Handbook

Land Mobile – Volume 5

Deployment of Broadband Wireless Access Systems

English Edition 2011
Radiocommunication Bureau

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Handbook

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Foreword

Broadband wireless access (BWA) systems allow for wireless access to data networks, with high data rates that can be used to deliver a wide range of services such as voice, data, voice-over-IP, and video services to businesses, homes or users on the move regardless of their location. In other words, the term broadband wireless access encompasses the full range of wireless technologies and applications for the delivery of fixed and mobile services. BWA is an effective and increasingly popular Information and Communication Technology (ICT). Access to broadband Internet can increase productivity and contribute to economic growth, for which broadband deserves a central role in development strategies.

This is the fifth volume of the Handbook on Land Mobile (including Wireless Access). The development of this multi-volume Handbook was started in the late 1990s within the ITU-R to meet an increasing need by the developing countries for a handbook on state of the art technologies covering the various aspects of the Land Mobile Service; including technologies and systems. The four volumes that have already been published to-date are:

– Volume 1 – Fixed Wireless Access.
– Volume 2 – Principles and Approaches on Evolution to IMT-2000/FPLMTS.
– Volume 3 – Dispatch and Advanced Messaging Systems.
– Volume 4 – Intelligent Transport Systems.

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

The specific purpose and scope of Volume 5 is to provide information on state-of-the-art technologies in terrestrial nomadic and mobile BWA systems, applications and technologies. It includes coverage of the societal economic benefits of broadband, services, trends and applications, technology including system topologies, architecture and standards, operational requirements in particular frequency needs and spectrum needs for operators to be able to deploy BWA systems, guidance on regulatory issues, and system deployment guidelines including the design of BWA deployments for profitability.

Volume 5 has been developed by a group of experts of Radiocommunication Working Party 5A. I wish to express my appreciation to the two Land Mobile Handbook Rapporteurs who led the development of this volume, Ms. Reema Hafez (Canada) who initiated it, and Dr. Gabrielle Owen (The Netherlands) who brought it to completion, and to the skilful editor for this volume, Ms. Justine Sider (Canada), as well as to all the experts who contributed to the development of the Handbook.

José M. Costa
Chairman, Radiocommunication Working Party 5A
Canada

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CHAPTER 1

INTRODUCTION

1.1 Purpose and scope of Handbook on Land Mobile

The Land Mobile Handbook has been developed to meet an increasing need by developing countries for a handbook on state of the art technologies covering various technologies and systems in the Land Mobile Service. The Handbook is organized in several volumes, four of which have already been published:

– Volume 1 – Fixed Wireless Access, (http://www.itu.int/pub/R-HDB-25/en).
– Volume 2 – Principles and Approaches on Evolution to IMT-2000/FPLMTS, (http://www.itu.int/pub/R-HDB-30/en).
– Volume 3 – Dispatch and Advanced Messaging Systems, (http://www.itu.int/pub/R-HDB-47/en).
– Volume 4 – Intelligent Transport Systems, (http://www.itu.int/pub/R-HDB-49/en).

The purpose of the Handbook is to assist in the decision making process involving planning, engineering and deployment of wireless based land mobile systems, especially in developing countries. It provides information that will assist in training engineers and planners in regulating, planning, engineering, and deployment aspects of these systems. The Handbook covers land mobile applications including, vehicular communications, in-building communication, out-of-building communication, as well as others such as Intelligent Transport Systems (ITS) applications. Systems covered encompass cellular-based systems, messaging systems, dispatch systems, fixed wireless access, as well as ITS.

The users of this Handbook are likely to fall into one of two categories. The first category includes decision makers and planners who would like the Handbook to provide them with enough information to aid in decision-making on system choices as far as their suitability to meet their 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, investments, regulation and policies, deployment strategies, short and long term implications, as well as other elements that are required for decision-making and planning purposes. The main body of Volume 5, in particular, is addressed to this category of readers, providing information of a general nature applicable to many types of broadband wireless access systems.

For the second category of users, engineers, the Handbook provides more in depth technical information on the characteristics of the various standards, systems and applications, systems design, traffic analysis and estimation, spectrum estimation, cell design, examples of deployment, as well as other pertinent information. The detailed information is organized into specific topics and it is provided in the annexes of Volume 5.

1.2 Background

The specific purpose and scope of Volume 5 is to provide information on state-of-the-art technology in terrestrial nomadic and mobile broadband wireless access (BWA) systems, applications and technologies.

Broadly defined, BWA systems allow for wireless access to data networks, with high data rates and as such can be used to deliver a range of services such as voice, data, voice-over-IP, and video services to businesses, homes or users on the move, whether inside or outside. In other words, the term broadband wireless access encompasses the full range of wireless technologies and applications for the delivery of fixed and mobile services.

From the point of view of connectivity, BWA is the equivalent of "last-mile" broadband wired access, such as ADSL or cable modems. However, where the "last mile" has a geographically fixed end-point for fixed BWA systems, in nomadic or mobile BWA systems, there is no fixed end-point. Users have freedom of movement.

Fixed BWA systems such as Multichannel Multipoint Distribution Service (MMDS) began to be deployed in the 1990s for fixed applications and these were described in Volume 1 of the Land Mobile Handbook (including wireless access).

Today, advances in technology have enabled the transition from fixed to nomadic and mobile BWA applications that serve a variety of user and application needs. Moreover, the trend in mobile BWA systems is toward small, portable terminals that allow for the convergence and delivery of a number of applications from voice to video within a local or metropolitan area network. These applications and systems are the subject of this volume.

The ITU calls for broadband Internet access for half the world's population by 2015[1]. The 9th edition of the ITU World Telecommunication/ICT Development Report (WTDR 2010) provides a mid-term review of the progress made in creating a global information society by 2015. The report reviews each one of the ten targets agreed upon by governments at the World Summit on the Information Society (WSIS). These targets range from connecting villages, schools, health centres and hospitals, scientific and research centres, libraries and government agencies to information and communication technologies, as well as developing online content[2].

Recognizing the importance of mobile broadband, the ITU and UNESCO announced[3] on 10 May 2010 the establishment of a top level Broadband Commission for Digital Development[4] which will define strategies for accelerating broadband rollout worldwide and examine applications that could see broadband networks improve the delivery of a huge range of social services, from healthcare to education, environmental management, safety and much more. The Broadband Commission reported its findings to United Nations Secretary-General Ban Ki-moon in September 2010, immediately before the summit in New York to review work on achieving the Millennium Development Goals by the target date of 2015. The initial outcomes of the Broadband Commission for Digital Development include two Reports (Available at: http://www.itu.int/net/pressoffice/press_releases/2010/33.aspx):

– "Broadband: A Leadership Imperative": it is a concise, high-level Report. Available at: http://www.broadbandcommission.org/report1.pdf
– "Broadband: A Platform for Progress" is a comprehensive analytical report that looks at financing models, return on investment, technology choices, and strategies for deployment across a range of different types of economies. Available at: http://www.broadbandcommission.org/report2.pdf

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1 *ITU News*, 5/2010, Special Edition for the World Telecommunications Development Conference (WTDC-10), June 2010, p. 12-16. Available at: http://www.itu.int/net/itunews/issues/2010/05/12.aspx

2 9th edition of the ITU World Telecommunication/ICT Development Report (WTDR 2010), launched at the World Telecommunication Development Conference 2010 (WTDC-10), in Hyderabad, India. Available at: http://www.itu.int/publ/D-IND-WTDR-2010/en

3 http://www.broadbandcommission.org/media/pressrelease_10may2010.pdf

4 http://www.broadbandcommission.org/

1.3 Societal economic benefits of broadband[5]

BWA is an effective and increasingly popular Information and Communication Technology (ICT). Access to broadband Internet can increase productivity and contribute to economic growth, for which broadband deserves a central role in development strategies. Broadband networks (both fixed and mobile) are necessary to deliver modern communication and information services that require high rates of data transmission. Enterprise file transfer, television and high-speed Internet are examples of such services. High-speed Internet connections provide ready access to a wide range of services, such as voice, video, music, film, radio, games, and publishing.

Broadband networks enhance the efficiency and reach of existing services and provide additional capacity for future applications. Indeed, broadband networks are key to the ongoing transformation of the ICT sector through the convergence of telecommunications, media and computing. The convergence process may comprise:

– Service convergence, which enables providers to use a single network to provide multiple services.
– Network convergence, which allows a service to travel over any combination of networks.
– Corporate convergence, by means of which firms merge or collaborate across sectors.

Driven by technology and demand, convergence is resulting in major changes in market structures and business models.

There is growing evidence that broadband has a considerable economic impact for individuals, firms, and communities. Individuals increasingly use broadband to acquire knowledge and skills to increase their employment opportunities. Where broadband has been introduced in rural areas of developing countries, villagers and farmers have gained better access to crop market prices, training, and job opportunities. In developed countries and urban areas in developing countries, an increasing number of individuals are building up social networks through broadband-enabled, peer-to-peer web-based groups that facilitate economic integration and drive development. Blogs (web logs, or online diaries), wikis (websites where users can contribute and edit content), video-sharing sites, and the like allow new, decentralized, and dynamic approaches to capturing and disseminating information that enable individuals to become better prepared for the knowledge economy [Johnson, Manyika and Yee, 2005].

Access to broadband can also support the growth of firms by lowering transaction costs and raising productivity. Realizing these performance improvements, however, depends on firm's ability to integrate their technological, business and organizational strategies. When fully absorbed, broadband drives intense, productive uses of online applications and services, making it possible to improve processes, introduce new business models, drive innovation and extend business links. A study involving business and technology decision makers in 1 200 companies in six Latin American countries – Argentina, Brazil, Chile, Colombia, Costa Rica and Mexico – showed that broadband deployment was associated with considerable improvements in business organization, including the speed and timing of business and process reengineering, process automation, data processing and diffusion of information within organizations [Momentum Research Group, 2005].

Firms in the media, export, and other information intensive sectors have benefited most from integrating broadband into their business processes. Clarke and Wallsten [2006] undertook a study

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5 The contents of this section are based on a publication by the World Bank: *Information and Communications for Development 2009: Extending Reach and Increasing Impact,* World Bank (2009); in particular, Chapter 3 by Christine Zhen-Wei Qiang and Carlo M. Rossotto with Kaoru Kimura, "Economic Impacts of Broadband". Available at: http://go.worldbank.org/NATLOH7HV0

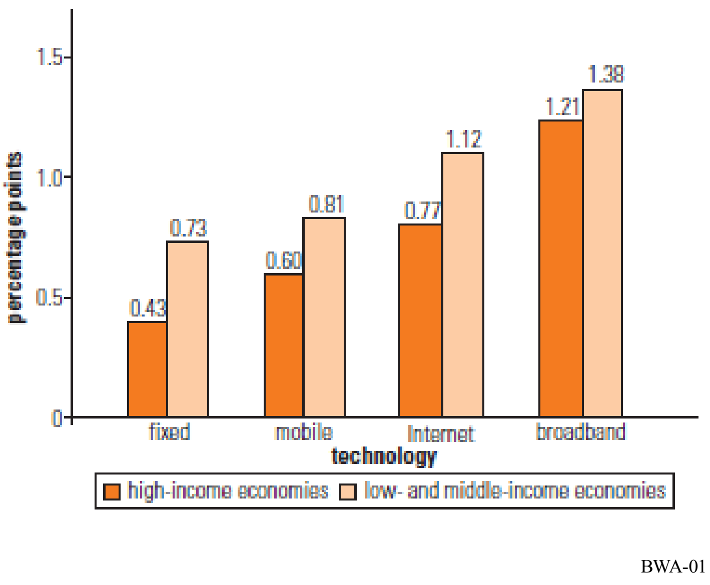
of 27 developed and 66 developing countries, in which they found that a 1 percentage-point increase in the number of Internet users is correlated with a rise in exports of 4.3 percentage points. Increases of 25% or more in the efficiency of claims processed per day have been documented by U.S. insurance companies that have adopted wireless broadband [Sprint, 2006]. Other industries that have benefited significantly from access to broadband include consulting, accounting, marketing, real estate, tourism and advertising.

Local communities around the world have realized considerable economic gains and new opportunities from broadband services. Studies from Canada, the United Kingdom, and the United States of America have suggested that broadband connectivity has a positive economic impact on job creation, community retention, retail sales, and tax revenues [Ford and Koutsky, 2005; Kelly, 2004; Strategic Networks Group 2003; Zilber, Schneier and Djwa, 2005]. In rural areas of developing countries, communities have recently begun to launch broadband services and applications giving local populations access to new markets and services. Facilitating information exchange and value creation between buyers and sellers of agricultural products, which has improved income and livelihoods in rural areas, is one prime example of this. Previously, such opportunities were available only in the largest or wealthiest localities.

According to a recent World Bank econometric analysis of 120 countries, for every 10 percentage-point increase in the penetration of broadband services, there is an increase in economic growth of 1.3 percentage points [Qiang, 2009]. This growth effect of broadband is significant and stronger in developing countries than in developed economies, and it is higher than that of telephony and Internet (see Fig. 1). The growth impact of ICT can be even more robust once the penetration reaches a critical mass.

FIGURE 1

Growth effects of ICT



Source: Qiang, 2009.

Note 1 – The y axis represents the percentage-point increase in economic growth per 10-percentage-point increase in telecommunications penetration. All results are statistically significant at the 1% level, except for that of broadband in developing countries, which is statistically significant at the 10% level.

Since broadband networks have the potential to contribute so much to economic development, they should be widely available at affordable prices and should become an integral part of national development strategies. Currently though, few people in developing economies have access to broadband networks. In 2007, an average of less than 5% of the population of low-income economies was connected to broadband networks, and that was mostly in urban centres. In this light, developing countries are missing a great development opportunity.

Broadband has been increasingly recognized as a service of general economic interest in recent years. The economic significance of broadband can be put into context by referring to similar changes in other areas of infrastructure, such as road, rail and electricity. Each of these infrastructure services transforms economic activities for citizens, firms, and governments; enables new activities; and provides nations with the ability to gain competitive and comparative advantages.

Although few of these advantages were foreseen when original investments were made, these types of infrastructure quickly became an essential part of economic lifestyles and activities. A similar assumption about the expected transformative benefits of broadband on economic and social variables has led many governments to set ambitious targets for its deployment.

The World Bank study summarizes key results and implications for developing countries. The main conclusion is that broadband has a significant impact on growth and deserves a central role in country development and competitiveness strategies.

Despite its short history, broadband seems to have a higher growth impact relative to communications technologies such as fixed and mobile telephony and the Internet (see Fig. 1). Thus, current differences in broadband penetration among countries may generate significant long-run growth benefits for early adopters. Moreover, there are more significant and stronger growth effects of ICT for developing countries than in developed countries.

The empirical findings in the World Bank study suggest that broadband's benefits are major and robust for both developed and developing countries. Developed countries have a longer track record of broadband diffusion and may therefore stand to benefit more to date. As the number of broadband subscriptions increases and the applications supported by broadband reach a critical mass, developing economies could enjoy the benefits of broadband, as with all other communications technologies.

Whether the great potential of broadband to contribute to growth and competitiveness is realized will depend on whether governments understand the opportunity and ensure that supportive conditions are in place through regulatory and policy reforms, as well as strategic investments and public-private partnerships. Realizing the full benefits of broadband also requires development of new content, services, and applications, as well as increased human capacity to integrate these technologies into economic activities. Broadband clearly deserves a central role in national development strategies.

References used in the text of the World Bank publication that is included in § 1.3

CLARKE, GEORGE and WALLSTEN Scott [2006] Has the Internet Increased Trade? Evidence from Industrial and Developing Countries. *Economic Inquiry* 44 (3): 465-84.

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1.4 Organization of Volume 5

Volume 5 is organized into a number of chapters providing key information to the reader, with detailed technical, operational, and regulatory information provided in the annexes. Detailed technical descriptions, including relevant standards, of nomadic and mobile BWA systems are provided in Annexes A and B. Annex C provides a list of acronyms used in this volume.

CHAPTER 2

OVERVIEW OF BROADBAND ACCESS SERVICES, SERVICE TRENDS AND APPLICATIONS

2.1 Introduction

Over the past decade, more and more administrations, public, private, and non-governmental organizations, as well as individuals, have turned to the Internet to conduct their affairs. Today, the Internet is used in the areas of business, industry, finance, government and education, to name a few. BWA has greatly enabled this trend, especially in countries and regions where wired access such as copper and fibre is expensive to implement. Moreover, advances in technologies have greatly enabled the convergence of broadband and mobile.

A number of BWA systems and applications, based on different standards, are available and the suitability of each depends on usage (fixed vs. nomadic/mobile), and performance and geographic requirements, among others. In countries where wired infrastructure is not well established, BWA systems can be more easily deployed to deliver services to population bases in dense urban environments as well as those in more remote areas. Some users may only require broadband Internet access for short-ranges whereas others users may require broadband access over longer distances. Moreover, these same users may require that their BWA applications be nomadic, mobile, fixed or a combination of all three. In sum, there are a number of multi-access solutions and the choice of which to implement will depend on the interplay of requirements, the use of various technologies to meet these requirements, the availability of spectrum (licensed vs. unlicensed), and the scale of network required for the delivery of BWA applications and services (local vs. metropolitan area networks).

2.2 BWA defined

In broad terms, wireless access is an end-user radio connection(s) to core networks. Access can be fixed, mobile or nomadic. BWA is defined by a set of interdependent ITU Recommendations referred to in this Handbook.

Recommendation ITU-R F.1399-1 – Vocabulary of terms for wireless access, provides definitions of wireless access terms.

Fixed wireless access is an application in which the location of the end-user termination and the network access point to be connected to the end-user are fixed, whereas mobile wireless access is an application in which the location of the end-user termination is mobile. For nomadic wireless access, the location of the end-user termination may be in different places but it must be stationary while in use.

Broadband wireless access applications have connection capabilities that are higher than the primary rate – e.g., 1 544 kbit/s (T1) or 2 048 kbit/s (E1)[6].

Recommendation ITU-R M.1801 identifies specific radio interface standards for BWA systems in the mobile service operating below 6 GHz. The standards included in this Recommendation are

[6] COSTA, J.M. [1993] DS1 Services and Standards, in *The Froehlich/Kent Encyclopedia of Telecommunications*, Vol. 6, Marcel Dekker, Inc., New York, New York, USA, p. 361-382. (Available at: http://people.itu.int/~costa/DS1.pdf

capable of supporting users at broadband data rates, taking into account the ITU-R definitions of “wireless access” and “broadband wireless access” found in Recommendation ITU-R F.1399.

