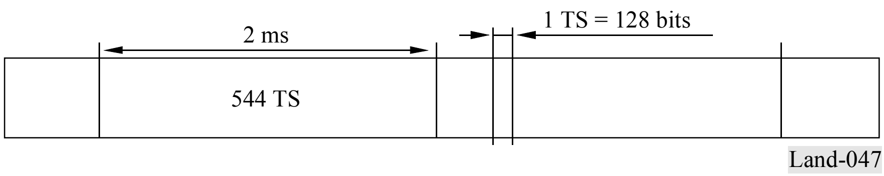
The basic hardware of all TSR stations is more or less the same. It should be noted that an antenna can cover several stations in the same radio access.

The software of the stations is configured either to transmit or receive information during a specific period of time and a specific antenna direction. This makes it possible to tailor bandwidth, traffic flow and network structures accurately to customers' requirements. All necessary configurations can be made through the user interface for the network management system.

The TSR system works with the bandwidth 28 MHz. Each station has the capacity to send or receive 544 128-bit time slots within a time frame of 2 ms. This means that each time slot corresponds to 64 kbps and that each TSR station can support traffic flows of up to 34 816 Mbps (simplex).

FIGURE 57

Frame structure in the radio interface. Each frame corresponds to 2 ms and consists of 544 time slots (TS).



2.3 Possible network structures and applications

Serial connection

FIGURE 58

Each station contains a logic function as CS, RS or TS but are physically the same. The system can be extended, without having to replace existing station hardware, either in serial, to cover a greater area, or in parallel, to increase capacity.

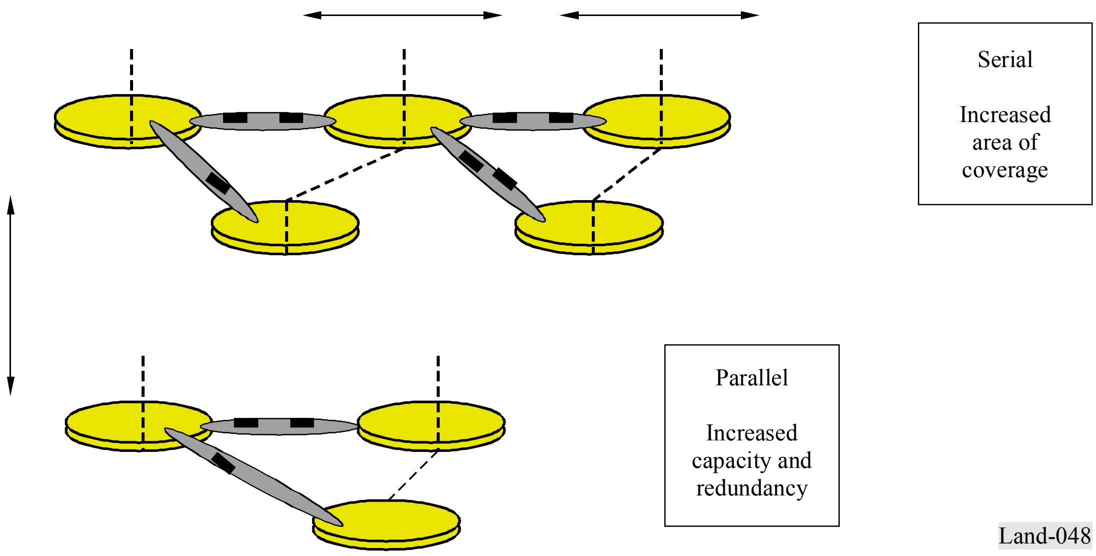
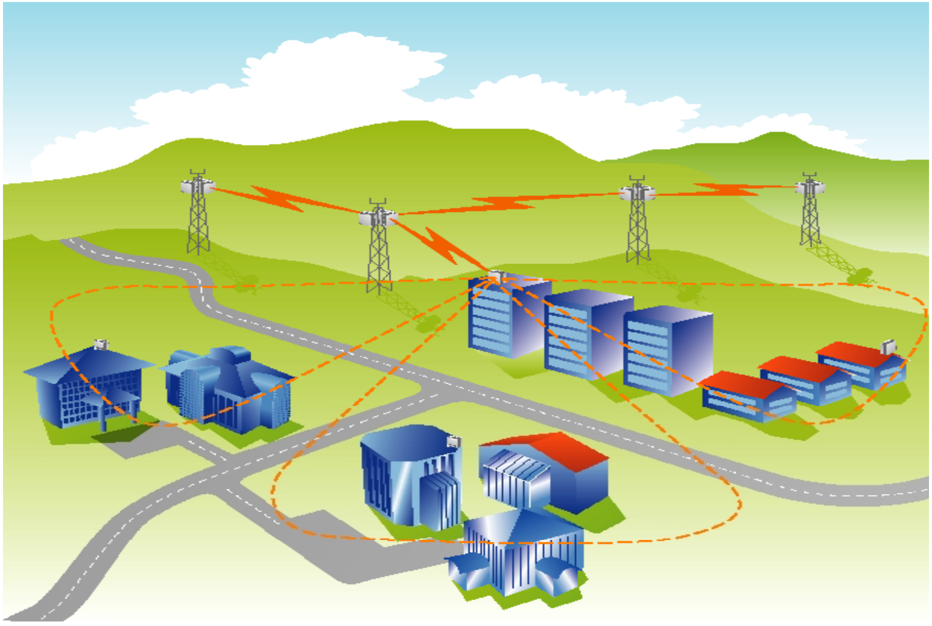


FIGURE 59

Application. TSR network providing broadband communication access to industrial areas, connecting them to other radio or fibre backbone systems. Mobile cellular network infrastructure may similarly be provided, and here route diversity is more valuable.



Land-049

3 General characteristics of broadband FWA system in Japan

3.1 Introduction

In very near future, it is expected that people use applications in a wider and more diversified manner as a way to utilize information and communications technologies. In order to make such applications feasible, it is indispensable to provide a highly sophisticated network infrastructure.

In view of the above, a broadband fixed-wireless access system, which connects general households and offices with the telecommunications facilities of telecom carriers using the frequency above 22 GHz band, has been studied for practical use. The propagation distance is usually a few kilometre or less. These point-to-point FWA system (referred to as P-P FWA hereafter) and point-to-multipoint FWA system (referred to as P-MP FWA hereafter) are on service in Japan.