2.3 Application trends

The demand for mobile BWA applications is being driven by a number of societal and business factors and trends. The following table summarizes some of these trends.

Societal	Business
– Increasingly computer-literate society – Movement toward work-at-home arrangements – Increasing travel and mobility E-Health – Need to provide care to the elderly and those in rural and remote areas – Need to control health care costs E-Learning – Recognition of increased economic and social benefits of a literate society	– Accelerating pace of electronic commerce (e-commerce) – Rapid adoption of new technologies – Consumer and business demand for single-platform technology convergence (FMC)

BWA systems operating in the mobile service should not only support a wide range of applications in use today but should be able to support a wide range of future services. The main applications in use today are the following:

– Internet access.

– Real-time video and audio.

– IP-based telephony.

– Computer gaming.

– Quad play.

2.3.1 E-Health

E-health (also referred to as telemedicine) has been touted as one of the primary applications made possible by broadband technology. E-health refers not only to making diagnoses and treating patients using high-speed telecommunication access with two-way voice, video and data transmission, but it can also refer to the ability of consumers to purchase medical supplies or prescription drugs online.

Broadband deployment has led to revolutionary developments in the medical field. E-health allows patients that are either too elderly, too sick or those in rural or remote areas too far away from medical facilities to “see” a doctor and receive medical attention using medical equipment and digital imagery technology. Thus, e-health enables improved access and better quality medical care to those who cannot visit a doctor in person, as well as offers early diagnosis and medical treatment. E-health also facilitates medical training for persons who can help doctors and patients in the diagnosis process from afar. While not only reducing transportation costs, it encourages the sharing of scarce resources for medical care.

Internationally, there are many examples where e-health has had a significant societal impact. With the appropriate technology and availability of broadband networks, e-health can be delivered anywhere.

For more information on applications for telemedicine and e-health applications, please see the ongoing work under ITU-D Question 14-1/2 – Application of telecommunications in health care[7].

2.3.2 E-Learning

E-learning is one of the most widely touted applications of broadband technology. Broadband technology enables students of all ages and from any geographic location to take advantage of educational opportunities in schools, universities and other kinds of educational institutions. Broadband can provide students the opportunity to see and interact with professors in real-time, collaborate on group projects when participants are located in different geographic locations, and give the poor, underprivileged, or disabled, the opportunity to learn a multitude of subjects without the burden of costly and time-consuming travel to educational institutions. Many nations and localities have used broadband technology to provide distance-learning opportunities for their citizens and many organizations have done so as well.

For example, there is a program which focuses on training students in the skills necessary to design, implement and operate computer networks. It utilizes web-based learning to facilitate rapid evolution and dissemination of up-to-date curricula. It can also provide widespread availability of information on the strategy and the programs that support it. Currently, the program includes partnerships with many organizations, in addition to the ITU, and has been established in almost 8 500 locations in over 130 countries, including 28 of the United Nation's officially designated Least Developed Countries[8].

2.4 Service environment: urban, suburban, remote and rural

BWA standards that are listed in Annex B support a range of applications in urban, suburban and rural areas for both generic broadband internet data and real-time data, including applications such as voice and videoconferencing. Coverage can be both LoS and NLoS.

Broadband RLANs, such as those based on the IEEE 802.11 standard, allow for high-speed access to the Internet at short distances – i.e., "islands" of connectivity. RLANs, coupled with a mesh network architecture described below, allow for the extension of coverage from hot spots – i.e. airports and cafes - to hot zones – i.e. metropolitan areas. Numerous local administrations in North America and Europe are moving to provide such municipal/urban networks based on the combination of WiFi and mesh (muni-WiFi).

Broadband cellular systems provide broadband capability in a metropolitan / larger area.

2.5 Fixed, nomadic and mobile applications

2.5.1 Fixed applications – General

Fixed applications are described in Volume 1 of the Land Mobile Handbook.

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7 www.itu.int/ITU-D/webdocuments/list_new.asp?question=Q14-1/2&lang=en&period=2002

8 World Telecommunications Development Conference.

2.5.2 Nomadic applications – General

Nomadic Wireless Access (NWA) includes broadband RLANs, which are described in Recommendation ITU-R M.1450 – Characteristics of broadband radio local area networks. Typical NWA applications are public and private wireless access offered in homes, SOHOs, schools, hospitals, hotels, conference centers, airports, shopping centres, etc. Today, broadband RLANs are widely used for semi-fixed (transportable) and portable computer equipment such as laptops and palmtops that can be used for a variety of broadband applications. The key feature is portability.

Generally, nomadic applications are used in offices or other indoor environments and in public spaces or outdoor environments. Devices for indoor use have low e.i.r.p.s, and the radio cells tend to be very small. The radius of such cells is in the order of 30 m or less. Devices used for outdoor environments usually have higher e.i.r.p.s and the radio cells have much larger radii. RLANs are typically deployed in a cellular structure but their areas of coverage are not contiguous, as is the case for cellular systems.

RLANs provide high data rates and system throughput but the geographic coverage is limited to about 100 m.

2.5.3 Mobile applications

IMT-2000 BWA systems are explained in detail in the following ITU publications:

- ITU Handbook [2003] Deployment of IMT-2000 Systems.
  http://www.itu.int/itudoc/gs/imt2000/84207.html
- ITU-R [2005] Migration to IMT-2000 Systems – Supplement 1 to the Handbook on Deployment of IMT-2000 Systems.
  http://www.itu.int/publ/R-HDB/publications.aspx?lang=en&parent=R-HDB-46
- ITU-D [2005] Guidelines on the Smooth Transition of Existing Mobile Networks to IMT-2000 for Developing Countries (GST), produced by ITU-D SG2 Q.18-1/2 (Strategy for migration of mobile networks to IMT-2000 and beyond).
- ITU-D [2004] Mid-term Guidelines (MTG) on the smooth transition of existing mobile networks to IMT-2000 for developing countries produced by ITU-D SG2 Q.18-1/2 (Strategy for migration networks to IMT-2000 and beyond).

As well, information on the radio interfaces of BWA systems can be found in Recommendation ITU-R M.1801.

CHAPTER 3

BROADBAND WIRELESS ACCESS SYSTEMS

3.1 Introduction

The need for broadband wireless access to provide advanced telecommunications services to consumers and businesses continues to grow worldwide. Service providers are seeking wireless solutions both to expand their existing networks and to implement new services.

3.2 Broadband wireless access standards

There are a number of standards developed by various standards organizations to deliver BWA services. Annex B contains detailed information on BWA standards.

CHAPTER 4

OPERATIONAL REQUIREMENTS

4.1 Introduction

A well-prepared business case is fundamental to a decision to deploy a BWA system, or indeed any technology. The business case must take into account customer (end user) demographics and needs, leading to an operational plan. A fundamental aspect for the operation of any BWA system is the availability and access to suitable spectrum. Based on the business plan the spectrum requirements need to be calculated according to the type of operation (see § 4.2). Guidance on frequency bands is shown in § 4.3, which may include license-exempt bands, licensed bands, and non-exclusive licensed bands. Further guidance on regulations applicable to the use of the radio frequency spectrum for broadband wireless access systems is provided in § 4.4.

4.2 Spectrum needs of operators

Once the frequency bands and type of spectrum has been determined, there are ITU-R Recommendations that provide guidance on methodologies and how to perform the calculations to determine the spectrum needs according to specific business and operational plans.

Recommendation ITU-R M. 1651 – A method for assessing the required spectrum for broadband nomadic wireless access systems including radio local area networks using the 5 GHz band, analyzes the various application environments for supporting nomadic users. The environments analyzed are the following: corporate office, public access, wide area access and home environments. BWA deployments using RLANs are generally intended to operate in unlicensed or licence-exempt spectrum and must allow adjacent uncoordinated networks to co-exist whilst providing high service quality to users. In the 5 GHz bands, sharing with primary users must also be possible – i.e., interference mitigation techniques such as Transmit Power Control (TPC) and Dynamic Frequency Selection (DFS) must be built into RLANs. MANs can operate in both licensed and unlicensed spectrum. As outlined in Recommendation ITU-R M.1651, sufficient spectrum is a necessary condition to allow satisfactory performance in the presence of other uncoordinated users in the 5 GHz band and is one of the key conditions for acceptance for these kinds of systems.

The application environment and spectrum calculation methodology for implementing mobility, including wide-scale BWA systems, can be found in Recommendations ITU-R M.1390 and ITU-R M.1768.

Recommendation ITU-R M.1390 provides a high-level generic methodology for the calculation of terrestrial spectrum requirement estimates. Although this methodology was originally developed for the calculation of IMT-2000 terrestrial spectrum requirements, it can also be used for other BWA public land mobile radio systems. Furthermore, it can be adapted for a single operator or for a region of any size with multiple operators. It provides a systematic approach that incorporates geographic influences, market and traffic impacts, technical and system aspects and consolidation of spectrum requirement results. The methodology is applicable to both circuit switched and packet switch-based radio transmission technologies and can accommodate services that are characterized by asymmetrical traffic flows.

Recommendation ITU-R M.1768 describes a methodology for the calculation of terrestrial spectrum requirement estimation for the future development of IMT-2000 and systems beyond IMT-2000 and provides a systematic approach that incorporates service categories (a combination of service type and traffic class), service environments (a combination of service usage pattern and teledensity), radio environments, market data analysis and traffic estimation by using these categories and environments, traffic distribution among radio access technique groups (RATGs), required system capacity calculation and resultant spectrum requirement determination. The methodology is applicable to both circuit switched and packet switch-based traffic and can accommodate multiple services.

4.3 Typical frequency bands / spectrum

A number of frequency bands all above 30 MHz have a mobile allocation; hence, they can be used for the provision of mobile and nomadic BWA applications. In addition bands which are allocated to the fixed service can also be used for nomadic BWA applications.

Recommendation ITU-R F.1401-1 provides guidance for the identification of possible frequency bands for fixed wireless access and related sharing studies. Although originally developed for terrestrial fixed wireless access applications in both the fixed service and the mobile service, the approaches are also applicable to mobile broadband. It includes a description of the main characteristics and applications of the frequency bands allocated to FS and MS that may be suitable for BWA in the following ranges: below 1 GHz, 1-3 GHz, 3-10 GHz, 10-30 GHz, 30-50 GHz and above 50 GHz. It also provides a 7-step methodology to identify possible bands for BWA and outlines the information to be compiled for the selection of frequency bands.

4.3.1 Licence-exempt bands

Unlicensed or licence-exempt bands can be used to implement BWA systems.

License-Exempt (LE) radio bands provide users with the advantages of easy entry and cost savings: there is no coordination with other users; there are no fees or only nominal fees; and a number of these bands tend to be harmonized worldwide, thereby providing economies of scale for equipment. The harmonized bands that are designated for Industrial, Scientific and Medical (ISM) devices would enable deployment of devices such as RLANs and other wireless access systems, which can allow for the delivery of BWA.

Services that operate on a LE basis must accept interference from primary services and must not cause interference to these services. Moreover, equipment that operates in LE bands does not have exclusive access to spectrum – i.e., LE operators must develop mechanisms to tolerate interference and may need to coordinate amongst themselves to avoid mutual interference without any expectation of intervention by regulators. The ability of a network deployed in LE bands to tolerate interference is largely a function of the equipment being used. It is important that the core product itself be designed with stability and radio frequency (RF) robustness as a key design goal, through the choice of appropriate modulation, antenna performance, data retransmission protocols, among other features.

In some countries, operators such as wireless Internet service providers use the LE bands to provide BWA services to clients. The use of bands in which their radio environment is not interference-free can be problematic for the delivery of quality of service (QoS) guarantees. For example, broadband data transmissions, which are bursty in nature, can tolerate some latency, which is created due to retransmissions and contention between devices. However, devices that support broadband voice and video applications are not as forgiving of latency in transmissions. Hence, LE bands for the use of these types of BWA applications may not be as ideal in terms of required levels of service.

4.3.2 Licensed bands

Licensed bands tend to have entry fees for operators that are in many cases associated with exclusive access to spectrum. Some implementations involve access to a particular geographic area for a specific frequency range (geographic licensing) or exclusive access to a particular frequency or set of frequencies (radio or site licensing). In such implementations, access to frequencies is coordinated by the regulator and is deemed exclusive – i.e., one licensee operates on a particular frequency/frequency band and is provided with interference protection rights by the regulator. No other licensees are permitted access to this spectrum. When interference between users arises, the regulator becomes involved if the interference cannot be resolved between by the operators.

4.3.3 Non-exclusive licensed bands

Some administrations are moving towards a new model of licensing spectrum in a flexible manner that could encourage more efficient use of the spectrum. This model is a mix of licensed and unlicensed approaches. In one implementation, spectrum licence fees are minimal as there is no exclusive access to spectrum in a particular geographic area or on a particular frequency/ frequency range. Moreover, as access to spectrum is non-exclusive, operators are required to employ mitigating measures to reduce interference between radiocommunication systems. Such measures can involve the use of site-specific information of licensees in a publicly accessible database and the requirement to deploy equipment that can sense its environment and avoid operating co-channel with other equipment.

Licensees do not have the same interference protection rights commonly associated with licensed systems. Moreover, licensees are expected to cooperate to identify and resolve possible interference issues amongst themselves.

4.3.4 Spectrum deployment aspects: the use of harmonized frequency arrangements

One important consideration in the deployment of BWA systems is the avoidance of interference between systems. The adoption of regionally and internationally harmonized frequency arrangements is an invaluable step in ensuring successful deployments of BWA systems. These frequency arrangements benefit end-users, operators and administrations by allowing for the mass production of equipment, which results in lower cost devices through economies of scale and improved services and applications including global roaming. Moreover, the adoption of such arrangements, along with the implementation of appropriate technical safeguards, mitigates interference between different systems.

Annex E provides technical analysis and guidance for successful deployments of different BWA systems. Mitigation measures discussed in this Annex include guard bands, filters and geographic separation, and are derived using ITU-R Recommendations and ITU-R Reports. ITU-R Recommendations and common regional decisions and recommendations on detailed frequency arrangements provide guidance on harmonized frequency arrangements for the development of specifications/standards by organizations such as 3GPP, 3GPP2 and IEEE. Such decisions and recommendations enable the implementation of coexisting and competing deployments of multi-operator environments in harmonized bands.

Measures to mitigate interference between FDD and TDD BWA systems that are in geographic and/or frequency proximity are discussed in some detail in Annex E. Two Reports[9] have recommended that a frequency separation of 5 MHz between FDD and TDD systems be implemented for systems operating at typical radio frequency power levels of 43 dBm. This 5 MHz block could be used as a restricted block for low power applications. Moreover, in one particular analysis[10] it is shown that additional filters of the order of 50 dB would be required for both

9 CEPT Report 19 and ECC Report 131

10 ECC Report 119

receiver and transmitter; the same measures would be required to avoid interference between unsynchronized TDD operations. Without filters, a frequency separation (guard band) of 10 MHz or more would be required.

However, the implementation of guard bands reduces spectrum efficiency. One way to minimize the number of guard bands is to partition spectrum between FDD and TDD systems into contiguous sub-bands[11] or blocks, thereby minimizing the number of cross-over points between FDD and TDD, and to synchronize TDD operations. The development of a common FDD-TDD frequency boundary that is harmonized regionally and/or internationally reduces the potential risk of interference. Interference could result in a loss of capacity, which impacts quality of service. Moreover, common frequency boundaries reduce the complexity, size and cost of the equipment.

When FDD and TDD operations are not harmonized, separation distances of up to 75 km could be required, depending on deployment scenarios (see Annex E). It is thus beneficial to harmonize spectrum arrangements within a geographical region.

Implementation guidelines

Considering the development costs and complexity of terminal devices for BWA, it is deemed necessary to introduce spectrum designs with pre-defined common frequency boundaries between sub-bands within one particular spectrum band under consideration.

In case there is a need to use FDD and TDD in the same band, then a common band plan having the same FDD to TDD splitting point in every country is essential.

If a common band plan is not followed, i.e. the TDD to FDD split is different in each country or deployment, this leads to several difficulties:

1. Spectrum is used in an inefficient way as guard bands will be needed at every FDD to TDD boundary.
2. Different FDD to TDD split creates difficulties at geographic borders between countries since coordination and/or mitigation are needed to safeguard that transmit and receive signals are not overlapping with neighboring countries. At least one country in Europe has nine neighboring countries to consider.
3. From an equipment design and manufacturing standpoint, each national band plan variant adds cost, complexity and size of equipment and thus reduces economies of scale and possibilities for global roaming. National band plans would also increase the interference potential and add market fragmentation and would lead to limitation of consumer choice of equipment.

Therefore, if FDD and TDD systems are used in a band, a common FDD-TDD frequency boundary should be used to reduce the potential of interference, and reduce the complexity, size and cost of the equipment; otherwise national band plans increase market fragmentation and lead to poor consumer choice.

Specific considerations with regard to detailed spectrum designs

Regardless of the type of the BWA radio technology used, it is necessary to introduce some boundaries of common spectrum design within a band under consideration. For example, the number of different recommended sub-bands needs to be limited for technical (complexity of terminal devices), operational and economical reasons (developmental costs).

[11] In this context, a sub-band refers to a contiguous range of frequencies for FDD uplink, for FDD downlink, or for TDD operation, within a band plan.

Therefore, when designing a common spectrum arrangement, it is essential to include the following principles, noting that in these principles "paired sub-band" refers to either the whole FDD UL block or the whole FDD DL block, not to the bands assigned to a particular operator:

a) the number of sub-bands within each band should be kept to a minimum;

b) paired sub-bands within a band need to be fixed in defined width of each sub-band and fixed in duplex separation as well as the transmission and receive directions;

c) unpaired sub-bands within a band need to fixed in defined width of each sub-band;

d) a combination of fixed paired and unpaired sub-bands can be contained within a band;

e) the number of sub-bands should be limited to a minimum practical number, e.g., three sub-bands would be regarded a practical arrangement when mixing paired and unpaired sub-bands where the unpaired sub-band would typically be placed in between the paired lower and upper sub-bands;

f) an individual country should preferably only select one arrangement per band.