The following sections outline about P-P FWA and P-MP FWA systems in Japan operating at the quasi-millimeter-wave band and the millimeter-wave band as of beginning 2000.

3.2 Point-to-point FWA system

This system using the frequency band of the 22.0-22.4 GHz, 22.6-23.0 GHz, 25.25-27.0 GHz, 38.05-38.5 GHz or 39.05-39.5 GHz is to be generally deployed in urban areas, and used for fast-speed data links such as LAN, WAN, ATM, etc., leased lines, and circuit switched connections and so forth. The expected users of this system include large-scale corporations that require a faster transmission rate of several tens of mega-bits per second, and corporations that require rates of several megabits per second. The propagation distance is four kilometres or less.

Therefore, the transmission capacity of P-P FWA is assumed at 6 Mbit/s, 45 Mbit/s, 52 Mbit/s, and 156 Mbit/s. Its duplex scheme is based on FDD (frequency division duplex).

An example of the configuration for P-P FWA is shown in Table 8.

TABLE 8

Example of configuration for P-P FWA

Item	**Contents**		
System classification	6M System	12M System	45M System
Frequency band	22/26/38 GHz	22/26/38 GHz	22/26/38 GHz
Duplex method	FDD	FDD	FDD
Modulation method	Multi-level modulation of 4 or more (4-PSK,4-FSK,16-QAM etc.)		
Transmission capacity	6.312 Mbit/s	12.624 Mbit/s	44.736 Mbit/s
Radio transmission rate	8.2 Mbit/s	16.4 Mbit/s	49.2 Mbit/s
Interface example	6.312 Mbit/s 1.544 Mbit/s×4	6.312 Mbit/s×2 1.544 Mbit/s×8	44.736 Mbit/s
Power of a radio transmitter	less than 500mW	less than 500mW	less than 500mW

Item	**Contents**	
System classification	52M System	156M System
Frequency band	22/26/38 GHz	22/26/38 GHz
Duplex method	FDD	FDD
Modulation method	QAM of 16 level or more	
Transmission capacity	51.84 Mbit/s	155.52 Mbit/s
Radio transmission rate	57 Mbit/s	172 Mbit/s
Interface example	51.84 Mbit/s 44.736 Mbit/s	155.52 Mbit/s 51.84 Mbit/s×3
Power of a radio transmitter	less than 500mW	less than 500mW

3.3 Point-to-multipoint FWA system

This system, which consists of many cells, using multiple access technology under the frequency band of the 25.25-27.0 GHz, 38.05-38.5 GHz or 39.05-39.5 GHz is to be deployed mainly from urban to suburban areas. As the system offers transmission rates from several tens of kilobits per second up to several mega-bits per second per subscriber, it can be used for N-ISDN, connection between LANs, Internet access and others. The main users of this system will include SOHOs and general households. The propagation distance is two kilometres or less.

Therefore, the total transmission capacity of P-MP FWA is assumed to be several tens of mega-bits per second. For the multiplexing mode, either TDMA or FDMA can be utilized, and for its duplex scheme, both TDD (time division duplex) and FDD systems are provided, which divide each of uplink and downlink on the time and frequency axes respectively.

An example of the configuration for P-MP FWA is shown in Table 9.

TABLE 9

Example of configuration for P-MP FWA

The table summarizes configuration examples for P-MP FWA systems based on three application types:

ATM connection type, LAN extension type and transmission connection type.

Item	Contents		
Mode	ATM connection type	LAN extension type	Transmission connection type
Service provided	Internet access/Internet telephone N-ISDN/B-ISDN FR/CR/VOD	Internet access Internet telephone	Internet access/Internet telephone N-ISDN/PSTN, leased line/FR/CR
Frequency band	26/38 GHz	26/38 GHz	26/38 GHz
Duplex method	TDD or FDD	TDD or FDD	TDD or FDD
Access method	TDMA or FDMA	TDMA or FDMA	TDMA or FDMA
Modulation method	GMSK, 4 (or more) PSK, 16 (or more) QAM		GMSK, 4 (or more) PSK, 16 (or more) QAM
Transmission capacity	FDD downlink/uplink: 25.6 Mbit/s TDD total transmission capacity: 52 Mbit/s	FDD downlink/uplink: 10 Mbit/s TDD total transmission capacity: 20 Mbit/s	FDD downlink/uplink: 20 Mbit/s TDD total transmission capacity: 40 Mbit/s
Radio transmission rate	FDD downlink/uplink: 36 Mbit/s TDD total transmission Rate: 72 Mbit/s	FDD downlink/uplink: 14 Mbit/s TDD total transmission Rate: 28 Mbit/s	FDD downlink/uplink: 28 Mbit/s TDD total transmission Rate: 56 Mbit/s
Power of a radio transmitter	less than 500 mW	less than 500 mW	less than 500 mW

4 Ericsson's broadband FWA system

General

Ericsson broadband-wireless IP system "Beewip™" provides a transparent medium for different types of IP services. Wireless Ethernet, based on 802.11, is carrying the IP traffic.

The system operates in the ITU standardized 3.5 GHz licensed frequency band. The system architecture supports dynamic bandwidth allocation and provides an "always on" connection at a data rate of up to 3 Mbit/s per subscriber.

Technology, architecture and configurations

Radio frequency system characteristics

Frequency band versions:	3 410-3 600 MHz
Duplex spacing	100 MHz
Modulation:	GFSK (1, 2 or 3 bits/symbol)
Access method:	FH-CDMA
Allocated bandwidth per RF channel:	between 10 MHz and 42 MHz
Subchannel spacing:	2 MHz
Hopping parameters:	250 µs max. hopping settling time
Dwell time:	default 128 ms
Bit rates:	gross bit rates of 1, 2 and 3 Mbit/s

Network configuration

The system consists of three main groups of physical nodes (see Figure 60, below):

The subscriber units consisting of an outdoor and indoor unit.

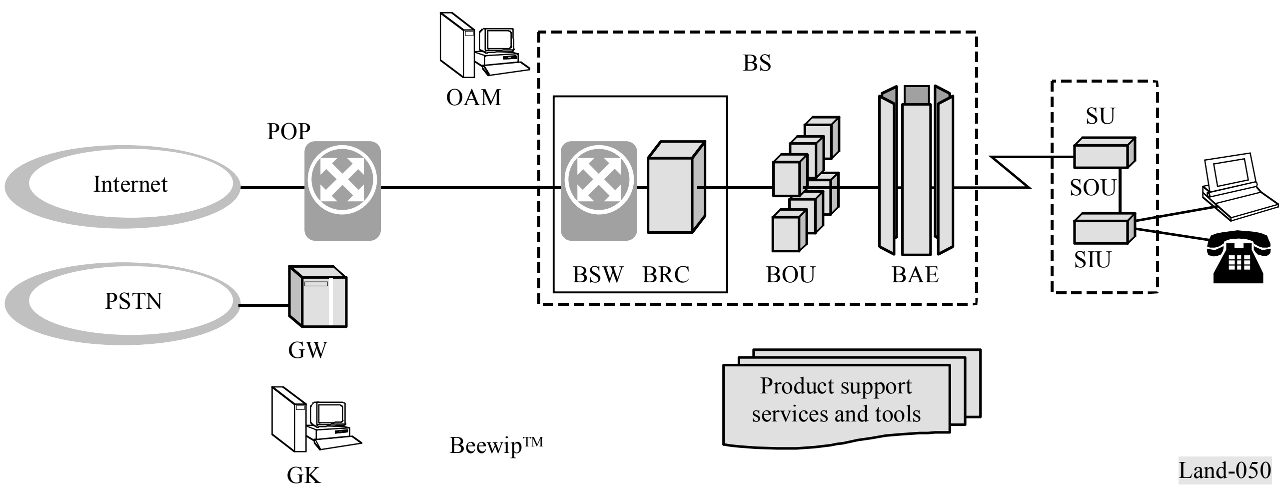
The base stations consisting of radio controller, switch, outdoor units and antenna elements.

The operation, administration and maintenance system consisting of hardware and software.

An in- or outdoor base station cabinet which houses the radio controller and switch.

FIGURE 60

Network configuration (inside the dotted lines is what is included in Beewip™)



SOU=subscriber outdoor unit, SIU=subscriber indoor unit.

BS=base station, BRC=base station radio controller, BSW=base station switch, BOU=base station outdoor unit, BAE=base station antenna element.

OAM=operation, administration and maintenance

The subscriber units (SU) are connected to the base station (BS) over the air interface. At the BS the traffic is concentrated and routed towards the point of presence (PoP) by the base station switch (BSW). Before routed towards the PoP, converting from 10BaseT Ethernet to the protocol used at the transmission media is done. The figure above shows the implementation of Ericssons Beewip™ system into existing networks. The connection of the system to the IP backbone for data transfer is directly via the (PoP), while the connection to the public switched telephone network (PSTN) is established by applying an additional gateway (GW) and gatekeeper (GK), since voice traffic is handled as voice over IP (VoIP). The BS provides all commonly used interfaces for the transmission media between BS and the PoP. The PoP concentrates the data and voice traffic for a given region towards the backbone.

The subscribers located in the covered area have access to the services via their subscriber units, which are located on their premises. There are different types of SUs available, offering different types of service packages. In total there are six different SU variants.

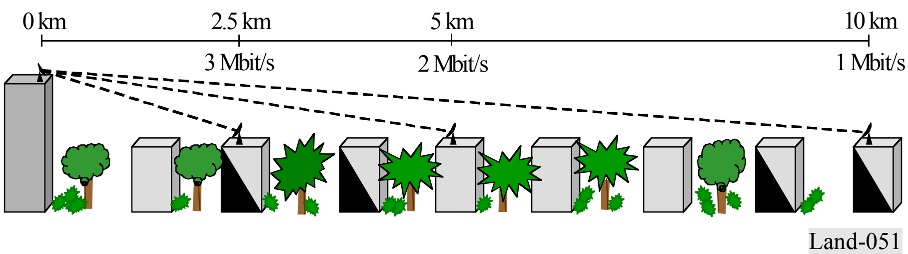
The operation, administration and maintenance (OAM) part enables the operator to remotely configure the nodes of the whole access network, to do remote software upgrades, and on the whole, control and monitor all traffic by fault and performance management functions.

Range

The maximum ranges for the different bit rates, when using the nominal radio characteristics of the system with a 60° antennae and a pathloss model for obstructed line of sight (OLOS), are approximately 10, 5 and 2.5 km for 1, 2 and 3 Mbit/s respectively. This typical OLOS scenario is depicted in Figure 61.

FIGURE 61

Deployment of the system in a typical urban/suburban scenario



In line of sight conditions 15 km range can be expected.

The OLOS scenario allows for easy and inexpensive installation for both the BAE and SOU.

Capacity

Beewip™ is a packet-oriented system, using FH-CDMA radio technology. For the capacity then, the carrier-to-interference ratio (*C*/*I*) is the figure of merit. The gross bit-rate values will be different in different deployment scenarios.

A worst-case scenario has been simulated, based on a large network and minimal amount of bandwidth in combination with a fully loaded system. This deployment scenario means a large network with closely adjacent base-stations, with all base-stations transmitting all the time. The result from those simulations showed that an average gross bit-rate in an OLOS scenario is 2.2 Mbit/s.

In a more typical traffic scenario there will be less interference and therefore better possibilities to send at higher bit-rates. In a network with less base stations and more bandwidth a gross bit-rate close to 3 Mbit/s can be expected.

Deployment

Ericssons Beewip™ system follows a cellular deployment structure where multiple cells provide coverage to a geographical area. Each cell contains one base station (BS) with several base station antenna elements (BAE) each driven by one base station outdoor unit (BOU). The BAEs are sectorial antennae covering a sector of either 60^o or 120^o.

The total number of subscribers that can be connected to a Beewip™ base station with six sectors depends not only on the manner of deployment, the terrain and the distance between BS and subscribers, but also on factors that are connected to the actual data traffic such as subscriber behaviour, offered services etc. All this might be very different for different implementations of the system.

Summary of capabilities

In summary, the Beewip™ system provides the following key attributes:

Features/highlights

LAN connection to Internet

– Provides a bandwidth management that enables to set symmetrically and unsymmetrical for up- and downlink with a resolution of 1 kbit/s.

– Data *and* voice services at the same time.

Prioritizes voice over data

– The connection to the PSTN is established by an of-the-shelf H.323 voice gateway.

– The possible voice codecs are: G.711 – 64kb/s, G.723.1 – 6.3 kbit/s, G.729A – 8 kbit/s.

External threats are handled by a firewall at the point of presence (PoP);

– Supports all types of IPv4 addressing, i.e. static, dynamic and private addressing. Also supports the future Internet addressing type, IPv6.