4.4 Guidance on regulatory issues

There are two fundamental principles in the regulations for the use of the radio frequency spectrum for broadband wireless access systems. One is the harmonization of frequency bands to achieve economies of scale, facilitate roaming, and minimize interference. This may include bands for coverage (below 1 GHz) and bands that are sufficiently large to support sufficient traffic capacity, and various regulatory regimes such as licensed, non-exclusive licensed, and license-exempt. The other fundamental principle is the adoption of technology neutrality when licensing spectrum, that is, a BWA operator should be able to deploy any technology that meets the regulatory requirements for the protection of other systems, which would be chosen according to the operator business plan. These two aspects are covered in the following sections.

4.4.1 Benefits of technology neutral regulation

Regulation plays an essential role in creating an environment that facilitates the development of mobile broadband networks and the subsequent adoption of the service by subscribers. The rapid pace of technological innovation has created a highly dynamic environment which requires a new, forward-looking approach to regulation.

Regulators seeking to promote the deployment of mobile broadband wireless access may want to consider the following guidance:

– Adopt a flexible regulatory framework that enables economic forces to drive technological innovation.

– Choose a technology-neutral approach to spectrum management and licensing that allows operators to deploy the technologies and services that best meet the end-user needs and social requirements.

– Ensure that network operators have access to the appropriate spectrum and to the flexible spectrum arrangements they need for a viable business model, including domestic and international roaming.

– Act in a timely fashion to make the regulatory changes that will enable the mobile industry to meet the emerging demand for mobile broadband services that exists today.

The introduction of multiple digital transmission systems requires regulators worldwide to adopt a flexible approach and trust economic forces to actively drive technological innovation. In the current dynamic environment dominated by a fast-paced technological innovation, the role of the regulator is likely to become more complex and wide-ranging. Rather than defining specific technology-based licensing conditions and spectrum allocations, regulators will increasingly need to pursue spectrum regulatory measures that allow network operators the freedom to adopt the most advanced and cost-effective technologies as they become available and that enable multiple wireless technologies to be deployed side-by-side while minimizing interference.

4.4.1.1 A technology-neutral approach

Technology developments and shifts in user demand happen in ever-shrinking timeframes, and it has become difficult to anticipate which technology will dominate and which services will be in greatest demand. The pace of change has accelerated in part because of heavier involvement by the computer and consumer electronic industries, which typically have shorter product cycles than the telecommunications industry. Wi-Fi is a clear example of a technology with a quick adoption cycle, mostly driven in a bottom-up fashion from laptop PC users, something few people predicted. Mobile BWA is expected to follow a similarly compressed timeline.

With increasing frequency, multiple wireless and wired technologies are integrated into a single device. The trend towards subscriber equipment that supports multiple wireless interfaces will enable users to automatically connect to the best network available, depending on location, device, bandwidth required and application used. To make this possible, network operators need to have the flexibility to roll out different technologies when and where appropriate. This will result in more intensive and efficient spectrum usage and a more carefully tailored package of mobile data services made available where most needed.

A technology-neutral regulatory approach allows operators to decide which technology to adopt and brings the necessary flexibility to their business plans, facilitating the deployment of cost-effective, advanced technologies. Spectrum allocations typically span 10 to 20 years, and it is likely that at some time during this period an operator may decide to move to a different technology that better fits its requirements.

Mandating a specific technology could discourage technological innovation, and in many cases it limits the ability for new entrants to compete. By allowing technology choice, operators can increase competition in the variety of services available, their pricing, and the applications they support.

4.4.1.2 Spectrum allocations

A key step to enabling the deployment of mobile broadband services is spectrum availability. Technology-neutral spectrum allocations are needed to address the new requirements of mobile broadband and enable the deployment of new technologies unencumbered by legacy ties to existing technologies.

Particular actions to promote mobile broadband include:

– Permit mobile broadband services in bands that have common global allocations.
– Let operators decide which applications within the land mobile service to offer within their spectrum holdings.
– Allow spectrum licensees to use a mix of duplexing schemes while ensuring compatibility with services in adjacent bands and the efficient use of radio spectrum.
– Introduce trading in rights of use in the secondary market.

4.4.1.3 Timing

Prompt regulatory action will allow citizens to benefit from mobile broadband services thanks to the convergence of three factors:

– A wide selection of mobile data devices with different functionalities, form factors and price points are available and these devices will drive an increase in demand for connectivity. There is already pent-up demand for mobile broadband in developed and emerging countries, and network operators are keen to deploy new technologies now that support these devices and the services they support.

– Commercial availability of new technologies makes it possible for operators to start deploying the infrastructure in the short term. A flexible regulatory environment will enable them to deploy these technologies using the spectrum they already have as well as in newly acquired spectrum bands.

4.4.2 Benefits of spectrum harmonization

Historically, spectrum harmonization has positively impacted mobile service deployments. The three major reasons are:

– Better economies of scale

– Lower financial risk for vendors of infrastructure and handsets

– Improved conditions for roaming.

4.4.2.1 Harmonisation expands the market for equipment and services

Spectrum harmonization enables globalization of markets for mobile network infrastructure and handsets. Globalization means better use of economies of scale, reduced manufacturer risks, shorter time-to-market and lower costs. Globalization also benefits buyers as it drives global competition and brings lower prices on infrastructure and handsets.

4.4.2.2 Fragmentation delays feature development and service interoperability

The development of handsets has benefited from global standards and global demand for features and performance – and continues to do so. Standardization and spectrum harmonization represent the most time- and cost-efficient path towards interoperability of networks.

4.4.2.3 Harmonized spectrum lowers the threshold for establishing roaming

When a mobile radio technology and a spectrum plan have an international base of users, it is easier for operators to make an attractive service to customers when roaming overseas.

The most obvious incompatibilities between different technologies and between different spectrum plans can be overcome technologically with multi-band, multi-mode terminals. However, the multiple radio interfaces needed in such terminals drive up the costs of development and manufacturing.

Despite the fact that a significant multi-system handset base exists, inter-standard roaming remains a niche business opportunity. Inter-standard, multi-band mobile roaming is well behind mainstream cellular technologies in commercial and technological development.

Experience from the cellular community proves that harmonized spectrum combined with standardized roaming processes lowers the threshold for successful roaming. Harmonization of technology and of spectrum plans creates necessary momentum for roaming and distributes roaming establishment costs among a larger community.

Studies have shown the benefit that increasing mobile phone penetration can have especially on developing economies. Studies have also shown the increased efficiency gains that developed economies have gained in productivity from internet usage. It seems likely that developing markets would also gain in productive efficiency from increased broadband internet penetration.

Non-harmonized frequency arrangements are likely to raise the costs, and/or lower the performance, of mobile broadband terminals. If terminals have lower performance specifications, this will mean that to provide the same quality of service will require extra infrastructure investments.

Neither of these outcomes (lower performance terminals, or higher cost terminals) is desirable, as they will limit mobile broadband penetration in these countries.

CHAPTER 5

SYSTEM DEPLOYMENT GUIDELINES

5.1 Introduction: Key issues to consider prior to deployment

When considering when and how to deploying a network using BWA systems, there are a number of key factors to be considered. For example, what types of services and applications will be offered and to which demographic group. What is the area that is being targeted – urban, suburban, rural, or remote? What types of systems and networks are already deployed in these areas? Can BWA networks interface with these existing networks?

The following section will examine in detail the types of issues and factors that must be examined when rolling out a network.

5.2 Deployment considerations: wireline vs. wireless

As wireless technology represents an increasing portion of the global communications infrastructure, it is important to understand overall broadband trends and the role between wireless and wireline technologies. Sometimes wireless and wireline technologies compete with each other, but in most instances they are complementary. For the most part, backhaul transport and core infrastructure for wireless networks are based on wireline approaches, whether optical or copper. This applies as readily to WiFi networks as it does to cellular networks.

Given that the inherent capacity of one fibre optical link exceeds the entire available radio frequency (RF) spectrum, data flow over wireless links will never represent more than a small percentage of the total global communications traffic. Nevertheless, wireless technology is playing a profound role in networking and communications, because it provides two fundamental capabilities: mobility and access. Mobility refers to untethered communication whether stationery or in motion. Access refers to communication services, whether telephony or Internet, easily provided across geographic areas and often more easily accomplished than with wireline approaches, especially in greenfield situations where there is little existing communications infrastructure.

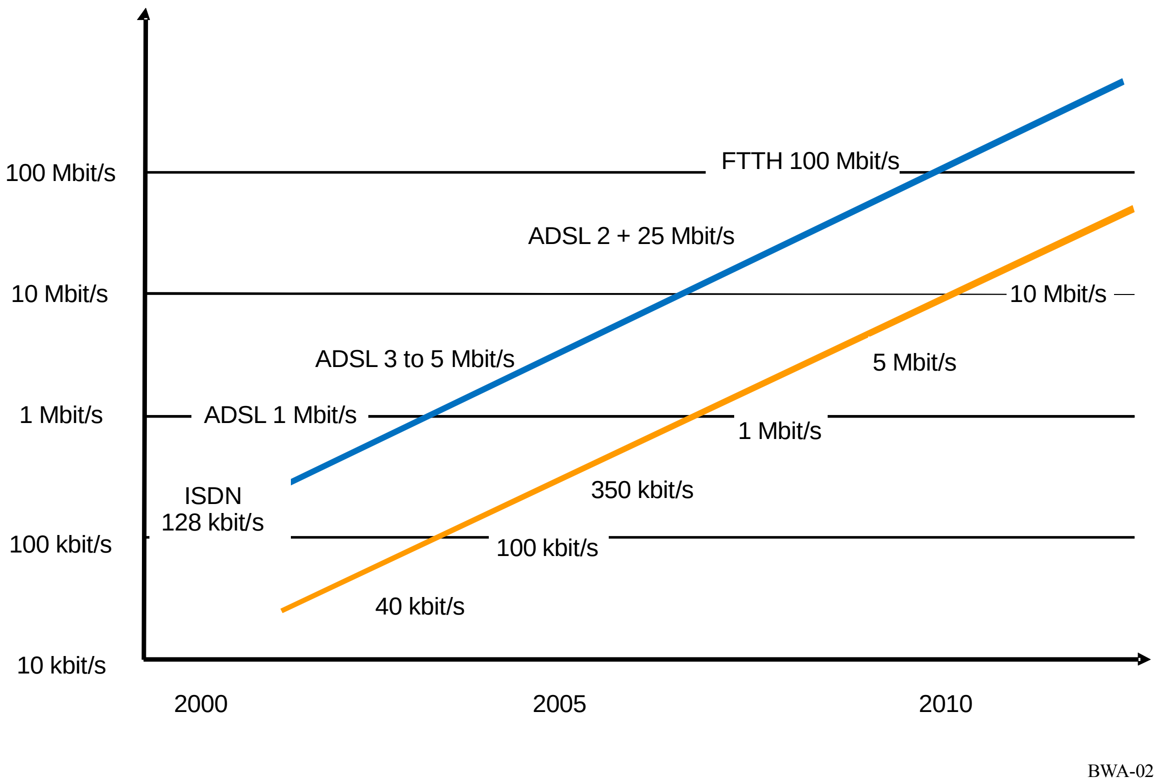
Thus, given these characteristics, mobile communications volume may be less than wireline, but its overall contribution to communications in the world and its social, political and economic impact, is just as significant.

The overwhelming global success of mobile telephony, and now the growing adoption of mobile data, conclusively demonstrate the desire for mobile-oriented communications. The question of using wireless technology, however, for access is more complex. One must consider the performance and capacity of wireless technologies relative to wireline approaches, what wireline infrastructure may already be available, and ongoing developments with wireline technology. In particular, wireline networks have always had greater capacity, and historically have delivered faster throughput rates.

Figure 2 shows advances in typical user throughput rates, and a consistent 10 x advantage of wireline technologies over wireless technologies.

FIGURE 2

Wireline and wireless advances



Mobile broadband combines compelling high-speed data services with mobility. Thus, the opportunities are limitless when considering the many diverse markets mobile broadband can successfully address. In developing countries, there is no doubt that mobile broadband technology will cater to both enterprises and their high-end mobile workers and consumers, for whom mobile broadband can be a cost-effective option, competing with digital subscriber line (DSL), for home use.

User's desire to be connected anytime, anywhere will be a primary source of demand. While user demand for social networking and search information services, as well as Internet businesses, increases the demand for mobile-broadband capabilities, the majority of early adopters of mobile broadband have been enterprises. Better connectivity means a business is more efficient. As a result, enterprise broadband-connectivity adoption is taking on the same "look and feel" as early mobile-phone service adoption. In the early 1990s, doctors, lawyers, salespeople, and executives already had home phones, office desk phones, and even receptionists. It was the productivity increases associated with being connected to a cellular network, however, that accelerated mobile-broadband growth throughout the world. Portio Research predicted in June 2008 that worldwide mobile data revenue would increase at an annual rate of 16% to reach $252 billion the end of 2012[12].

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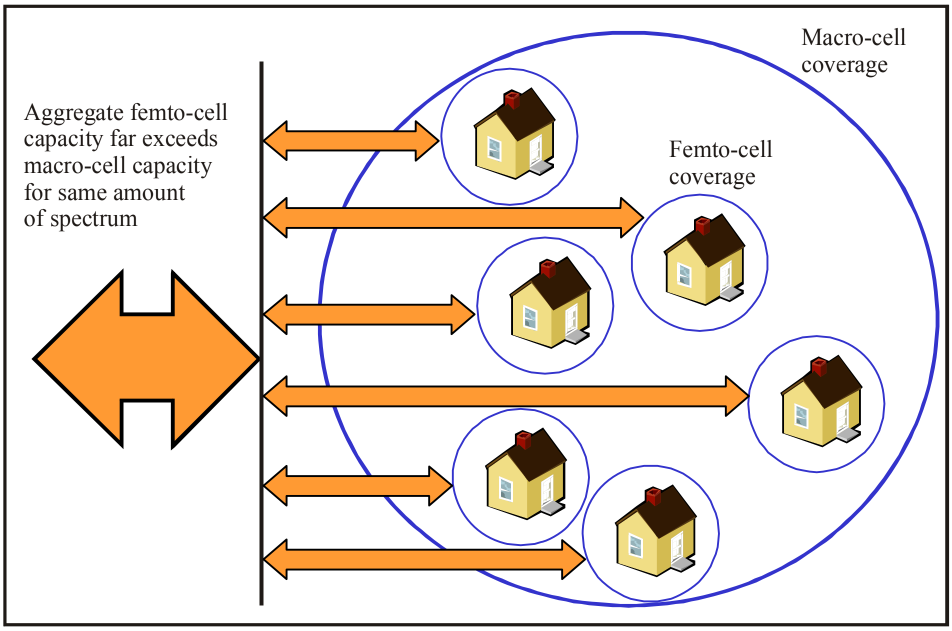
12 "Mobile Data Services Markets 2008", Portio Research, June 11, 2008.

Overall, whether in business or in our personal lives, the world of voice and data is quickly becoming one that must be *untethered, but always connected*.

Although it is true that most BWA systems are now offering throughputs of about 2 Mbit/s – which is comparable to what many users experience with a basic DSL or cable-modem service – the overall capacity of wireless systems is generally lower than it is with wireline systems. This is especially true when wireless is compared to optical fibre, which some operators are now deploying to people's homes. With wireline operators looking to provide 20 to 100 Mbit/s to either people's homes or businesses via next-generation cable-modem services, very high-speed DSL (VDSL), or fibre – especially for services such as high-definition IP Television (IPTV) – the question becomes, is it possible to match these rates using wireless approaches? The answer is "yes" from a purely technical perspective, but it is "no" from a practical point of view. It is only possible to achieve these rates by using large amounts of spectrum, generally more than is available for current BWA systems, and by using relatively small cell sizes. Otherwise, it simply will not be possible to deliver the hundreds of gigabytes per month that users will soon be consuming over their broadband connections with wide-area wireless networks. Consider today's high definition (HD) television content that demands 6 to 9 Mbit/s of continuous connectivity, where one subscriber could essentially consume the entire capacity of a cell sector. A possible wireless approach to address such high-data consumption is with hierarchical cell approaches, such as femto cells as shown in Fig. 3. This presupposes, however, an existing wireline Internet connection (e.g., DSL).

FIGURE 3

Femto cells used to expand capacity



BWA-03

What makes much more sense today is using wireless technology for access only when there are no good wireline alternatives. Hence, the interest developing countries have in broadband-wireless technologies. What changes the dynamics of the business model in these areas is that operators can cost-effectively deploy voice (which is inherently low bandwidth) and lower-speed data services, mostly because of the lack of wireline offerings. Deploying at lower capacity – as measured by lower bits per second (bit/s) per km^2 – means larger cell sizes, and thus fewer cell sites and much lower deployment costs.

Table 1 summarizes the strengths and weaknesses of wireless versus wireline broadband approaches.

TABLE 1

Strengths and weakness of broadband approaches

	Strength	**Weakness**
Cellular mobile broadband	Constant connectivity. Broadband capability across wide areas. Good access solution for areas lacking wireline infrastructure. Capacity/coverage enhancement options via femto cells.	Lower capacity than wireline approaches. Future evolution to serve high-bandwidth applications such as IP TV.
Wireline broadband	High capacity broadband at very high data rates. Evolution to extremely high throughput rates.	Expensive to deploy new networks, especially in developing economies lacking infrastructure.

This is not a static situation, however. In the longer term, a number of developments could make high-capacity broadband-wireless systems more competitive with wireline approaches. Among these developments are mesh capabilities to reduce deployment costs, higher spectral efficiency, low-cost commoditized base stations, and future spectrum allocations for mobile-broadband systems. However, any such future success is somewhat speculative and dependent on many developments including technology and broadband application evolution.

Cellular mobile broadband technologies clearly address user needs; hence, their success. The cellular mobile broadband roadmap, which anticipate continual performance and capacity improvements, provide the technical means to deliver on proven business models. As the applications for mobile broadband continue to expand, cellular technologies will continue to provide a competitive platform for tomorrow's new business opportunities.