Prime advantages

– The IP network services are transparently forwarded to Internet and the destination site.

– Complies with useful and important standards like IEEE 802.1q (VLAN), IEEE 802.3x (Congestion control) and ETSI EN 301 253 (FH-CDMA).

– Cost-efficiently scalable expansions of the operators network services.

– Rapid deployment.

– Integrated voice and data solution.

Applications

– Urban and suburban area.

– "Last mile" connectivity.

Service provisioning

– IP access providers

– Cellular operators

– Competitive local operators (CAP, CLEC) (Competitive access providers, competitive local exchange carriers)

– FWA operators

5 Alcatel's 7390 LMDS broadband wireless access system

5.1 General

The Alcatel 7390 LMDS family meets the need for a broadband point-to-multipoint fixed wireless access system which can be used by both incumbent and new telecom operators, cable TV system operators, and other wireless network providers. It can be deployed as part of a fully integrated network solution which includes:

– synchronous digital hierarchy (SDH)/synchronous optical network (SONET) transmission technologies (fiber or radio) and ATM-based services

– narrow-band/broadband switches.

– broadband remote access node (RAN).

– cellular/wireless local access products.

– voice interconnection systems, such as SS7, V5.2 and TR-303

– fully integrated network and service management.

The Alcatel LMDS has been designed with a flexible channel allocation which supports a wide range of radio frequency variants with very high frequency re-use. The multiple access scheme used by the system is TDMA.

The Alcatel LMDS enables service providers to cater for the small to medium business user (SME), either in a single or multi-tenant building, as well as the SOHO and even residential user in a multiple dwelling complex. Voice, data and IP based services can be offered simultaneously and cost effectively.

Service interfaces provide nxE1/T1, clear E1/T1, ISDN/POTS and Ethernet 10BaseT for enhanced IP service support.

Multiple network termination devices can be connected to a single customer site radio to increase the service port density. At the base station site, or central office interfaces to the data network are provided, either via ATM or high density TDM. Concentrated switched services can be connected to Class 5 PSTN offices via GR303 or V5.2, further reducing the cost of capital equipment and operational expense.

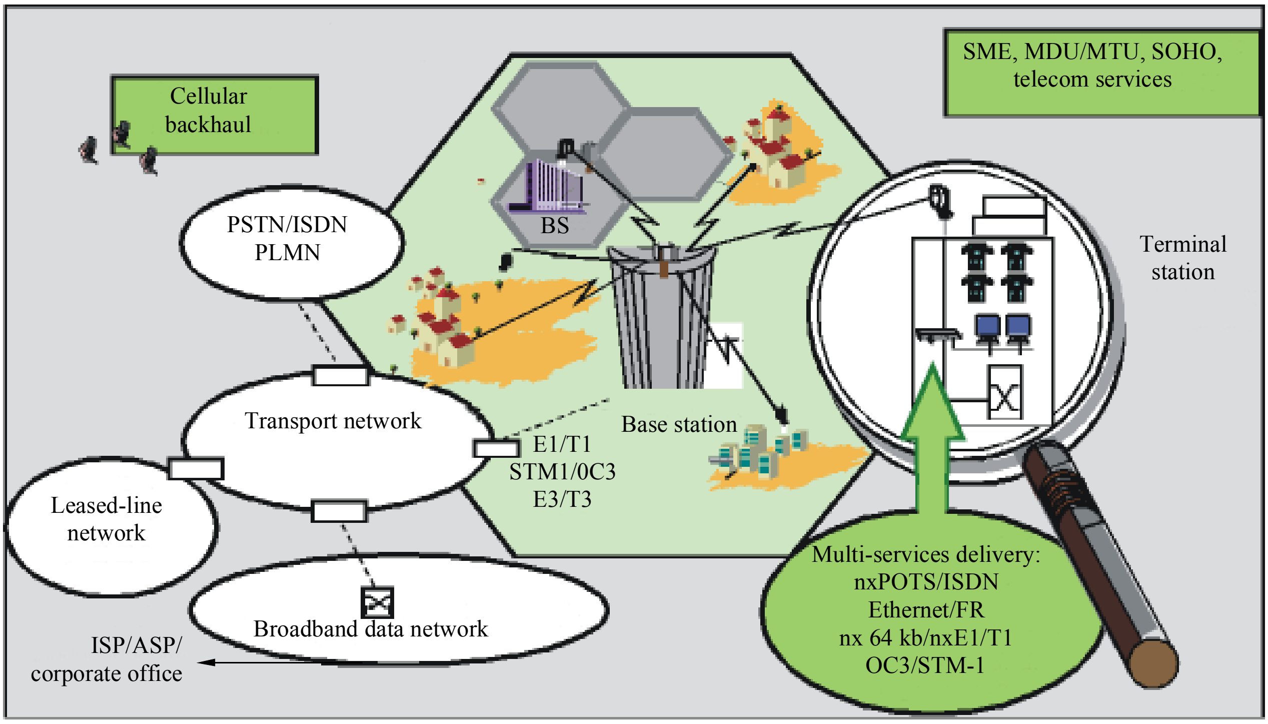
The Alcatel LMDS solution also offers switched voice solution with an SS7 interface.

5.2 Architecture

The Alcatel LMDS solution is a point-to-multipoint system designed to give an architecture for broadband connection in urban environment. The system is installed with a common base station (BS) and many distributed customer terminal stations (TS).

FIGURE 62

Application model



The BS utilizes sector antennas to achieve cell coverage and the TS uses a small size parabolic antenna to access the BS.

Base Stations act as hubs, transmitting the telephone, data and IP based services to the customers over a line of sight range of approx. 4 km at maximum.

The Alcatel LMDS key sub-system features are:

– Cellular type network interconnected with PSTN/ISDN/PLMN/leased-line/broadband networks.

– Base stations with split mounted indoor-outdoor architecture.

– Terminal stations with split mounted indoor-outdoor architecture, and the possibility to connect several network Termination (NT: indoor units) to the same radio termination (RT: outdoor unit).

A simple network is made up of:

– multiple terminal stations: Each customer is equipped with a TS which provides the access and adaptation required for the system, customers are installed using unobstructed, clear line-of-sight (LOS) radio links to the respective host base station.

– a base station: The BS serves many TSs from a central location with line of sight to the TSs. The BS provides the appropriate interfaces between the radio access and the backbone networks together with the management centre,

– a management center common to multiple cells. The management center provides the interfaces for the operator.