5.3 Designing BWA deployments for profitability

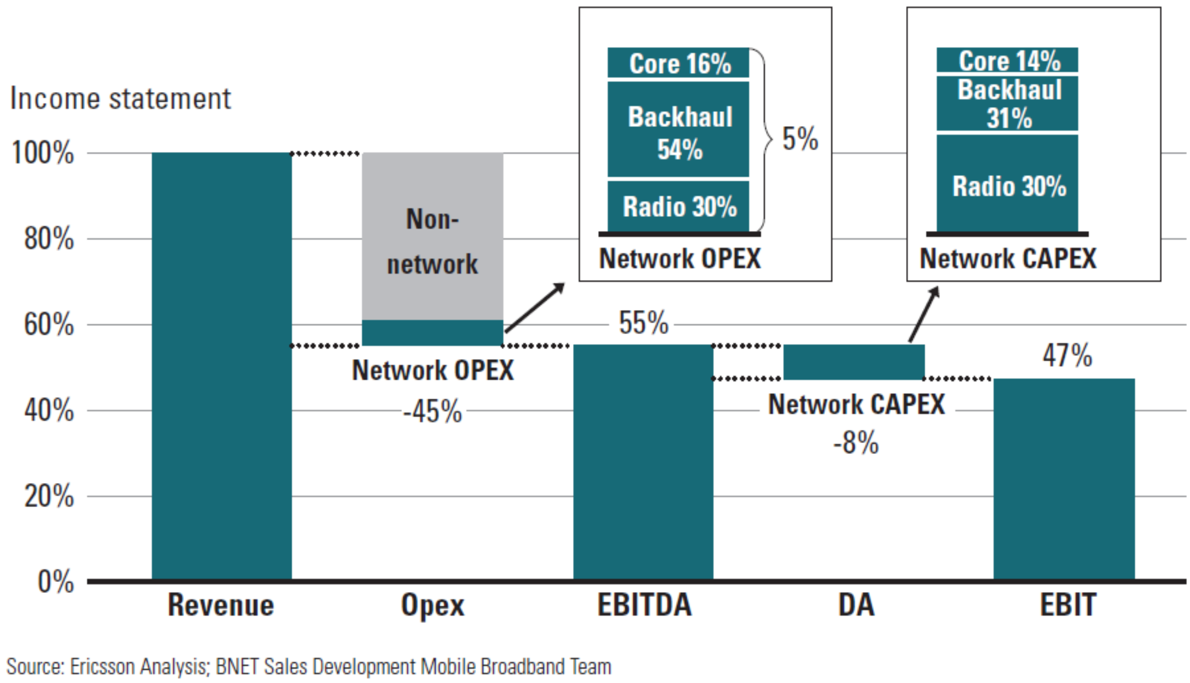
Dimensioning networks and figuring out the right price and packaging are important steps for operators. Cost-benefit analyses based on real operator cases have revealed that mobile broadband is, in fact, very profitable. In this section general guidance is provided on the key elements in designing BWA deployments for profitability.

An increasing number of operators are relying heavily on mobile broadband by positioning it as an alternative to DSL or cable. These operators are seeing substantial subscriber growth, reaching typically 3% – even as high as 5% – of the population after two or fewer years of offering the service. Mobile broadband business cases show high profit margins, even if the operator is only a pure bit-pipe provider catering to the needs of subscribers using computers.

Figure 4 shows an example of a cost-benefit analysis based on real and forecasted costs and revenues[13].

FIGURE 4

Mobile broadband profitability



Glossary – CAPEX: Capital Expenditure; DA: Depreciation and Amortization; EBIT: Earnings Before Interest and Taxes; EBITDA: Earnings Before Interest, Taxes, Depreciation, and Amortization; OPEX: Operational Expenditure.

This analysis was made as an investment case, meaning that any costs that occurred prior to the decision to launch mobile broadband are considered to be sunk costs. The result, even after only a few years and with good but not aggressive growth, shows margins in line with or above what operators typically generate today. The conclusion at this stage is that mobile broadband provides a great addition to any operator's business, and can match and compete effectively with DSL.

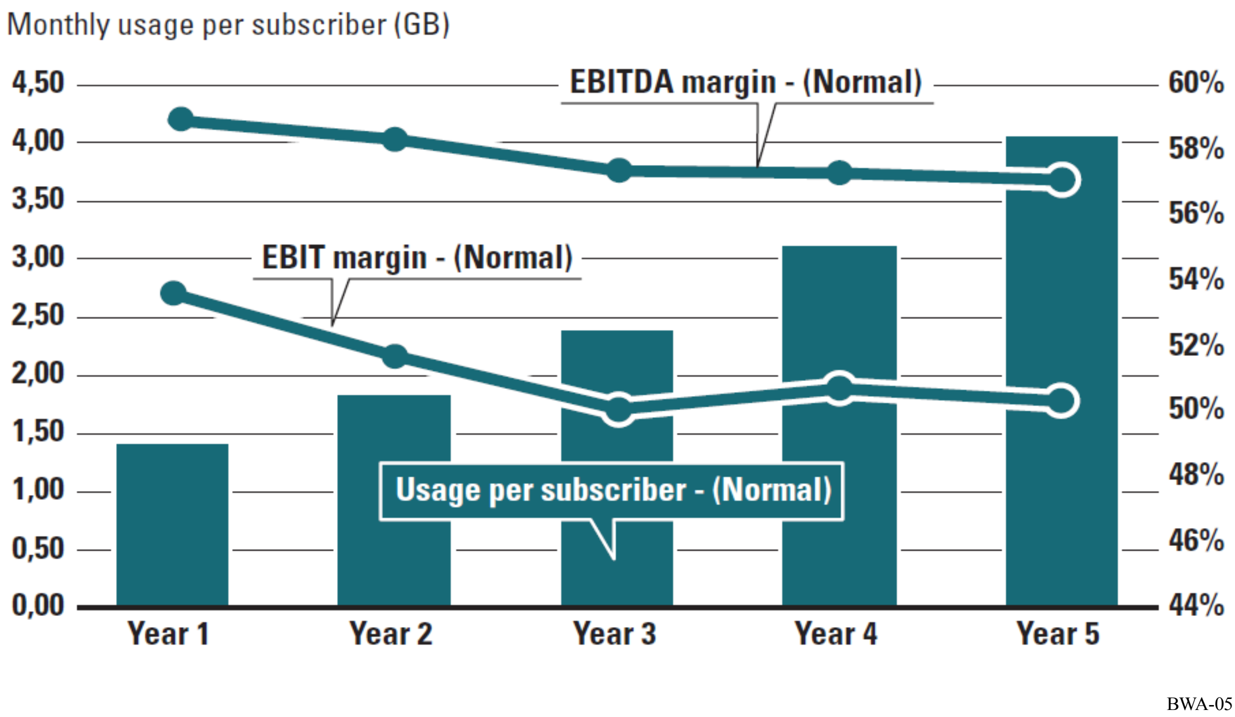
One aspect that needs to be highlighted is the importance of scale. Indeed, when subscriber numbers increase, both traffic and revenue rise. The operator will eventually have to invest in more capacity, in the form of additional carriers. Each added carrier represents an investment. Because these investments are driven by traffic from more subscribers, there is, of course, a correlation to revenue. That makes the ability to improve cost-efficiency important; otherwise, margins would slowly deteriorate as users demand more capacity and tariffs are lowered. Meeting this requirement is what

13 For the assumptions made in this example and the details of the calculation, the reader is referred to the article BLENNERUD, G. [2009] Don't worry – mobile broadband is profitable. Ericsson Business Review, No. 2, p. 54-58. Available online

the technical evolution is all about. On this basis, Fig. 5 shows the projected 30% year-to-year growth for an example BWA system[14].

FIGURE 5

Projected 30% year-to-year growth



Simple calculations such as those described above do not tell the full story of a real business, but they provide a good indicator. Fortunately, tools exist based on research in cooperation with established operators from all parts of the world. These tools can make a complete end-to-end analysis, including all aspects relevant to the business case. Even voice and SMS traffic, though not part of mobile broadband, should be considered because they affect overall network dimensions. Mobile broadband must share network capacity with other services, especially the radio bearer, and voice in particular. One of the difficulties is in identifying or allocating costs that are strictly related to mobile broadband. To assist in this, the tools make the analysis based on existing traffic patterns and forecasts, creating a scenario for a number of years, say five years, and permit assessing the effect of changing parameters. What would happen, for instance, if traffic per subscriber increased dramatically? Not the statistical average, which can increase because a few users generate huge amounts of data, such as when using peer-to-peer; but rather a traffic increase that an operator must consider when dimensioning the network. The tools may also investigate what would happen if an operator moved away from E1/T1 (backhaul on leased lines) and used microwave links instead. All this can be considered together with the effects that variations in subscriber uptake could have on the business case.

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[14] For the assumptions made in this example and the details of the calculation, the reader is referred to the article BLENNERUD, G. [2009] Don't worry – mobile broadband is profitable. Ericsson Business Review, No. 2, p. 54-58, Available online

The most important element of profitability is subscribers paying for the service. Profitability would drop unless enough subscribers are added, that is the population penetration increases. The strategies for population coverage do vary between operators and the requirements are different in different countries as population density also varies substantially.

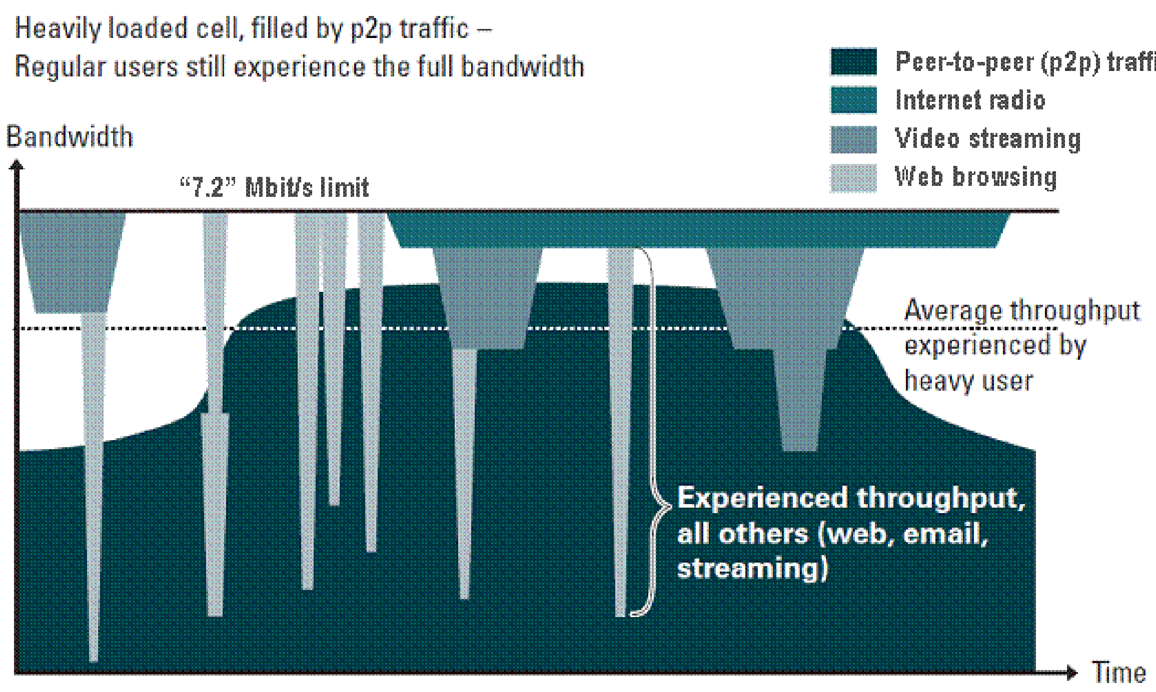
A flat rate pricing scheme promotes subscriber uptake and is the easiest pricing for consumers to understand. All or most mobile networks today have been running voice, SMS, MMS, and some mobile data traffic. None of these have generated much traffic per subscriber. Revenue growth has been well aligned with traffic growth (and thus traffic cost) per subscriber. Then along came this new service that, compared to SMS, for example, easily generates 10, 100, or even 1 000 times more traffic per subscriber.

The three applications generating the highest volume on the internet today are peer-to-peer file sharing, web browsing, and video streaming. Peer-to-peer alone accounts for over 60% of all household-generated traffic. And with traffic per subscriber increasing at a yearly rate of 30%, driven mainly by file sharing, peer-to-peer represents an opportunity.

Operators want as many profitable subscribers as possible. This means that investments made in the network are driven by the bulk of subscribers and not by a few heavy users. This can be addressed by introducing traffic-handling priority throughout the network, which allows the network itself to manage its resources. The operator would introduce a fair-use clause in the subscriber's contract so it can manage heavy usage intelligently. Most commonly, mobile broadband operators use unconditional throttling today, which means that once the fair-use level is reached, the throughput drops to a predetermined level. Typically, though, these speeds don't allow for meaningful use of the broadband connection.

FIGURE 6

Traffic handling priority



BWA-06

Traffic-handling priority gives the heavy user a lower priority in the network once the fair-use level is reached, as illustrated in Fig. 6. The heavy user would experience a degradation of the service only when competing for resources in a congested situation. But in peer-to-peer, the experienced reduction of the throughput will, over time and even within an hour, be limited. Only in heavily loaded cells does a peer-to-peer user experience serious problems. Those sites could be targeted for capacity upgrades since it is normal usage that is creating the congestion.

Traffic-handling priority allows an operator to focus on dimensioning the network for normal usage while still allowing unlimited traffic. The consumer gets better overall quality and the comfort of using an unlimited service that does not generate surprises on the bill.

In the long run, unlimited flat rate plans with a fair-use clause are potentially cheaper and more profitable for the operator than plans with only monthly data-volume limits. Subscriber uptake aside, the size of the plans is increasing drastically, driven by competition and as a means to segment the market. In this case, as the data-traffic increases, the only control the operator has is the size of the monthly data-volume plans. For example, data-volume plans of 10, 20, or even 50 GB are already offered by some operators. However, the fair-use level for an unlimited flat rate plan may not need to change at all, or at least very little, over time since it does provide a "unlimited traffic" model. The segmentation is instead done through speed and price.

Unlimited flat rate plans are a complex issue, and it is difficult to predict what will actually happen in a network when this model is applied. Although the model does allow each user to generate as much data-traffic as they want, other factors influence the outcome. The operator's chosen position in the market determines which subscribers it attracts. This in turn defines the behaviour of its subscriber base. Great variations exist between operators in the same market with similar packaging and pricing.

The above discussion is based entirely on PC-based communications which demonstrates that there is good profitability even in offering a simple bit pipe. Introducing intelligent management functions in the network allows the operator to handle all sorts of situations, such as separating application streams from each other, or varying traffic – and perhaps pricing – depending on time of day; or giving different priority to Smartphone users over PC users; or giving paying mobile-TV viewers a higher priority than "best effort" internet.

The recipe for mobile broadband profitability

Based on numerous case studies[15] two primary trends need to be assessed by an operator:

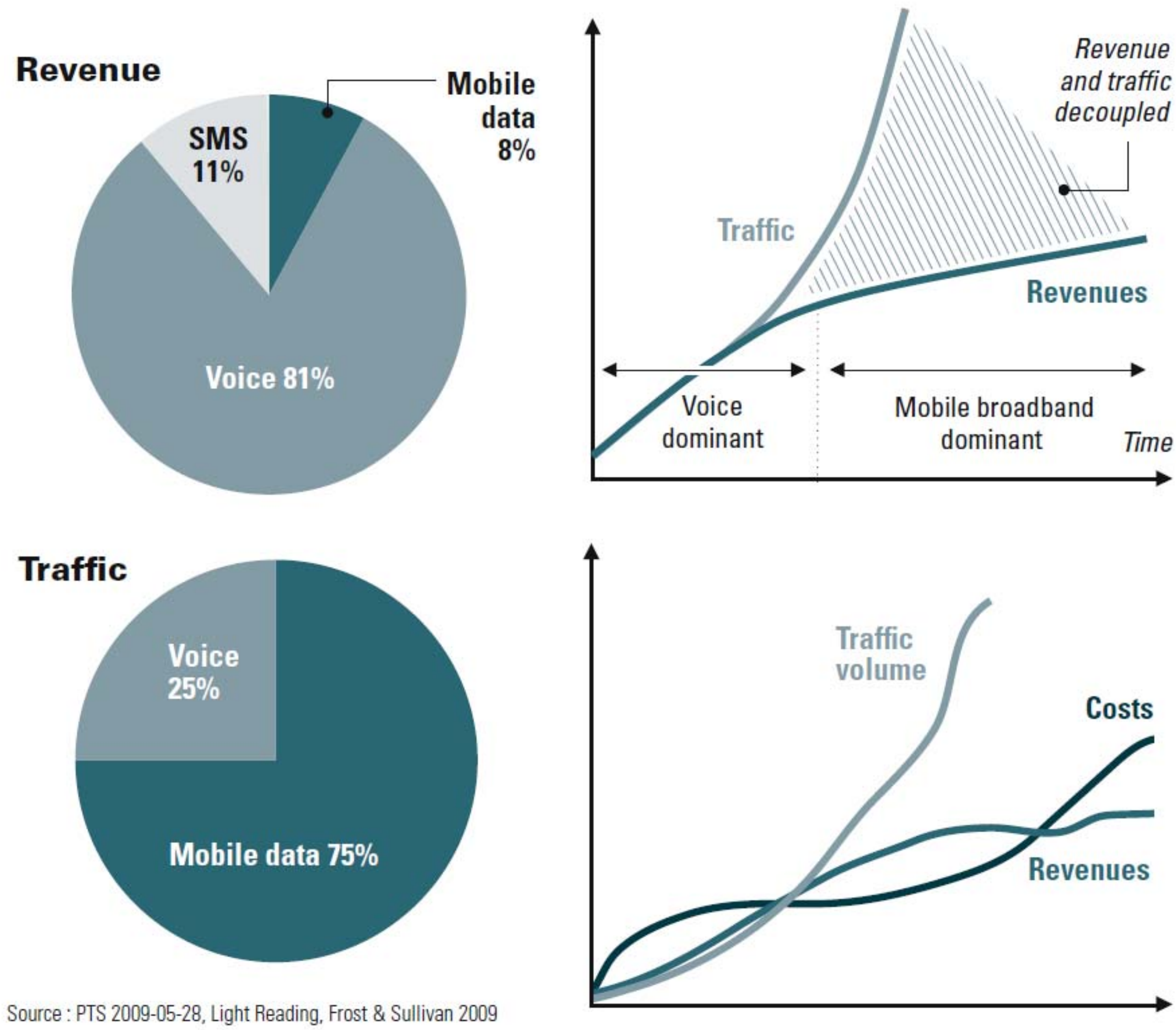
1. The overall utilization of the network and its close connection to profitability.
2. The cost per GB/MB while keeping the internal accounting principles in order. Network capabilities need to be taken into account if there is an allocation of cost between, for example, voice and broadband.