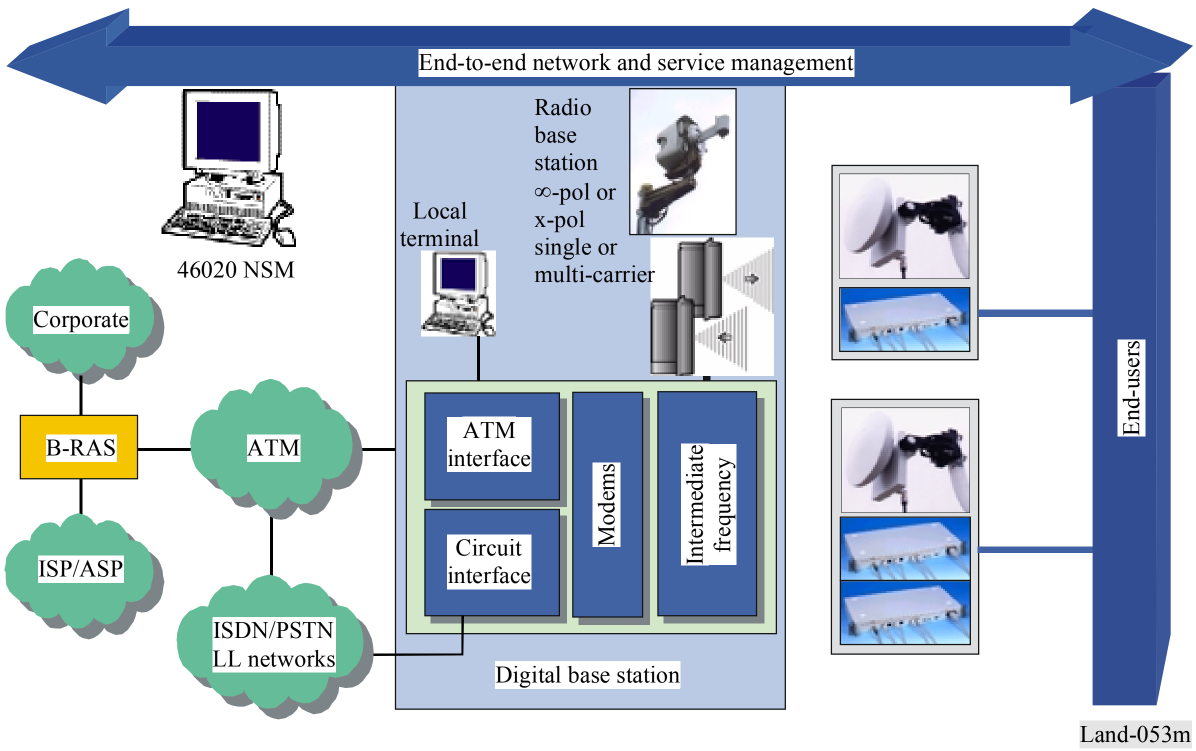
5.3 Technical characteristics

5.3.1 System description

The complete system is illustrated in the following figure:

FIGURE 63

System characteristics



5.3.2 Network interfaces

These interfaces are used for interconnection either to the broadband data network, the leased-line network or the PSTN/ISDN, they are of two types: ATM or G703.

5.3.2.1 Bursty data traffic

The data oriented traffic is sent on an ATM interface, generally through an ATM switched network either to a router or to an broadband RAN (remote access node).

Permanent virtual circuits (PVC) are used between the network terminations and the router or the broadband (RAN) using the bridged mode encapsulation (RFC 1483) which enables IP and IPx types of traffic.

5.3.2.2 Circuit oriented traffic

Access to the network for both telephony and leased line services is using E1 or T1 interface.

Physically the interfaces can be provided either on dedicated T1/E1 interfaces complying with ITU-T Recommendation G.703 (1 544 kbit/s for T1 or 2 048 kbit/s for E1), or sent through an ATM interface to an ATM switch, which must be equiped with CEM board (Circuit Emulation over ATM).

For leased lines, the system establishes a permanent radio link between the base station and the terminal station Network Termination (NT) on which the leased line is declared. The radio system is fully transparent to the type of traffic carried.

For telephony, the access to the PSTN or ISDN telephone networks is carried out via the n x E1/T1 concentrated interface supporting V5.2 or GR303, through the optional sub-system elements. For SS7 telephony an external gateway is utlised.

5.3.3 Subscriber interfaces

The Alcatel LMDS solution is a multi-service platform offering a mix of leased line, switched voice, ISDN and IP based services.

TABLE 10

Subscriber interfaces

Telephony	POTS :
	ITU-T G.713
	ISDN BA 2B+D U interface:
	ITU-T G961
	ISDN PRI:
	ETS 300011
Signalling	V5.2
DATA	Ethernet 10 Base T
E1	G.703
	X21
ATM	STM1/0C3
	ITU-T G709
	PVC

5.3.4 Radio interface

5.3.4.1 Frequency plans

The Alcatel LMDS system is developed in several frequency bands in order to accomodate regional and/or national requirements. The following table gives the main specifications of the frequency plans.

TABLE 11

Frequency plans

Frequency Band	Freqency Range & Duplex	Region
26 GHz CEPT ERC T/R13-02	24.5-26.5 GHz 1 008 MHz duplex	Region 1
28 GHz CEPT ERC T/R13-02	27.5-29.5 GHz 1 008 MHz duplex	Region 1
26 GHz Japan	25.25-27 GHz 855 MHz duplex	Japan
25 GHz Korea	24.3-26 GHz 1 480 MHz duplex	Korea
LMCS A-F US LMDS A (sym)	25.35-28.35 GHz 500 MHz block	Pacific Rim, Canada, USA, Latin America
US LMDS A (asym)	25.35-28.35 GHz 31.075-31.225 GHz	USA
24 GHz	24.25-25.25 GHz 800 MHz duplex	USA, Canada
31 GHz (US LMDS B)	31-31-075 GHz 31.225-31.3 GHz 225 MHz duplex	USA
38 GHz	38.6-39.3 GHz 39.3-40 GHz 700 MHz duplex	USA, Canada, South America

5.3.4.2 RF physical layer

The air interface complies with the DAVIC 1.2 Specification Part 8, Lower layer Protocols and Physical Interfaces.

It uses the frequency division duplex (FDD) mode to separate the outward and return channels. This return channel is divided into up to four sub-channels: a terminal station can access any of these channels, with the choice made by the MAC protocol. The downlink uses time division multiplex in which the basic circuit is not the byte but the ATM cell. The uplink uses a TDMA access mode superposed over the channel selection FDM mode.

5.3.4.3 Carrier bandwidths supported

The Alcatel LMDS wireless access system supports the following carrier bandwidths;

– Downstream: 14, 21, 28, 36 MHz

– Upstream: 3.5, 7, 9 MHz

5.3.4.4 Radio transmission characteristics

The following tables give the frame rate and period chosen for the Alcatel LMDS system as the main radio characteristics:

TABLE 12

Radio characteristics – downlink

	Down-stream			
Channel bandwidth	14 MHz		28 MHz	
Occupied bandwidth	13.63 MHz		27.25 MHz	
Roll-off factor	35%		35%	
Modulation	QPSK		QPSK	
Gross bit rate	20.19 Mbit/s		40.37 Mbit/s	
	25 GHz	28 GHz	25 GHz	28 GHz
BS output power* (antenna port)	17 dBm	17 dBm	17 dBm	17 dBm
Tx antenna gain*	15 dB	15 dB	15 dB	15 dB
Rx antenna gain*	35 dB	34.5 dB	35 dB	34.5 dB
RF Rx level for BER* @ 10^{-6}	-84 dBm	-84 dBm	-81 dBm	-81 dBm
* Typical values One down-stream carrier is combined with up to four up-stream carriers.				

TABLE 13

Radio characteristics – uplink

	Upstream			
Channel bandwidth	3.5 MHz		7 MHz	
Occupied bandwidth	3.36 MHz		6.72 MHz	
Roll-off factor	25%		25%	
Modulation	D-QPSK		D-QPSK	
Gross bit rate	5.38 Mbit/s		10.75 Mbit/s	
	25 GHz	28 GHz	25 GHz	28 GHz
TS output power* (antenna port)	14 dBm	14 dBm	14 dBm	14 dBm
Tx antenna gain*	35 dB	34.5 dB	35 dB	34.5 dB
Rx antenna gain* (with radome)	15 dB	15 dB	15 dB	15 dB
RF Rx level for BER* @ 10^{-6}	-86.1 dBm	-86.1dBm	-83 dBm	-83 dBm
* Typical values				

ANNEX 8

Wireless access to the Internet

Internet over wireless issues

References

1 Internet Engineering Task Force draft memo on "Long Thin Networks" 26 February 1998.

1 Introduction

With the explosive growth of the Internet, wireless access to the Internet will likely become a major driving force for the industry. This can be seen in recent developments in standards activities related to second- and third-generation personal communications, fixed wireless access, broadband wireless access and satellite services.

Optimized wireless networking is one of the major hurdles that must be solved if ubiquitous access to networking resources is to develop. However, current data networking protocols have been optimized primarily for wired networks. Wireless environments have very different characteristics in terms of latency, jitter, and error rate as compared to wired networks. Accordingly, traditional protocols are ill-suited to this medium and wireless raises new issues to be addressed in standardization forums.

IP-based wireless networks can be grouped into:

– wireless local area networks (W-LANs - for example, IEEE 802.11 compliant networks);

– wireless wide area networks (W-WANs - for example, IMT-2000);

– broadband wireless access networks (BWA - for example local multipoint distribution systems (LMDS);

– satellite networks.

BWA and W-WANs present the most serious challenges, given that the length of the wireless link is typically 4 to 5 times as long as that of their W-LAN counterparts. Satellite causes different issues due to their much greater link lengths. In the near future, 3rd Generation wireless services will offer mobility at 384 kbit/s and more, whereas satellite and BWA may offer >10 Mbit/s for fixed users. The required buffer for many of these is larger than the default 8 kbyte buffer space used by many TCP implementations. This means that, whereas for W-LANs the default buffer space is enough, future systems will operate inefficiently (that is, they will not be able to fill the pipe) unless they override the default value. A 3rd Generation wireless service offering 2 Mbit/s with 200-millisecond latency requires a 50 kbyte buffer. Most importantly, latency across a link adversely affects throughput. The long latencies also push the limits (and commonly transgress them) for what is acceptable to users of interactive applications.

A typical architecture includes:

– a wireless terminal device (possibly mobile), connected via

– a wireless link (which may, in fact comprise several hops at the link layer), to

– a base station (sometimes referred to as an intermediate agent or node) connected via

– a wireline link, which in turn interfaces with

– the landline Internet and millions of legacy servers and web sites.

Although this architecture is not concerned with paths that include two wireless segments separated by a wired one, this may occur, for example, if one mobile device connects across its immediate wireless segment via a base station to the Internet, and then via a second wireless segment to another terminal device. Quite often, mobile devices connect to a legacy server on the wired Internet. Typically, the endpoints of the wireless segment are the base station and the mobile device. However, the latter may be a wireless router to a mobile network. This is also important and has applications in, for example, disaster recovery.

The target architecture has implications which concern the deployability of candidate solutions. In particular, an important requirement is that the networking stack on the legacy servers cannot be altered. It would be preferable to only change the networking stack at the base station, although changing it at the user devices is certainly an option and perhaps a necessity.

Mobile devices can be envisioned that can use the wireless medium very efficiently, but overcome some of its traditional constraints. Full mobility will enable terminal devices to have the flexibility and agility to use whichever happens to be the best network connection available at any given point in time or space. Accordingly, devices may be able to switch from a wired office LAN and hand over their ongoing connections to continue on, say, a wireless WAN. This type of agility also requires Mobile IP.

The following issues need to be considered:

– What are the error characteristics of the wireless medium? The link may present a higher BER than a wireline network due to burst errors and disconnections.

  1) higher BER due to random errors (which implies longer and more variable delays due to link-layer error corrections and retransmissions)

  2) an interruption in service due to a handover or a disconnection.

– Is the wireless service datagram oriented, or is it a virtual circuit? Currently, switched virtual circuits are more common, but packet networks are starting to appear, for example, LMDS, CDPD and General Packet Radio Service (GPRS) in GSM.

– What kind of reliability does the link provide? Wireless services typically retransmit a packet (frame) until it has been acknowledged by the target. They may allow the user to turn off this behaviour. For example, GSM allows RLP (radio link protocol) to be turned off. In GSM RLP, a frame is retransmitted until the maximum number of retransmissions (protocol parameter) is reached. What happens when this limit is reached is determined by the telecom operator: the physical link connection is either disconnected or a link reset is enforced where the sequence numbers are resynchronized and the transmit and receive buffers are flushed resulting in lost data. Some wireless services, like CDMA IS95-RLP, limit the latency on the wireless link by retransmitting a frame only a couple of times. This decreases the residual frame error rate significantly, but does not provide fully reliable link service.