In the past, operators often allocated costs between product areas using a model based on traffic load. This worked well when the difference in traffic between services was limited. With the introduction of broadband things changed dramatically. There are numerous pictures and graphs showing the "gap" between traffic and revenue, such as that shown in Fig. 7. But the correct assumptions about traffic relative to cost need to be made.

[15] BLENNERUD, G. [2009] The recipe for mobile broadband profitability. Ericsson Business Review, No. 3, p. 46-50. Available online

FIGURE 7

Traffic versus revenue



BWA-07

In some cases studied, the internal cost structure is such that the transport unit internally is charging the product owners (voice, mobile broadband, SMS, etc.) on a per MB basis. Quite soon after launching mobile broadband, some operators noted two trends. One is that broadband looked to be unprofitable, and the other is that the unit responsible for transport is suddenly growing rapidly and improving margins drastically. The next step is then to realign the transfer pricing to better suit the new service mix.

In current BWA deployments there is a difference in capacity (spectrum efficiency) of roughly 10 to 12 times when comparing voice and the latest IMT-2000 enhancements on a 5 MHz carrier. This basically means that a voice byte is currently about 12 times more costly than a mobile broadband byte. This relation will change further as high speed data evolves, and of course change again if voice is moved over to packet.

If this cost uneven relation is not taken into account, and in most current studies it is not (the cost allocation is done on an equal basis), the end result is that mobile broadband is over loaded with cost by a factor of at least 10 times.

Of course this might be simplifying things a bit since quite often operators also use other key performance indicators, such as subscriber base for example, to allocate cost. This lessens the effect somewhat but even a lesser overestimating of costs still means there is a risk that the operator is not pursuing the mobile broadband opportunity in the way it should.

To make things a bit more concrete, let's develop a realistic example. Looking at averages from a group of operators in a single market, mobile broadband accounts for close to 80% of the mobile network traffic, but only 15% of the subscriber base. The cost per subscriber will differ significantly depending on allocation method.

In order to calculate correctly, it is necessary to first identify the "actual" load that mobile broadband represents on the capital invested. This can be done using the three simple steps in Fig. 8.

FIGURE 8

Weighting and allocating cost towards mobile broadband subscribers

1 *Calculate the relative load of mobile broadband subscribers vs voice subscribers*

$$\textbf{Load factor} = \frac{\text{Mobile broadband traffic / Mobile broadband subscribers / 12}}{\text{Voice traffic / Voice subscribers}} = \textbf{1.9*}$$

2 *Calculate the percentage of the cost to be allocated towards mobile broadband subscribers*

$$\textbf{Allocation factor} = \frac{\text{Mobile broadband subscribers x Load factor}}{\text{Total amount of subscribers}} \textbf{ x 100\% = 28\% in this example}$$

3 *Allocate cost towards subscribers of each respective service type*

$$\textbf{Cost per mobile broadband subscriber} = \frac{\text{Cost to be allocated x Allocation factor (28\%)}}{\text{Mobile broadband subscribers}}$$

*With mobile broadband at 80% of traffic and 15% of subscribers

BWA-08

With mobile broadband representing 15% of subscribers and 80% of traffic, this "load factor" calculates to 1.9 and the resulting per subscriber cost is 2.2 times what a voice subscriber costs. A sensitivity analysis might be interesting here. What would happen if a wireless operator manages to get to a situation where 50% of the subscribers use mobile broadband? How much traffic can they represent and still not cost more than voice subscribers? Doing the calculations, it appears that somewhere around 92% of the traffic can be broadband in such a case.

This result is quite astonishing, and it tells us that it is natural to have this “imbalance” between mobile broadband traffic and voice traffic. Simply put, this is what BWA systems were designed for.

In this example the whole network cost was assumed to be allocated to voice and mobile broadband respectively. This is still not entirely fair, at least in a case in which the IMT-2000 network already exists and was built out when mobile broadband was introduced. This brings us to the discussion about different views of what can be considered “sunk cost.” If an operator really wants to know how well the investment in BWA is doing, the operator must ensure that not too many other costs are mixed into the equation. Would the operator allocate cost from the already existing IMT-2000 network if the operator were to launch a mobile TV service?

A more correct way to assess costs is to let each service carry its own costs first, and then distribute only the common costs. Only investments made to specifically enable mobile broadband, on top of the already existing network, should then be allocated. Think of it as an investment in a whole new channel on the 5 MHz spectrum, a channel that is 12 times more efficient to run data over than the circuit channel used for voice.

There is really no single correct way of allocating costs, but the important thing is to strive for “fairness” between services. The aim is to minimize the risk of promoting unprofitable services or penalizing those that are truly profitable.

The effects of this in the market can be seen when a service is priced too high to be competitive, though it may be in line with internal cost estimations. A less obvious situation may be that the price is set at an attractive level, but that the limitations put on the end user are too strict, making the service less competitive. In the end these things affect the take up rate negatively, and since telecom is very much about economies of scale, it becomes somewhat of a self fulfilling prophecy.

The simplest way to get costs down quickly is to work towards rapid growth in subscriber numbers.

Not surprisingly the operators following these principles are also some of the most successful in terms of subscriber uptake. This also means that they are at a point where their utilization of the network is such that it is possible to be profitable.

The utilization levels in most BWA networks today are typically low, compared to the overall radio network capacity. Of course networks are still seeing heavy load in some areas. Any site built in big cities is expected to carry heavy traffic. But these areas are also where operators typically generate the most revenue and profit per site. It is outside of such areas that operators need to get subscriber numbers up and raise traffic.

The way to effectively handle the traffic load may differ significantly from operator to operator, as might their respective challenges. Even in markets in which operators may have very similar packaging and pricing, great differences can be seen in the average consumption per user and per month. In some markets there may be differences as big as a factor of five to 10 times. This is true for both fixed and mobile broadband networks and really only shows that it is very much dependent on how each operator positions themselves in the market.

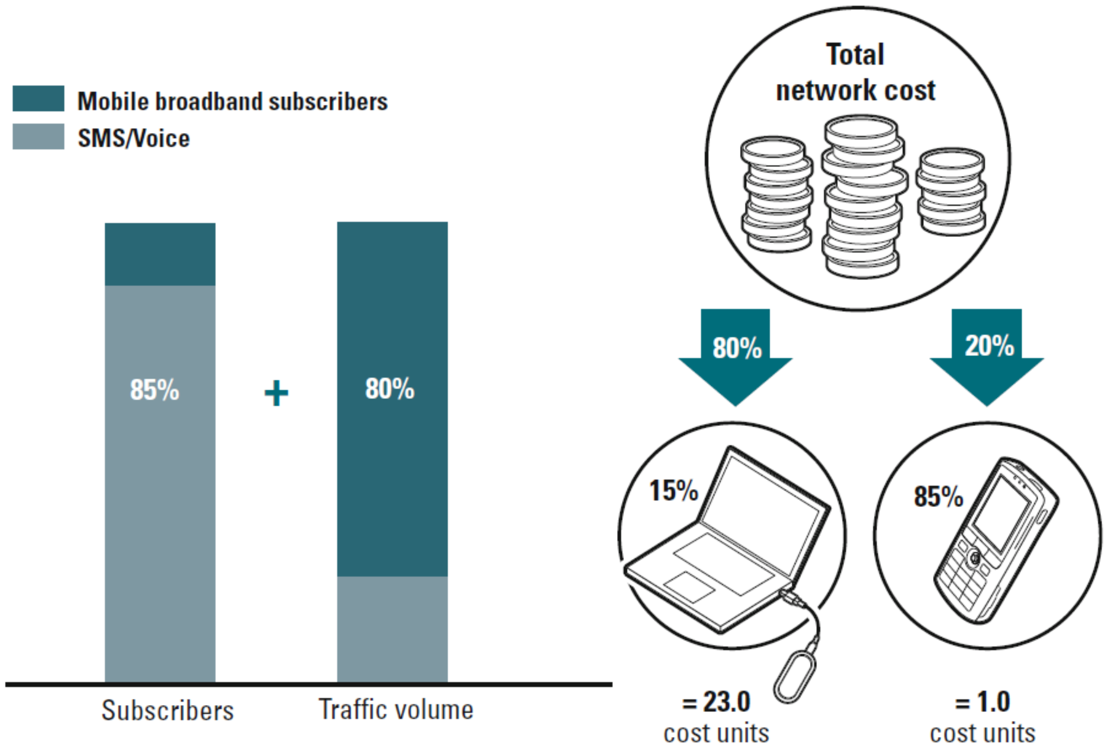
There are two main drivers for high data consumption today, peer-to-peer file sharing and video streaming. Peer-to-peer has been dominating the scene for some time although video streaming services are growing fast. Music and radio streaming also generate a lot of traffic, but on a per user basis it can not measure up to the file sharing and video streaming. And though video streaming is growing rapidly and higher bitrates are increasing the demand, there is one limitation that differentiates it from peer-to-peer. With file sharing, all the “work” is done by a computer, which may be downloading files every hour of the day. Video streaming on the other hand is typically limited by the individual's time spent in front of the screen.

The operator needs to find a balance between addressing traffic issues that drive costs and limiting end users too much, which may impact uptake. To the end user, there is virtually no correlation between volume and value. To the operator there is a correlation between volume (at busy hour) and cost. The mechanism an operator uses to handle the traffic needs to take this difference into account. By focusing on packages with different amounts of GB, the operator is actually putting a value on volume for the end user.

At the moment this is probably the most common method to limit the costs driving data consumption. This works fairly well in that it actually reduces the traffic per user, although there are operators with these limitations in place who have higher average traffic per user than operators without any limitations. This points to the fact that it may be the operators position on the market, more even than the packaging itself, that determines the usage pattern. This approach is illustrated in Fig. 9.

FIGURE 9

The "unfair" way of allocating cost

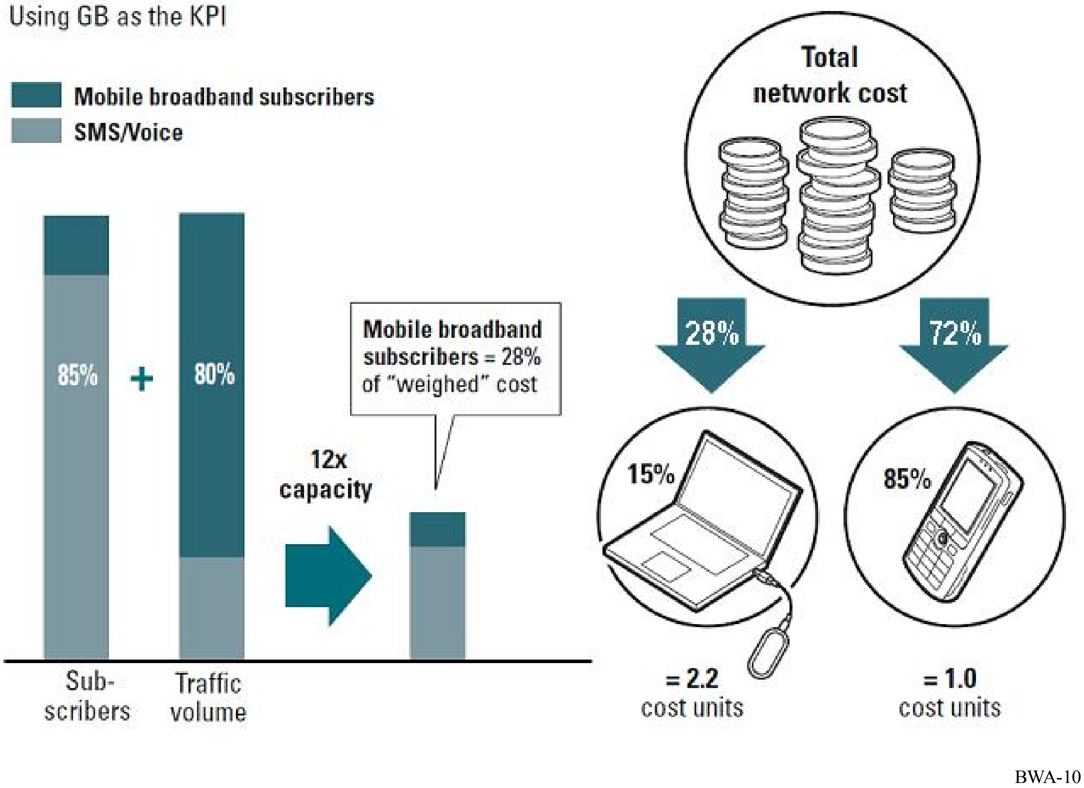


BWA-09

A bit more finesse is achieved when operators use their own network resources to handle the problems when, where and if they arise. The name for this is "traffic handling priority," which allows the network to lower the priority of the traffic of certain users, for example when the usage level reaches a certain limit. The "fair use level" set by the operator is then in fact the level towards which the cost is in a sense "capped." At the same time, each individual user is able to keep downloading data at the speed allowed by the system and their subscription. The operator will be forced to consider upgrading or expanding a site only at the point when "normal" subscribers are filling up a base station site and there is congestion. . To the heavy user, the average degradation in speed will differ but in most cases it is probably not severe enough to be even noticed, until, that is, the data from other users actually start to fill up the pipe. Still, any traffic – peer-to-peer traffic in particular – can continue flowing outside of the busiest times of the day. This approach is illustrated in Fig. 10.

FIGURE 10

Allocating costs in a "fair" way



Glossary – GB: Gigabyte; KPI: Key Performance Indicator.

Business models that work

Using a pricing and packaging principle in which end users are allowed to download as much as they "can" is known to be the most attractive to the end user. And to the end user, a surprise bill every month – which is what packaging with a price per MB generates – is the worst thing possible.

This poses a dilemma for the operator, since traffic is a cost driver in the network (at least during the busiest hours). Over time operators must be able to raise prices in order to both invest in the network and keep up with ever increasing demand. On a global level, monthly usage per individual is increasing by around 20 to 30% yearly. This means that when there are no more new subscribers or subscriptions, operators will still have to expand their networks.

The pricing for plans with monthly data-volume limits may seem to be solving both the issue of traffic management as well as providing a possibility to charge more for those who consume more. And of course in order to charge more, operators need a mechanism that – in the consumers' eyes – makes a reasonable connection between consumption and price.

Speed has proven to be a reasonable way to communicate value to the consumer. It is also possible to relate speed to different application types. Furthermore, speed also has a cost to the operator, even more so perhaps than traffic volume. Speed or pipe size is what costs money in terms of investments, while the bytes that flow through the pipe outside the dimensioning hour (busy hour) do not really cost.

The downside of traffic handling priority is that it does not motivate user to pay more, even if consumption increases. But that is only true in networks with a low load level and then there is no real cost increase to the operator either. The main motivation for traffic handling priority is that the operator should not be forced to upgrade only to cater to a small number of heavy users.

The trend in the market has been to offer larger and larger data-volume limits in the hunt for market share. If the data-volume limits are increased without the price tag being changed, then this method can very well prove to be more costly than no limit offers with intelligent management mechanisms.

There is emerging evidence in operator reporting that mobile broadband is profitable, even in the "worst case" bit pipe situation. As described previously, it is important to do the internal cost calculation exercises right. And in doing so it is even possible to put a "cap" on the cost per subscriber by using intelligent functions in the network.

Going forward the most complex area of them all must also be considered – which business models to use. Operators need to experiment and learn how to market mobile broadband in new ways while maintaining strong current subscriber growth and securing sustainable and long term revenue growth for the industry.

In summary, the basic pre-requisites for profitability are:

– Efficient networks. The case studies all assume a mobile broadband network based on a technology capable of handling things like quality of service and dynamically mixing voice and data, as well as good coverage generally.
– Efficient organization and management: knowing how to allocate resources and how to determine whether mobile broadband is profitable or not.
– Understanding the capabilities of the different technologies used in a given network, and using that understanding when calculating cost.
– Handling P2P challenges in the right way. Let the system do the "thinking".
– The right business model. Flat fees and data-volume plans work, but new methods are possible.

5.4 Technical evolution / migration to next generation systems

Considerable discussion in the wireless industry has focused on the relative benefits of time-division multiple access (TDMA), code-division multiple access (CDMA) and, more recently, orthogonal frequency-division multiplexing/orthogonal frequency-division multiple access (OFDM/OFDMA). Many times, one technology or the other is positioned as having fundamental advantages over another. However, any of these three approaches, when fully optimized, can effectively match the capabilities of any other. TDMA is a case in point. Through innovations like frequency hopping, the adaptive multi rate (AMR) vocoder for voice, and EDGE for data performance optimization, TDMA is able to effectively compete with the capacity and data throughput of CDMA.

Despite the evolution of TDMA capabilities, the cellular industry has generally adopted CDMA as an IMT-2000 technology. Although there are some significant differences between CDMA2000 and wideband code-division multiple access/high speed packet access (WCDMA/HSPA), such as channel bandwidths and chip rates, both technologies use many of the same techniques to achieve roughly the same degree of spectral efficiency and typical performance. These techniques include efficient schedulers, higher order modulation, Turbo codes, and adaptive modulation and coding.

OFDM/OFDMA systems employing larger bandwidth channels provide an inherent advantage over TDMA or CDMA systems, since they transmit mutually orthogonal subchannels at a lower symbol rate, and address the problem of intersymbol interference induced by multipath propagation, greatly simplifying channel equalization.

However, for TDMA or CDMA systems, advanced receiver architectures – including options such as practical equalization approaches and interference cancellation techniques – are already commercially available in chipsets and can match this performance advantage in smaller bandwidth channels.

For larger bandwidths in combination with advanced antenna approaches such as MIMO or adaptive antenna systems (AAS), OFDM/OFDMA enables less computationally complex implementations than those based on CDMA. Hence, OFDM/OFDMA is more readily realizable in mobile devices. However, studies have shown that the complexity advantage of OFDM/OFDMA may be quite small (that is, less than a factor of two) if frequency domain equalizers are used for CDMA-based technologies. In other words, OFDM/OFDMA is currently a favored approach for radio systems that have high peak rates. OFDM/OFDMA also has an advantage in that it can scale easily for different amounts of available bandwidth. This in turn allows OFDM/OFDMA to be progressively deployed in available spectrum by using different numbers of subcarriers.

An OFDM/OFDMA technology can also take better advantage of wider radio channels (for example, 10 MHz or higher) by not requiring guard bands between radio carriers (for example, HSPA carriers).

Advances in CDMA technology, such as equalization, MIMO, interference cancellation, and higher-order modulation, allow these systems to more closely match OFDMA-based systems in 5 MHz of spectrum.

Table 2 summarizes the attributes of the different wireless multiple access techniques.

Because OFDM/OFDMA has only modest advantages over CDMA in 5 MHz channels, for the case of IMT-2000 systems, the advancement of HSPA is a logical and effective strategy in extending the life of operator's large deployments, reducing overall infrastructure investments, decreasing capital and operational expenditures, and allowing operators to offer competitive services.

OFDM/OFDMA is the access technique for next generation mobile broadband technologies with an all-IP end-to-end architecture. Today's CDMA networks are based on a circuit switched architecture optimized for voice services. The growing availability of multi-mode, multi-band devices is expected to enable seamless connectivity between today's networks and OFDM/OFDMA-based networks.

TABLE 2

Summary of different wireless multiple access techniques

Technique	Technologies employing technique	Comments
TDMA	GSM, GPRS, EDGE, Telecommunications Industry Association/Electronics Industry Association (TIA/EIA)-136 TDMA	First digital cellular approach. Hugely successful with GSM. New enhancements being designed for GSM/EDGE
CDMA	CDMA2000 1x component, CDMA2000 EV-DO, WCDMA, HSPA, HSPA+ Institute of Electrical and Electronic Engineers (IEEE) 802.11b	Basis for nearly all new 3G networks. Mature, efficient, and will dominate wide-area wireless systems for the remainder of this decade and well into next.
OFDM/OFDMA	802.16-2009/WiMAX, 3GPP LTE, IEEE 802.11a/g/n, IEEE 802.20, Third Generation Partnership Project 2 (3GPP2) UMB, 3GPP2 Enhanced Broadcast Multicast Services (EBCMCS), 3GPP Enhanced Multimedia Broadcast Multicast Service (eMBMS), Digital Video Broadcasting-H (DVB-H), Forward Link Only (FLO)	Adopted as basis for IMT-Advanced. Effective approach for broadcast systems, higher bandwidth radio systems, and high peak data rates and high average spectral efficiency in large blocks of spectrum. High tolerance to multi-path and self-interference. Support for frequency selective scheduling and fractional frequency reuse. Also provides flexibility in the amount of spectrum used. Well suited for systems planned for the next decade.

5.5 Sharing with other systems

Recommendation ITU-R M.1825 provides guidance to perform sharing studies related to systems in the land mobile service. It establishes a list of system parameters provides information on the methodologies that can be used, and describes mitigation techniques that can improve spectrum sharing.

5.5.1 BWA systems and sharing with other systems

ITU-R Reports provide technical and operational characteristics for use in sharing studies between BWA systems – including IMT-2000 systems – and other systems. These characteristics can be found in the following Reports:

– Report ITU-R M.2116 – Characteristics of broadband wireless access systems operating in the land mobile service for use in sharing studies.

– Report ITU-R M.2039 – Characteristics of terrestrial IMT-2000 systems for frequency sharing/interference analyses.

CHAPTER 6

SYSTEM TOPOLOGIES / ARCHITECTURE

There are a number of different approaches to implementing BWA systems. Deployment depends, among other things, on the type and range of services that will be offered to consumers and businesses.

6.1 RLAN

Broadband RLANs are most often deployed in a point-to-multipoint architecture (see Recommendation ITU-R M.1450). The multipoint architecture employs two system configurations:

– point-to-multipoint centralized system (multiple devices connecting to a central device or access point via a radio interface;

– point-to-multipoint non-centralized system (multiple devices communicating in a small area on an ad hoc basis.

6.2 Mesh network

A wireless mesh network architecture enables the deployment of RLANs (based on the 802.11 standard) beyond traditional hot spots and enterprise campuses to create a community area network. The characteristics are the following:

– Wireless mesh networks are multi-hop (multipoint-to-multipoint) systems in which devices assist each other in transmitting packets through the networks.

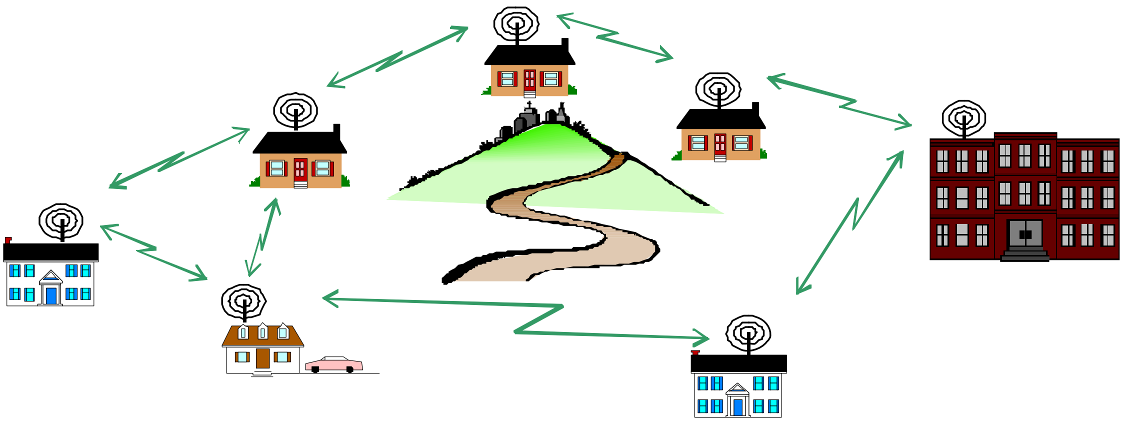
– A node can send and receive messages. It also functions as a router and can relay messages for its neighbours. In such a network, only one or a few of the nodes are connected to the external network (e.g., Internet) via cables.

– In a wireless mesh network, multiple nodes cooperate to relay a message to its destination. The mesh topology enhances the overall reliability of the network, which is particularly important when operating in harsh industrial environment.

– A mesh network offers multiple redundant communications paths throughout the network. If one link fails for any reason (including the introduction of strong RF interference), the network automatically routes messages through alternate paths.

– A mesh network is self-organizing and does not require manual configuration. Adding a new node or relocating an existing one is as simple as plugging the AC power connection in and turning it on. The network discovers the new node and automatically incorporates it into the existing system.

– Some of the challenges of designing wireless mesh networks are in balancing the tradeoffs between range and capacity, supporting and optimizing multi-hop routing, guaranteeing security and fairness amongst all the network nodes, and implementing self-management and self-healing features with minimal outside intervention.



BWA-§6.2

6.3 Cellular network architecture

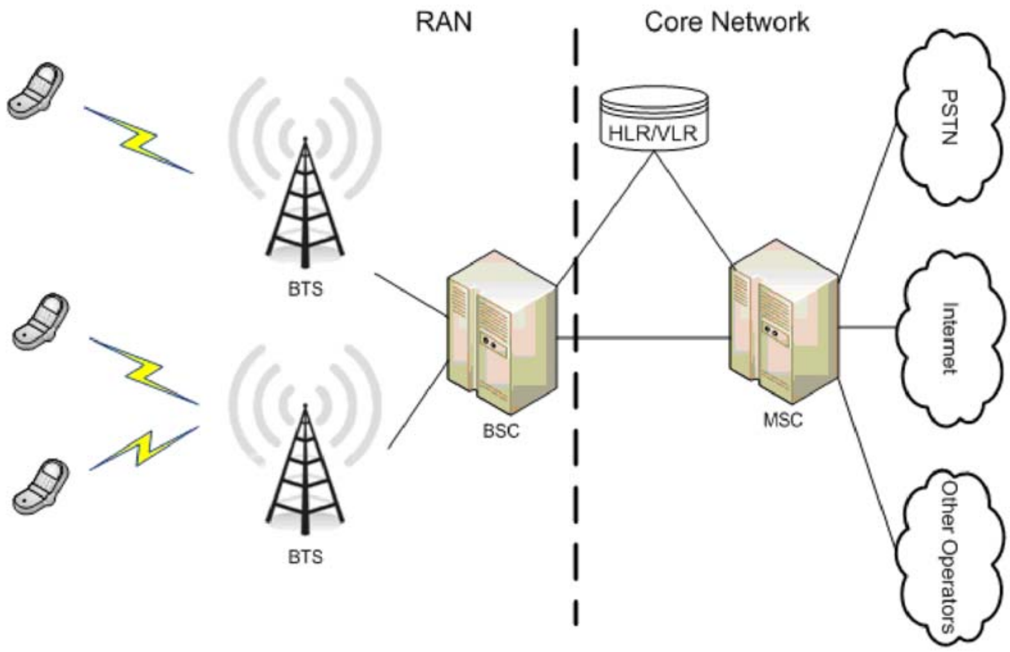
A wireless cellular network architecture enables the deployment of wide area networks (WANs) covering significant geographical areas. The high level structure is the following:

– Wireless cellular networks consist of radio access networks (RANs) connected to a Core network.

– The RANs consist of base stations and their controller functions.

– The Core network provides Mobility Management, Authentication, Authorization, etc. functions and access to the Internet or other networks.

Technology specific architectures are given in the Annexes.



BWA-§6.3

6.4 Femtocells

Femtocells are low-power cellular base stations that allow service providers to extend mobile service coverage inside the home, while backhauling cellular traffic over broadband connections. In simple terms, they are the cellular version of a Wi-Fi hot spot in the home; however, femtocells use cellular frequencies instead of Wi-Fi spectrum. Femtocells look like a typical WiFi access point (AP) or router and use a high-speed internet connection (DSL or cable) rather than the wireless network to convey a call from a handset to the carrier's switching station, where it is directed to its destination.

Indoor mobile coverage is a problem for both users and providers. When designing their networks, cellular providers must incorporate a very large link budget margin to provide for any sort of continuous coverage from outdoor to indoor transmission as the walls absorb the majority of the RF energy and the signal that does penetrate the wall is then scattered along multiple paths. As such, most homes are very difficult places from which to make or receive a cell phone call. This problem is compounded in 3G networks, which use higher frequency bands than cellular networks. The result is that 3G signals have more difficulty penetrating buildings than cellular or 2G signals.

Moreover, the fast data rates required for new mobile data services applications such as music, video and podcasts are only possible when the quality of the signal is strong and signal quality decreases with the inverse square of distance. The farther one is from a base station, the weaker the signal.

By providing a high quality signal to indoor users of mobile data services via a home base station, femtocells can encourage the use of such services. From provider's standpoint, femtocells can assist in reducing customer churn brought about by a network's poor indoor coverage.

While indoor coverage can be designed into the outdoor macro network design, it is cost prohibitive to design RF coverage for 100% of indoor scenarios. By acting as mini base stations, femtocells are intended to allow for seamless outdoor/indoor coverage.

When users enter their homes and come within range of their femtocell base station, the handset will hand off calls to the femtocell, even if the signal from the macro or external network is still strong.

ANNEX A

1 Abbreviations and Acronyms

3GPP	3rd Generation Partnership Project
3GPP2	3rd Generation Partnership Project 2
AAA	Authentication, Authorization, Accounting
AAS	Adaptive antenna systems
A-MAS	adaptive multi-antenna signal
AMR	Adaptive multi rate
AP	access point
ASN	Access service network
ASP	Application service provider
ATs	access terminals
bit/s	bits per second
BRCH	block resource channel
BWA	Broadband wireless access
CS	Client server
CSN	Connectivity (Core) service network
DLC	Data link control
DRCH	Distributed resource channel
EDGE	Enhanced data rates for global evolution
e.i.r.p.	Equivalent/effective isotropically radiated power
eNBs	evolved UTRAN nodeBs
EPC	Evolved packet core
FDD	Frequency-division duplex
FDMA	Frequency-division multiple access
F-DPICH	forward dedicated pilot channel
FEC	Forward error correction
FFR	fractional frequency reuse
FFT	Fast Fourier transform
FMC	Fixed mobile convergence
FOSI	fast other sector indication

H-ARQ	Hybrid automatic repeat request
HC-SDMA	High capacity-spatial division multiple access
H-FDD	Half frequency division duplex
HS	Home server
HSDPA	High speed downlink packet access
HSPA	High speed packet access
HSUPA	High speed uplink packet access
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IM	Instant messaging
IMT-2000	International Mobile Telecommunications-2000
ISI	inter-symbol interference
ISM	Industrial, Scientific and Medical
ITS	Intelligent Transport Systems
LE	License-Exempt
LMS	Least mean square
LoS	Line-of-sight
LTE	Long term evolution
MAC	Media access control
MAN	Metropolitan area network
MCS	modulation and coding scheme
MCW	multi-codeword
MIMO	Multiple-input and multiple-output
MMDS	Multichannel Multipoint Distribution Service
MS	Management server
NAP	Network access provider
NGN	Next generation network
NLoS	Non line-of-sight
NSP	Network service provider
NWA	Nomadic wireless access
OFDM	Orthogonal frequency-division multiplexing
OFDMA	Orthogonal frequency-division multiple Access
PHY	Physical layer
PKMv2	Key management protocol
p.s.d.	power spectral density

PSS	packet services switch
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase shift keying
RAN	radio access network
RATGs	radio access technique groups
RF	Radio frequency
RLAN	radio local area networks
RLP	Radio link protocol
RMS	Recursive least squares
RNC	radio network controller
RNS	radio network subsystems
SC-FDMA	Single carrier FDMA
SCW	single codeword
SISO	Single-input and single-output
SOHO	Small office home office
TDD	Time-division duplex
TDMA	Time-division multiple access
UE	user equipment
UMB	Ultra mobile broadband
WCDMA	Wideband code-division multiple access

2 Further description of some terminology and definitions

MIMO

A technique for boosting wireless bandwidth and range by taking advantage of multiplexing. MIMO algorithms send information out over two or more antennas. The radio signals reflect off objects, and MIMO uses these paths to carry more information, which is recombined on the receiving side by the MIMO algorithms.

OFDM

Orthogonal frequency-division multiplexing (OFDM) is an FDM modulation technique that divides a communications channel into a small number of equally spaced frequency bands, each of which carry a portion or sub-signal of the radio signal. These sub-signals are then transmitted simultaneously at different frequencies to the receiver.

OFDMA

Orthogonal frequency-division multiple access (OFDMA) is a multiple access scheme for OFDM systems. It works by assigning a subset of subcarriers to individual users.

– OFDMA is the "multi-user" version of OFDM

- Functions by partitioning the resources in the time-frequency space, by assigning units along the OFDM signal index and OFDM sub-carrier index.
- Each OFDMA user transmits symbols using sub-carriers that remain orthogonal to those of other users.
- More than one sub-carrier can be assigned to one user to support high rate applications.
- Allows simultaneous transmission from several users ⇒ better spectral efficiency.
- Multiuser interference is introduced if there is frequency synchronization error.

OFDMA is used in the mobility mode of IEEE 802.16 WirelessMAN Air Interface standard.

Scalable OFDMA access

SOFDMA is a modulation scheme that can assign a subset of subcarriers to a number of individual users, thereby allowing multiple users to simultaneously connect on the same frequency without interference.

ANNEX B

DESCRIPTIONS OF STANDARDS

1 High Capacity-Spatial Division Multiple Access (HC-SDMA) radio interface technology and iBurst™ broadband wireless system

1.1 Overview: HC-SDMA

HC-SDMA is a new ANSI standard (ATIS.0700004.2005) developed by the Alliance of Telecommunications Industry Solutions (ATIS), formerly Committee T1, adhering to its Wideband Wireless Internet Network Access (WWINA) requirements and embodied in the iBurst Broadband Wireless system already deployed commercially on several continents.

The HC-SDMA standard is available at:

– High Capacity – Spatial Division Multiple Access (HC-SDMA) Radio Interface Standard (ATIS-0700004.2005, September 2005). Available at: https://www.atis.org/docstore/product.aspx?id=22595

Based on a commercially proven technology, the HC-SDMA standard specifies the radio interface for the wide-area mobile broadband iBurst[16] system offering a combination of high speed, wide range and high base-station capacity.

An iBurst system is an end-to-end, standards-based, pure IP solution for wireless data and VoIP, with equipment that is available from major manufacturers. Today's commercially available end-user devices include PCMCIA cards targeted at laptop and PDA users, and desktop units for home and small business applications. Off-the-shelf routers and access points can also connect directly to the desktop unit. The iBurst solution offers per-user data rates in excess of 1 Mbit/s today. IBurst base stations, which operate in unpaired spectrum, provide 20 Mbit/s net usable throughput in 5 MHz and 40 Mbit/s throughput in 10 MHz. The iBurst system is commercially deployed in Australia, South Africa, Kenya, Ghana, Azerbaijan, Norway, and Lebanon and has numerous other trial deployments in the Americas, Asia, Europe and Africa.

The HC-SDMA standard leverages time-division duplex (TDD) and adaptive multi-antenna signal (A-MAS™[17]) processing technologies, along with state of the art spatial processing algorithms to produce one of the world's most spectrally efficient mobile telecommunications systems that can provide a mobile broadband service deployed in as little as a single (unpaired) 5 MHz band of spectrum licensed for mobile services. IBurst is designed to operate in licensed spectrum below 3 GHz to offer full mobility and wide area coverage which is the best suited for mobile applications.

Because it is based on TDD technology and does not require symmetrical paired bands separated by an appropriate band gap or duplexer spacing, iBurst can easily be re-banded for different frequency bands.

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[16] Information on the iBurst Association is available at: http://www.iburst.org/

[17] A-MAS™ is a trademark owned by the ArrayComm.