– Does the user device transmit and receive at the same time? Doing so increases the cost of the electronics on the user device. Typically, this is not the case in WANs, but is typical for BWA.

– Does the user device directly address more than one peer on the wireless link? Packets to each different peer may traverse spatially distinct wireless paths. Accordingly, the path to each peer may exhibit very different characteristics. Quite commonly, the user device addresses only one peer (the base station) at any given point in time. When this is not the case, techniques such as channel-state dependent packet scheduling come into play.

Should it be IP or not?

The first decision is whether to use IP as the underlying network protocol or not. In particular, some data protocols evolved from wireless telephony are not always - though at times they may be - layered on top of IP. These proposals are based on the concept of proxies that provide adaptation services between the wireless and wireline segments.

This is a reasonable model for user devices that always communicate through the proxy. However, many wireless user devices are expected to utilize wireline networks whenever they are available. This model closely follows current laptop usage patterns: devices typically utilize LANs, and only resort to dial-up access when "out of the office."

For these devices, an architecture that assumes IP is the best approach, because it will be required for communications that do not traverse the base station (for example, upon reconnection to a W-LAN or a 10BaseT network at the office).

Underlying network error characteristics

Using IP as the underlying network protocol requires a certain (low) level of link robustness that is expected of wireless links and may be typical of BWA, but not WANs.

IP, and the protocols that are carried in IP packets, are protected end-to-end by checksums that are relatively weak (and, in some cases, optional). For much of the Internet, these checksums are sufficient; in wireless environments, the error characteristics of the raw wireless link are much less robust than the rest of the end-to-end path. Hence for paths that include wireless links, exclusively relying on end-to-end mechanisms to detect and correct transmission errors is undesirable. These should be complemented by local link-level mechanisms. Otherwise, damaged IP packets are propagated through the network only to be discarded at the destination host. For example, intermediate routers are required to check the IP header checksum, but not the UDP or TCP checksums. Accordingly, when the payload of an IP packet is corrupted, this is not detected until the packet arrives at its ultimate destination.

A better approach is to use link-layer mechanisms such as FEC, retransmissions, and so on in order to improve the characteristics of the wireless link and present a much more reliable service to IP. This approach has been taken by CDPD, Ricochet and CDMA.

This approach is roughly analogous to the successful deployment of point-to-point protocol (PPP), with robust framing and 16-bit check summing, on wireline networks as a replacement for the serial line interface protocol (SLIP), with only a single framing byte and no checksumming.

The use of FEC is recommended in satellite environments.

Notice that the link-layer could adapt its frame size to the prevalent BER. It would perform its own fragmentation and reassembly so that IP could still enjoy a large enough MTU size.

A common concern for using IP as a transport is the header overhead it implies. Typically, the underlying link-layer appears as PPP to the IP layer above. This allows for header compression schemes which greatly alleviate the problem.

Non-IP alternatives

A number of non-IP alternatives aimed at wireless environments have been proposed. One representative proposal is discussed here.

Wireless application protocol (WAP)

The WAP specifies an application framework and network protocols for wireless devices such as mobile telephones, pagers, and PDAs. The architecture requires a proxy between the mobile device and the server. The WAP protocol stack is layered over a datagram transport service. Such a service is provided by most wireless networks; for example, IS-136, GSM SMS/USSD, and UDP in IP networks like CDPD and GSM GPRS. The core of the WAP protocols is a binary HTTP/1.1 protocol with additional features such as header caching between requests and a shared state between client and server.

Deploying non-IP alternatives

IP is such a fundamental element of the Internet that non-IP alternatives face substantial obstacles to deployment, because they do not exploit the IP infrastructure. Any non-IP alternative that is used to provide gateway access to the Internet must map between IP addresses and non-IP addresses, must terminate IP-level security at a gateway, and cannot use IP-oriented discovery protocols (Dynamic host configuration protocol, domain name services, lightweight directory access protocol, service location protocol, etc.) without translation at a gateway.

A further complexity occurs when a device supports both wireless and wireline operation. If the device uses IP for wireless operation, uninterrupted operation when the device is connected to a wireline network is possible (using mobile IP). If a non-IP alternative is used, this switchover is more difficult to accomplish.

Non-IP alternatives face the burden of proof that IP is so ill-suited to a wireless environment that it is not a viable technology.

IP-based alternatives

Given its worldwide deployment, IP is an obvious choice for the underlying network technology. Optimizations implemented at this level benefit traditional Internet application protocols as well as new ones layered on top of IP or UDP.

Path MTU discovery

Path MTU discovery benefits any protocol built on top of IP. It allows a sender to determine what the maximum end-to-end transmission unit is to a given destination. Without path MTU discovery, the default MTU size is 512. The benefits of using a larger MTU are:

– Smaller ratio of header overhead to data.

– Allows TCP to grow its congestion window faster, since it increases in units of segments.

Of course, for a given BER, a larger MTU has a correspondingly larger probability of error within any given segment. The BER may be reduced using lower level techniques like FEC and link-layer retransmissions. The issue is that now delays may become a problem due to the additional retransmissions, and the fact that packet transmission time increases with a larger MTU.

Path MTU Discovery is recommended in satellite environments.

Non-TCP (transmission control protocol) proposals

Other proposals assume an underlying IP datagram service, and implement an optimized transport either directly on top of IP or on top of UDP. Not relying on TCP is a bold move, given the wealth of experience and research related to it. It could be argued that the Internet has not collapsed because its main protocol, TCP, is very careful in how it uses the network, and generally treats it as a black box assuming all packet losses are due to congestion and prudently backing off. This avoids further congestion.

However, in the wireless medium, packet losses may also be due to corruption due to high BER, fading, and so on. Here, the right approach is to try harder, instead of backing off.

The case for TCP

This is one of the most hotly debated issues in the wireless arena. Here are some arguments against it:

– It is generally recognized that TCP does not perform well in the presence of significant levels of non-congestion loss. TCP detractors argue that the wireless medium is one such case, and that it is hard enough to fix TCP. They argue that it is easier to start from scratch.

– TCP has too much header overhead.