1.2 Description of the HC-SDMA radio interface

The key features of the HC-SDMA radio interface are:

– TDD/TDMA, 625 kHz channel spacing;
– peak per-user data rates from 1 to 16 Mbit/s downlink and from 345 kbit/s to 5.5 Mbit/s uplink, with the higher peak rates achieved via carrier aggregation;
– 4 bit/s/Hz/cell spectral efficiency (20 Mbit/s in 5 MHz);
– 3:1 downlink/uplink throughput asymmetry;
– tiered modulation and channel coding for link quality adaptation;
– forward error correction (FEC) and automatic repeat request (ARQ) for error-free link within coverage area;
– bandwidth on demand, dynamic resource allocation;
– adaptive antenna spatial processing for enhanced signal quality, resource management and collision resolution;
– mobility (handover) support;
– built-in air interface quality of service (QoS) support.

1.2.1 Air interface handover

Handover of an end-to-end IP session is the combined result of handover in the radio network from one cell to another with re-routing of the end-user's IP session to reflect the new serving cell. One type of carriage supported by the HC-SDMA air interface is Point-to-Point Protocol (PPP) encapsulated IP data between an IP Service Provider and an end-user device such as a laptop. PPP [IETF RFC 1661, *et al*] is a low-overhead – one to two bytes per IP packet – tunnelling protocol with the advantages of near-universal availability on IP devices, combined with universal deployment of equipment for PPP termination, provisioning, billing, rating and so forth in service provider networks. PPP also has the advantage of segregating IP sessions in the transport network, thereby allowing overlapping address spaces as typically used by corporate VPNs. One type of handover currently supported by the air interface is the lightweight Simple IP model employed by 3GPP2 (cf. 3GPP2 P.S0001-B, "Wireless IP Network Standard") for micro-mobility, complemented when necessary by Mobile IP (cf. IETF RFC 2002, *et al*), for example when handing over to a dissimilar access network such as IEEE 802.11.

The HC-SDMA air interface's make-before-break handover scheme is user terminal (UT)-directed. Each UT monitors the broadcast channels from surrounding base stations (BSs) and ranks candidates based on signal power and other factors. A UT can perform these measurements as well as register with a candidate new serving BS while exchanging TCH data with its current serving BS. The handover for user data is make-before-break with the TCH data being redirected to the new serving BS after successful registration.

1.2.2 Adaptive multi-antenna signal processing technology

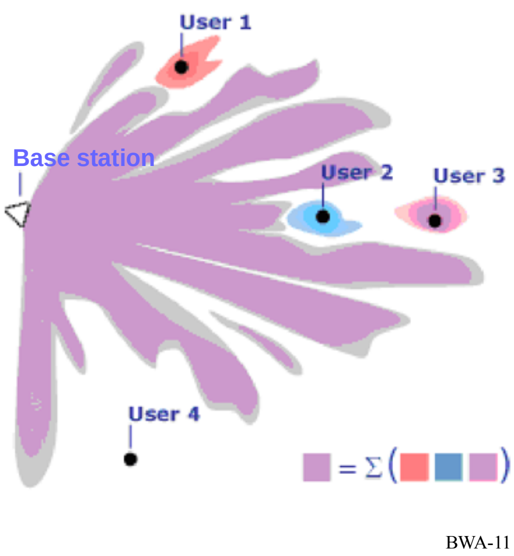
At the core of the HC-SDMA standard is adaptive multi-antenna signal (A-MAS) processing, also referred to as spatial processing technology that dramatically increases the efficient use of radio spectrum and results in exceptional improvements in the capacity, coverage and service quality of wireless networks.

A-MAS creates these significant benefits through interference management and signal quality enhancement. A typical base station uses a single antenna or pair of antennas to communicate with its users. An A-MAS equipped base station employs a small collection of simple antennas, an "antenna array," with sophisticated signal processing to greatly reduce the amount of excess energy radiated by the base station. At the same time, the signal processing allows the base station to listen selectively to its users, mitigating the effects of interference presented by other users in the network. The antenna array also provides a gain in signal power, improving the quality of the radio link for the same amount of total power radiated by the base station and user terminal. Improved link quality translates into higher data rates, extended range and longer battery lifetimes at the user terminals.

With A-MAS technology, each cell in a network can use the same frequency allocation by eliminating inter-cell interference. In fact, A-MAS technology even enables a system to reuse a frequency allocation multiple times within a given cell by directing energy only where it is required. HC-SDMA infrastructure supports up to three spatial channels of SDMA – which means each radio resource can be used up to three times per sector. Figure 11 illustrates the effect of A-MAS technology at work in HC-SDMA systems.

FIGURE 11

Illustration of A-MAS SDMA at work in an HC-SDMA base station



1.2.3 Spectral efficiency of the HC-SDMA radio interface

Spectral efficiency measures the ability of a wireless system to deliver information, "data services," with a given amount of radio spectrum. In cellular radio systems, spectral efficiency is measured in bits/second/Hertz/cell (bit/s/Hz/cell). Many factors contribute to the spectral efficiency of a system, including the modulation formats, air interface "overhead" (signalling information other than user data), multiple access method, and usage model, among others. These factors all contribute to the bits/second/Hertz dimensions of the unit. The appearance of a "per cell" dimension may seem surprising, but the throughput of a particular cell's base station in a cellular network is almost always substantially less than that of a single cell in isolation. The reason is self-interference generated in the network, requiring the operator to allocate frequencies in blocks that are separated in space by one or more cells. This separation is represented by a reuse factor, where a lower number is representative of a more efficient system.

The HC-SDMA system's spectral efficiency is represented in the calculation below:

– 625 kHz carriers;

– three time slots per carrier;

– 475 kbit/s of user data per slot;

– effective frequency reuse pattern of 1/2.

This yields the following spectral efficiency:

(3 slots x 475 kbit/s/slot) / 625 kHz / 0.5 reuse = 4.28 bit/s/Hz/cell

1.2.4 Radio system capacity and economics

An HC-SDMA system's spectral efficiency of 4 bit/s/Hz/cell means that an HC-SDMA radio network can support a given mobile customer base with far fewer sites and far less spectrum than would be required with other technologies and, hence, with greatly reduced capital and operating costs. With 10 MHz of usable spectrum, for example, each HC-SDMA base station would provide 40 Mbit/s of access capacity. A-MAS technology's improvement in link quality or signal strength translates roughly into a doubling of range (or a quadrupling of area) for the HC-SDMA system.

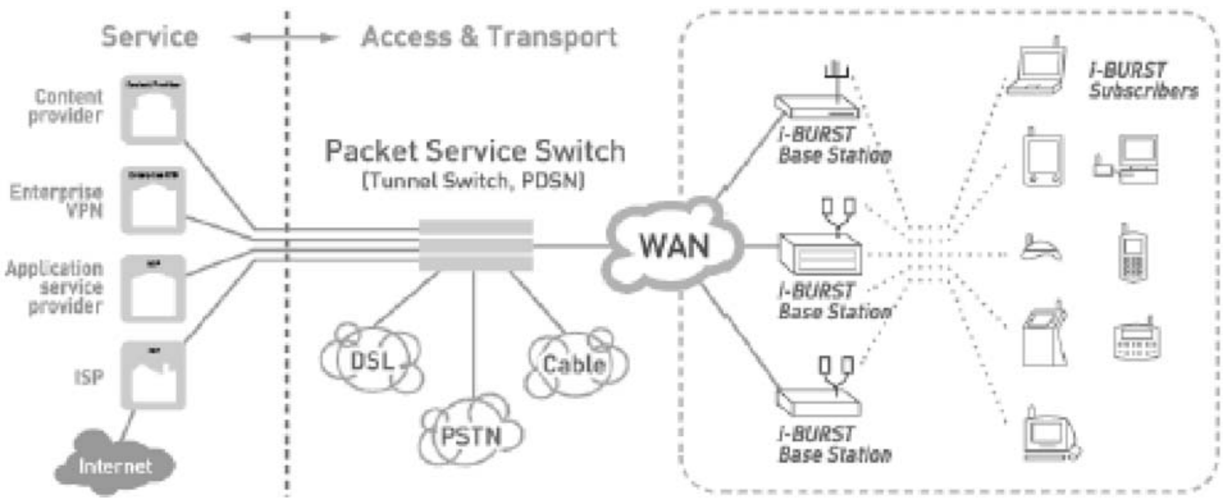
1.3 iBurst network architecture

A common access and transport network architecture

Figure 12 depicts a common access and transport iBurst network allowing several service providers to simultaneously provide branded services to their respective end users. A separate business unit of the access and transport operator could, itself, be one of those service providers.

FIGURE 12

Common access and transport network



BWA-12

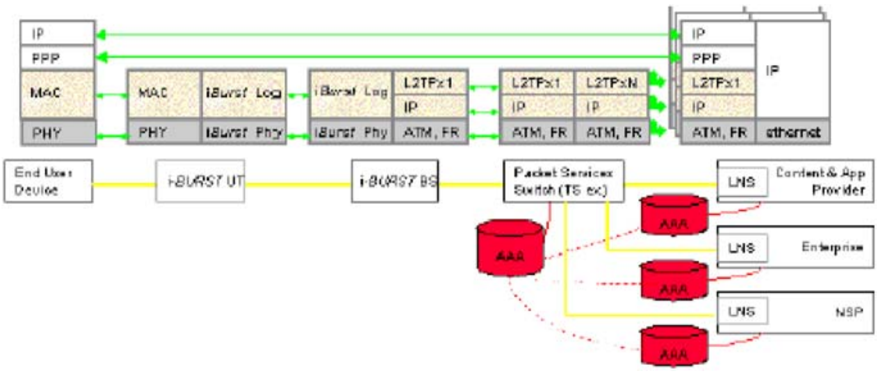
The access and transport operator aggregates a variety of "last mile" access technologies and then switches end-user sessions to the appropriate service provider. Key to this scheme is the packet services switch (PSS), which acts as an aggregation point and as a “switchboard” to route user sessions. The switching decisions are typically made on the basis of structured usernames provided by the user during PPP authentication. For example, logging in as “joe@aol.com” would cause the user session to be directed to AOL’s site and request authentication for user “joe,” while logging in as “mary@hercompany.com” would cause the user session to be connected to her company’s site, perhaps for corporate VPN access, and request authentication for user “mary.” PSS technology is widely deployed in the networks of major ISPs and carriers. In addition to aggregating user sessions from a variety of media, the PSS presents these sessions in a unified fashion to the service provider’s network, freeing the service provider of the need to maintain different content and service bases for each access class.

1.4 iBurst protocol stack

The iBurst system enables end-to-end IP-over-PPP connectivity between the service providers and their customers, consistent with the predominant service model in the wired access world. Moving left to right in Fig. 13, one can see that a user’s PPP session is carried by a variety of different media and protocols.

FIGURE 13

iBurst user data network elements and protocol stack



BWA-13

Figure 13 also depicts Authentication, Authorization, Accounting (AAA) servers and AAA connections between the access and transport domain and the service domain.

1.5 iBurst network service offerings

1.5.1 Mobile service offering

Mobile connectivity is provided through the iBurst Access Card. When connected to a mobile device such as a laptop or PDA, it provides connectivity on the move as long as the device remains inside the network coverage area.

1.5.2 Fixed / Portable service offering

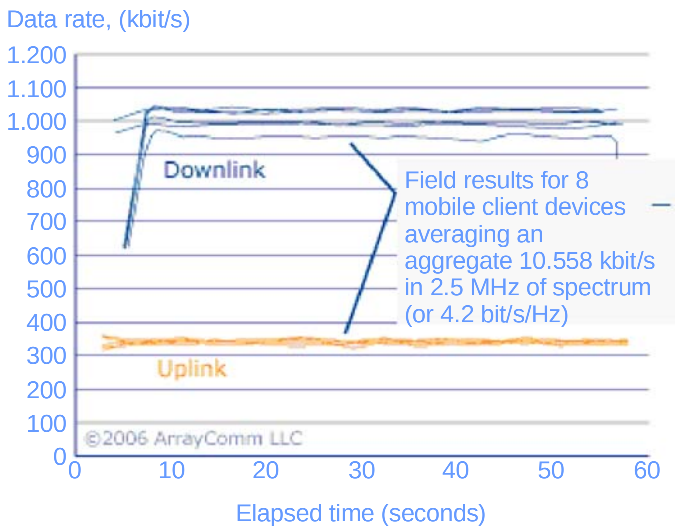
The iBurst Access Bridge provides connectivity in a primarily fixed mode. The device looks similar to a traditional modem. It has a connection to mains power, a small extending aerial and ports allowing connectivity through either Ethernet or USB. This provides the benefits of a fixed broadband connection with the addition of portability, allowing the service to be disconnected by simply unplugging it from the mains and moving it to a new location to be reconnected by powering up the iBurst Access Bridge again. The iBurst Access Bridge can be connected to a single computer for access or attached to a local area network or a wireless network for the access to be shared between several devices in a home or office.

1.6 iBurst commercial network performance

Engineered from the ground up to take maximum advantage of A-MAS technology, iBurst (HC-SDMA) offers up to 20 Mbit/s of aggregate usable IP-traffic capacity per sector in each 5 MHz TDD allocation and supports both fixed and fully mobile broadband users. As the standard's name implies, the key to the system's capacity is spatial processing and interference management software, supporting up to 3 SDMA channels on each physical carrier in each cell. Figure 14 shows the performance of commercially deployed iBurst (HC-SDMA) networks that demonstrate more than 4.0 bits/s/Hz/sector spectral efficiency with mobile client devices.

FIGURE 14

Commercial performance of iBurst (HC-SDMA) networks



BWA-14

From both extensive testing of these networks and enthusiastic subscriber response, the substantial performance value of A-MAS in HC-SDMA systems has been validated in the forge of commercial service.

ArrayComm is a registered trademark, and iBurst is a trademark of ArrayComm, LLC.

2 eXtended Global Platform: XGP

eXtended Global Platform: based on microcellular networks for broadband wireless access systems.

2.1 Background: eXtended Global Platform: XGP

eXtended Global Platform (or Next-generation PHS in another name) is a new mobile BWA system, which was enhanced from the mature original PHS by introducing latest technologies. The standard of eXtended Global Platform was developed by XGP Forum as one of the new BWA methods with high data rates for both (up/down) links and a high efficiency of spectral utilization.

"XGP Forum" is an open international association established in 1995 firstly as "PHS MoU Group", which is consisted of companies and organizations involved in or interested in PHS or XGP services, such as telecommunications carriers, service providers, equipment manufacturers, technology providers, telecommunications authorities, and public organizations. The main objective of XGP Forum is to introduce, operate and spread the PHS and XGP on a world-wide basis and thereby to contribute to the improved convenience of telecommunications users and to the consequential benefit of the people in the world.

PHS, "Personal Handy-phone System", was originally developed as a digital cordless telephone system upon the early concept of fixed/mobile convergence (FMC). However, PHS can serve, and actually has been utilized, as an ordinary mobile phone system such as PDC or GSM, because of its handover function and its high-quality voice service. Therefore, PHS is now regarded as one of mobile phone systems, which has some unique concepts such as "micro-cell". Because of micro-cell, PHS doesn't need wide frequency bandwidth, and large facility for radio equipment. Therefore, PHS is comparatively easy to introduce because its scale of investments is small at the beginning phase of deployment. PHS has expanded worldwide, especially in Asia after its start up in Japan. Today, the number of PHS subscribers has reached over 100 million in the world.

PHS systems including eXtended Global Platform utilize micro-cell concept as a main feature. Generally speaking, a micro-cell system is superior in an efficiency of spectral utilization per one square kilometer to other macro-cell systems. The main causal factor for realizing the micro-cell system is an autonomous decentralized control method for the channel assignment. And because of that, the advantages of PHS are not only the improved efficiency of spectral utilization but also its simplified cell designing while rigorous cell designing is necessary in typical macro-cell systems.

PHS specification has evolved repeatedly since the original standard decision, and its maximum data rate will be 1Mbit/s in "Enhanced PHS" commercial service in the near future. The air interface of "Enhanced PHS" actually has functions such as packet switching communication, multi-channel connection, various rate modulation (BPSK – 256-QAM), adaptive modulation, half-rate transmission, and multi-slot bundle, most of which were not included in PHS original standard published in 1993. The "Enhanced PHS" is suitable for not only mobile phone systems but also for fixed wireless access (FWA) systems, because PHS was originally started from a digital cordless telephone system based on the network facility for a fixed service and it is not difficult to deploy macro-cell networks (several kilometers in cell radius) for services in suburban area, although the network basically operates on micro-cell design.

The "Enhanced PHS" introduced here is, in a broad sense, included in "Next-generation PHS". However, "Next-generation PHS", in a narrow sense, indicates a BWA system as "eXtended Global Platform" which is utilizing orthogonal frequency division multiplexing (OFDM) technology besides basic PHS concepts, and it will realize higher maximum data rate of over 20 Mbit/s, and higher efficiency of spectral utilization.

2.2 Features of eXtended Global Platform in comparison with the Enhanced PHS

As explained above, the term "Next-generation PHS" in a broad sense indicates two systems, one of which is the "Enhanced PHS" based on time division multiple access/time division duplex (TDMA/TDD), and the other is narrowly-defined "Next-generation PHS (eXtended Global

Platform)" based on orthogonal frequency division multiple access (OFDMA) +TDMA/TDD. The comparison of the "Enhanced PHS" and the narrowly-defined "Next-generation PHS (eXtended Global Platform)" is shown in Table 3. "PHS" had grown up to the "Enhanced PHS", and also will grow up to the narrowly-defined "Next-generation PHS (eXtended Global Platform)" by integrating technical improvements.

TABLE 3

Basic elements of next-generation PHS /eXtended Global Platform in comparison with the enhanced PHS

	(Enhanced) PHS	**Next gen. PHS**
Multiple access method	TDMA	OFDMA/TDMA
Duplex method	TDD	TDD
Operation Bandwith	300 kHz, 900 kHz	1.25-20 MHz
Frame duration	5 ms/Symmetric	5 ms / Symmetric
Modulation method	BPSK-256-QAM	BPSK-256-QAM
Maximum data rate (SISO, up/down total)	1 024 kbit/s (300 kHz, single-channel, 256-QAM	38 Mbit/s (10 MHz, down-256-QAM, up-64-QAM
Basic cell size	Micro cell	Micro cell
Sub-carrier spacing	–	37.5 kHz
FFT size	–	256 (10 MHz) / 512 (20 MHz)
Data length	–	26.667 µs
GI	–	3.333 µs
Symbol length	–	30.00 µs
Technologies of efficient spectral utilization	Adaptive array ant. SDMA	Adaptive array ant. SDMA, MIMO

"eXtended Global Platform" achieves high efficiency of spectral utilization by utilizing technologies such as adaptive array antenna (AAA), spatial division multiple access (SDMA) and multiple-input multiple-output (MIMO). It also has, as the preceding systems do, the functions of autonomous decentralized control for dynamic channel assignment in order to make the micro-cell network work efficiently, thereby achieving high efficiency of spectral utilization.