– By the time the mechanisms are in place to fix it, TCP is very heavy, and ill-suited for use by lightweight, portable devices.

and here are some in support of TCP:

– It is preferable to continue using the same protocol that the rest of the Internet uses for compatibility reasons. Any extensions specific to the wireless link may be negotiated.

– Legacy mechanisms may be reused (for example congestion control).

– Link-layer FEC and ARQ can reduce the BER such that any losses TCP does see are, in fact, caused by congestion (or a sustained interruption of link connectivity). Modern W-WAN technologies do this (CDPD, US-TDMA, CDMA, GSM), thus improving TCP throughput.

– Handoffs among different technologies are made possible by Mobile IP, but only if the same protocols, namely TCP/IP, are used throughout.

– Given TCP's wealth of research and experience, alternative protocols are relatively immature, and the full implications of their widespread deployment not clearly understood.

Overall, the performance of TCP over long-thin networks can be improved significantly.

ANNEX 9

REFERENCES

1 Standards

The short forms of relevant standards are as follows:

Rec. ITU-R F.1244, "Radio Local Area Networks"

Rec. ITU-R F.1399, "Vocabulary of terms for wireless access"

Rec. ITU-R F.1400, "Performance and availability requirements and objectives for fixed wireless access to public switched telephone network"

Rec. ITU-R F.1401, "Frequency bands for fixed wireless access systems and the identification methodology"

Rec. ITU-R F.1402, "Frequency sharing criteria between a land mobile wireless access system and a fixed wireless access system using the same equipment type as the mobile wireless access system"

Rec. ITU-R F.1488, "Frequency block arrangements for fixed wireless access (FWA) systems in the range 3 400-3 800 MHz"

Rec. ITU-R F.1489, "A methodology for assessing the level of operational compatibility between fixed wireless access (FWA) and radiolocation systems when sharing the band 3.4-3.7 GHz"

Rec. ITU-R F.1490, "Generic requirements for Fixed Wireless Access (FWA) applications"

Rec. ITU-R F.1499, "Radio transmission systems for fixed broadband wireless access (BWA) based on cable modem standards"

Draft new Recommendation ITU-R **F.[9/BL/2]**, "Spectrum requirement methodology when fixed wireless access (FWA) and mobile wireless access (MWA) networks using the same type of equipment coexist in the same frequency band"

Rec. ITU-R P.837, "Characteristics of precipitation for propagation modelling"

Rec. ITU-R P.838, "Specific attenuation model for rain for use in prediction methods"

Rec. ITU-R P.530, "Propagation data and prediction methods required for the design of terrestrial line-of-sight systems"

Rec. ITU-R M.1073, "Digital cellular land mobile telecommunication systems"

Rec. ITU-R M.1033, "Digital and operational characteristics of cordless telephones and cordless telecommunication systems"

Rec. ITU-R M.1450, "Characteristics of broadband radio local area networks (RLANs)"

Rec. ITU-R M.1454, "E.i.r.p. density limit and operational restrictions for RLANs or other wireless access transmitters in order to ensure the protection of feeder links of non-geostationary systems in the mobile-satellite service in the frequency band 5 150-5 250 MHz"

ITU-T Rec. G.703, "Physical/electrical characteristics of hierarchical digital interfaces"

ANSI J-STD-007, "Air interface specification for 1.8 to 2.0 GHz frequency hopping time division multiple access (TDMA) for personal communications services"

ANSI J-STD-008, "Personal Station - Base station compatibility requirements for 1.8 to 2.0 GHz Code Division Multiple Access (CDMA) personal communications systems"

ANSI J-STD-009, "PCS IS-136 based mobile station minimum performance 1 900 MHz standard"

ANSI J-STD-010, "PCS IS-136 based base station minimum performance 1 900 MHz standard"

ANSI J-STD-011, "PCS IS-136 based air interface compatibility 1 900 MHz standard"

ANSI J-STD-017 (Trial Use) and EIA/TIA/IS-661, "A composite CDMA/TDMA air interface compatibility standard for personal communications in 1.85-1.99 GHz for licensed applications"

ANSI J-STD-018, "Recommended minimum performance requirements for 1.8 to 2.0 GHz code division multiple access (CDMA) personal stations"

ANSI J-STD-019, "Recommended minimum performance requirements for base stations supporting 1.8 to 2.0 GHz code division multiple access (CDMA) personal stations"

EIA/TIA/IS-95-A, "Mobile station-base station compatibility standard for dual-mode wideband spread spectrum cellular system"

United Kingdom Total Access Communications System Compatibility Specification, ISSUE 4 (TACS Specification)

EIA/TIA 553, "Mobile Station - Land Station Compatibility Specification" (AMPS Specifications).

ETSI Standards - ETS 300 500 series and 700 series "Digital cellular telecommunications system (GSM xy.uv)"

ETSI draft European standard EN 301 021, 1997 "Transmission and Multiplexing (TM); Digital Radio-Relay Systems (DRRS); Time Division Multiple Access (TDMA) point-to-multipoint DRSS in the frequency range 3 to 11 GHz"

RCR STD-28, "Personal Handy Phone System". RCR Standard STD-28 ver.2

TTC JT-Q921-b, "PHS Public Cell Station - Digital Network interface Layer 2 - Specification". TTC Standard JT-Q921-b

TTC JT-Q931-b, "PHS Public Cell Station - Digital Network interface Layer 3 - Specification". TTC Standard JT-Q931-b

TTC JT-G961, "Digital Transmission System on Metallic Local Lines for ISDN Basic Rate Access". TTC Standard JT-G961

C-IF1.00, "General Description of Interface Specifications between Terminal Equipment and WLL subscriber Unit". PHS MoU Document C-IF1.00

C-IF2.00, "General Description of Interface Specifications between WLL subscriber Unit of WLL Personal Station and WLL Cell Station". PHS MoU Document C-IF2.00

C-IF3.00, "General Description of Interface Specifications between WLL Access Controller and Service Node". PHS MoU Document C-IF3.00

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ALPHABETICAL INDEX

NOTES	
Abbreviations:	When abbreviations are not explained in this alphabetical index, see "Terminology and acronyms" in Annex 1.
Numbering:	References giving a full numbering indicate the precise sub-section referred to. Whenever the number is less precise, the quoted term may appear throughout the referred section or sub-section.
Frequent words:	Some terms may appear frequently throughout the handbook and they are only quoted for the their first or most significant locations.

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