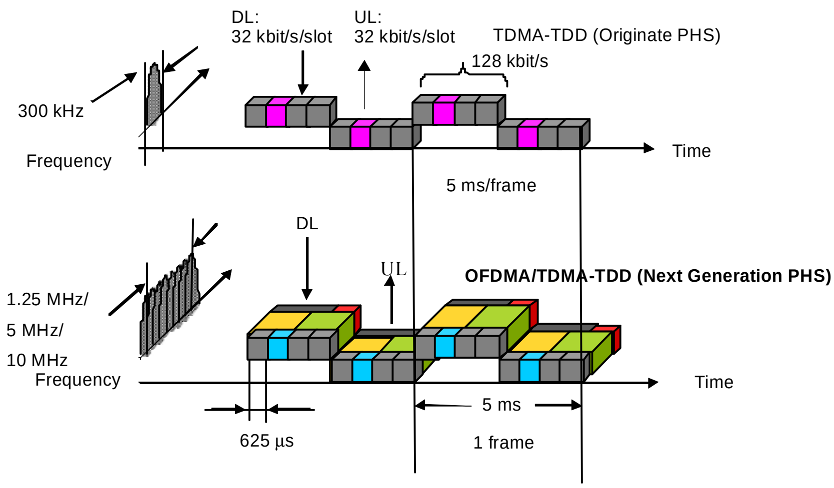
2.3 Link access technique

As depicted in Fig. 15, the "eXtended Global Platform" radio interface has two dimensions for multiple access. One dimension is time domain control realized by TDMA and the other dimension is frequency domain control realized by OFDMA. In the time domain, the time-frame structure is the same as that of the original PHS which is 5 ms symmetric frame. In the frequency domain, one or more sub-channel consisted of OFDM subcarriers would be flexibly allocated to users, depending on conditions such as user's demand, channel usage, and channel quality.

The time-frame has 8 slots of 5 ms each, the consecutive 4 slots are for downlink, and the other consecutive 4 slots are for uplink. Each slot of 4 slots is separately assigned to users and also can be assigned continuously for one user. Moreover, continuous assignment of more than 4 slots is possible when asymmetric frame structure is employed.

FIGURE 15

TDMA-TDD in original PHS and OFDMA/TDMA-TDD in eXtended Global Platform

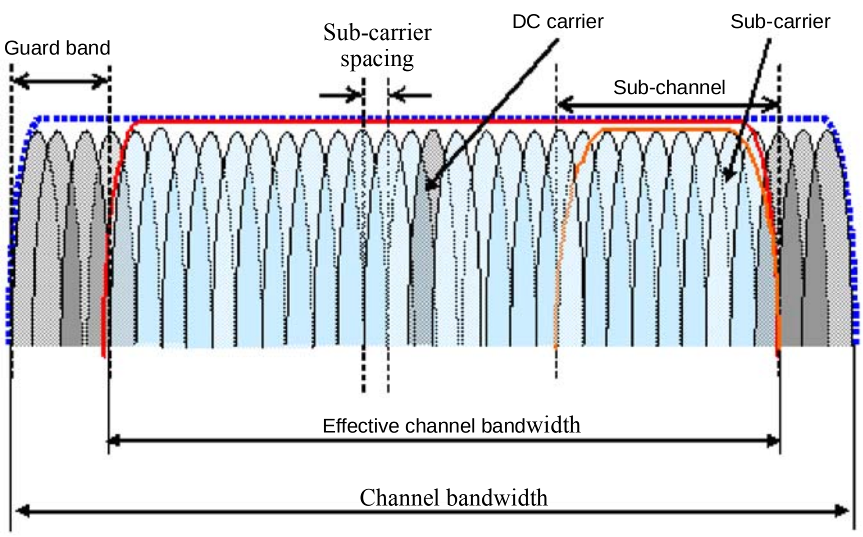


BWA-15

In the frequency domain control employing OFDMA, the radio interface can use several defined classes of effective bandwidth: 1.25 MHz, 2.5 MHz, 5 MHz, 10 MHz and 20 MHz. As shown in Fig. 16, "eXtended Global Platform" has multiple sub-channels in its effective channel bandwidth, and each sub-channel consists of multiple sub-carriers. The sub-carrier spacing in this system is 37.5 kHz which is comparatively wider than typical OFDM systems.

FIGURE 16

OFDM structure



BWA-16

2.4 Other major techniques

Other major techniques are described below. These techniques achieve increase of the throughput, expansion of the cell area and improvement in the QoS.

Adaptive array antenna

With the adaptive array antenna, a cell station can adaptively form a beam toward an intended portable station. This adaptive beam forming technique enables cell stations to concentrate their transmit power to the intended users and to interfere less to unintended users. Therefore, it will improve the overall performance of the system. The technique has been already employed in the original PHS; however, eXtended Global Platform is also suitable for performing adaptive beam forming based on adaptive array antenna because it inherits the symmetric TDD frame. Utilizing the reciprocity of a TDD channel, the signal amplitude and phase for each antenna are controlled according to the channel state estimated from the portable stations received signal.

MIMO

Multiple-input multiple-output (MIMO) is a technique to transfer multiple data streams in parallel by using multiple antennas at the transmitter and receiver. Since the data streams are sent simultaneously in the same frequency band, MIMO can increase data throughput without additional bandwidth compared to single-input and single-output (SISO).

2.4.1 Link adaptation control

To satisfy required quality levels for radio links, transmit power control and selective modulation and coding scheme (MCS) control are to be performed as link adaptation controls. A portable station sends its channel quality indicator (CQI) to the cell station, and the cell station controls parameters such as transmit power and MCS for next transmission based on adaptive algorithms.

2.4.2 Autonomous decentralized control method for the channel assignment

In eXtended Global Platform, each cell station assigns the best channels for the portable station link assignment requirements. Although the system does not need detailed cell designing taking into account cell locations and frequency assignment, the cell stations will acquire and release the frequency resource in an autonomous distributed manner.

2.4.3 Error detection and correction

When receiving the data, the reception side has the error detection and correction system.

2.4.4 H-ARQ

H-ARQ, Hybrid Automatic Repeat Request, is supported for this system to keep the high reliable communication quality. H-ARQ is the error control system, which combines the FEC, forward Error Correction and Automatic Repeat Request.

2.5 System architecture

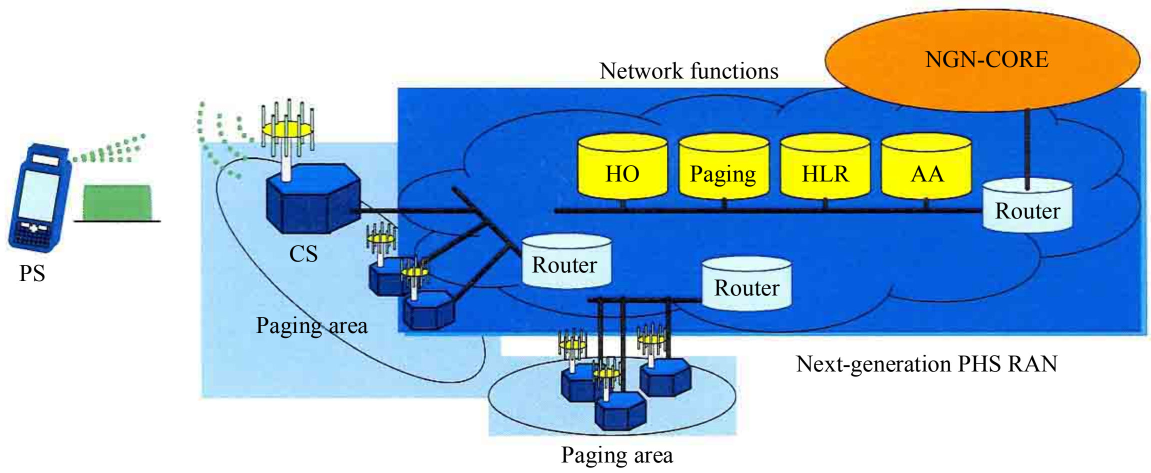
In eXtended Global Platform system, the network backbone should be all-IP network for both voice and data services. All data should be conveyed on packet, and the voice traffic also should be transferred on Vo-IP. Considering the quality of the network for voice and data communications, QoS control is absolutely necessary.

Total network configuration should be considered as next generation network (NGN) system. Some providers might adopt NGN Core for all-IP-NW core.

The example of future network is shown in Fig. 17. The terminals of all-IP-System may have always IP address and its services may be realized by using the applications based on IP technology.

FIGURE 17

Next-generation PHS /eXtended Global Platform network



For the eXtended Global Platform radio access network (RAN), the following functions have been defined: a) paging-function, b) home location register (HLR)-function, c) handover (HO)-function, d) authentication and authorization (AA)-function.

a) Paging-function

Original PHS system has the Paging function. Paging Area consists of several cell stations, and portable station, which will enter into this area, or switched on in this area, will register its location to Location Register. When the portable station is paged, all the cell stations in this paging area transmit Paging message.

b) Home location register (HLR)-function

HLR, Home Location Register, has the function to control the location information for each portable station. eXtended Global Platform system has the stand-by zone control function, which is wider than Paging area, and controls Paging function in this stand-by zone by this HLR function.

c) Handover (HO)-function

Hand-over function in eXtended Global Platform realizes the seamless radio link connection between portable station and cell station switching to other cell station, without interrupting voice communication. For example, this will be realized by multi-link to both originate and destination cell station from portable station, and by transferring the information to destination cell station network, such as IP session and user authentication information.

d) Authentication and authorization (AA)-function

When portable station accesses to network, Network has the Authentication and Authorization function for this portable station or equipment terminals. This authentication function will be classified to equipments, users, and services, according to the system service criteria.

2.6 Cell designing of eXtended Global Platform

As mentioned earlier, eXtended Global Platform is adopting micro-cell system, which utilizes the autonomous decentralized control method. Using this method, even in the case of macro-cell, it is not necessary to perform strict cell designing before installation of new cell stations. Therefore, the coordination of cell deployment is simple and speedy without complicated theories, measurements, or calculations. Moreover, the reinforcement of service area can be achieved simply and speedily by just installing cell stations at suitable places. Therefore, eXtended Global Platform radio network is easy to maintain and expand compared to other systems that require the strict cell designing plan.

The specifications for the eXtended Global Platform system (also known as next generation PHS) can be found at these locations:

A-GN4.00-TS Next Generation PHS Specifications, http://www.xgpforum.com/document/

STD-T95 OFDMA/TDMA TDD Broadband Wireless Access System (Next Generation PHS), http://www.arib.or.jp/english/html/overview/st_ej.html

3 IMT-2000 CDMA Multi-Carrier

3.1 Introduction

CDMA Multi-Carrier (IMT-MC) or CDMA2000 represents part of the IMT-2000 family of standards and includes CDMA2000 1X and CDMA2000 1xEV-DO technologies. IMT-2000 technology specifications are defined in a number of ITU Recommendations, most notably Recommendation ITU-R M.1457 and the ITU-T Q.174x series of Recommendations, which respectively describe the radio interfaces and core networks for the IMT-2000 family of standards. IMT-2000 is the result of collaboration of many entities, inside the ITU (ITU-R and ITU-T), and outside the ITU (3GPP, 3GPP2, etc.).

The specifications for the IMT-2000 CDMA Multi-Carrier High Rate Packet Data (also known as cdma2000 1xEV-DO) can be found at this location:

http://www.3gpp2.org/Public_html/specs/index.cfm

The CDMA2000 EV-DO family of standards provides the following key capabilities/features:

– full QoS and efficient support for a wide variety of packet data applications such as VoIP, video telephony, wireless gaming, push-over-cellular, broadcast/multicast;
– backward compatible multi-carrier support up to 20 MHz;
– broadcast/multicast;
– flexible duplex;
– hybrid frequency re-use.

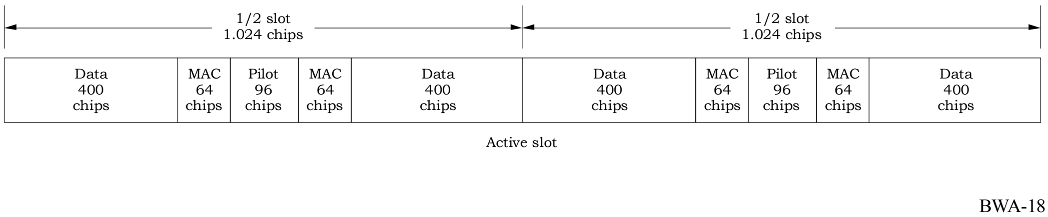
3.2 CDMA2000 1xEV-DO Release 0

As in previous CDMA and CDMA2000 systems, the 1xEV-DO Release 0 carriers are allocated 1.25 MHz bandwidth and use a direct-sequence (DS) spread waveform at 1.2288 Mcps.

The fundamental timing unit for downlink transmissions is a 1.66…ms slot that contains the pilot and MAC channels and a data portion that may contain the traffic or control channel as shown in Fig. 18. Unlike IS-2000 where a frame is 20 ms, a frame in 1xEV-DO Release 0 is 26.66…ms.

FIGURE 18

1xEV-DO Release 0 downlink slot structure



The pilot channel is transmitted at full-power for 96 chips every half-slot providing not only a reference for coherent demodulation of traffic and MAC channels but also a 1 200 Hz sampling of the wireless channel state. The MAC channel consists of a Reverse Activity (RA) channel and up to Reverse Power Control (RPC) channels. The RA channel from a particular sector provides a 1-bit feedback to all the terminals that can receive that sectors forward link indicating whether or not its uplink load exceeds a threshold. The Traffic channel is transmitted to a single user at a time. 1xEV-DO Release 0 uses a TDM downlink instead of CDM downlink used in IS-2000 systems. The traffic channel data rate used by the access network for transmission to the access terminal is determined by the data rate control (DRC) message sent by the access terminal on the uplink. A combination of Hybrid – Automatic Repeat re-Quest (H-ARQ) and multi-user diversity improve performance in a variety of channel conditions, the former results in capacity gains in fast-fading channels and the latter in slow-fading channels.

The uplink in 1xEV-DO Release 0 is similar to that in IS-2000 with a key differences being the use of stochastic distributed rate control with direct measurement of Rise-over-Thermal (RoT). The uplink MAC channel protocol defines the rules used by each access terminal and employs a distributed algorithm subject to feedback control.

3.3 CDMA2000 1xEV-DO Revision A

Key enhancements offered by cdma2000 1xEV-DO Revision A are:

– An uplink physical layer with Hybrid ARQ (H-ARQ) support, higher order modulation (QPSK and 8-PSK), higher peak rate (1.8 Mbit/s), and finer rate quantization.

– An uplink MAC layer with contention-managed multi-flow QoS support, comprehensive network control of spectral efficiency and latency trade-off for each flow and a more robust interference control mechanism that permits system operation at higher rise-over-thermal (RoT) or load.

– A downlink physical layer with higher peak rate (3.1 Mbit/s), finer rate quantization, and short packets that provide transmission delay reduction and better downlink resource utilization.
– A downlink MAC layer with Packet Division Multiple Access (PDMA), transmission delay reduction by permitting transmission to terminals that report a null-rate DRC, and seamless adaptive server selection that eliminates transmission delays due to downlink server changes. Using PDMA the access network can transmit data to multiple users using the same physical layer packet thereby improving not only the physical layer packing efficiency but also the transmission latency.
– Rapid connection setup for applications that require "instant-connect" via use of shorter inter-packet intervals (that allow a reasonable trade-off between rapid connection setup and maximizing terminal battery life) and a higher rate access channel.

3.3.1 Downlink

Key enhancements to the physical layer and MAC layer in the DO Revision A downlink are:
– short-packets i.e., 128-bit, 256-bit, and 512-bit;
– higher peak data rates (3.1 Mbit/s) and finer rate quantization;
– one-to-many mapping of DRC index to transmission formats;
– packet division multiple access via the use of multi-user packets;
– seamless adaptive server selection.

Substantial improvement in link (or packing) efficiency can be achieved by the use of multi-user packets, i.e., transmitting data to multiple access terminals using the same physical layer packet. This technique enables support of large numbers of low-rate, delay-sensitive applications. The downlink scheduler continues to serve single user packets using opportunistic scheduling to exploit multi-user diversity where possible.

3.3.2 Uplink

Key enhancements to the physical uplink in DO Revision A are:
– physical layer H-ARQ;
– higher data rates (peak data rate of 1.8 Mbit/s/1.25 MHz) and finer rate quantization;
– comprehensive centralized control with minimal signaling overhead.

3.3.3 Comprehensive centralized control

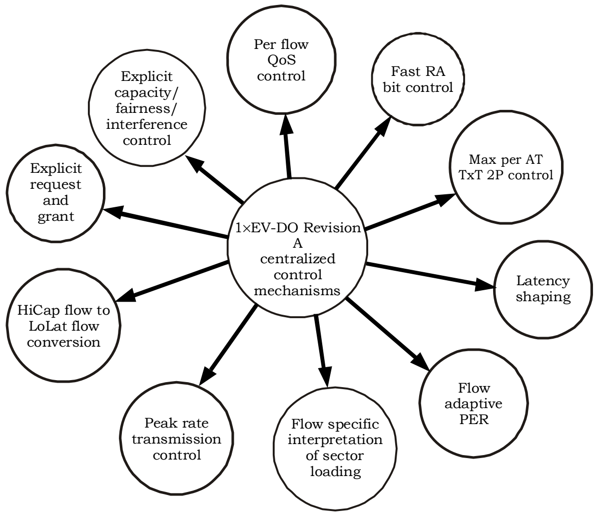
1xEV-DO Revision A provides the access network several mechanisms for centralized control in addition to those provided by 1xEV-DO Release 0. Figure 19 illustrates centralized control mechanisms in DO Revision A.

3.4 CDMA2000 1xEV-DO Revision B

Multi-carrier EV-DO is backward compatible with 1xEV-DO Revision A systems and protects operator and end-user investments in infrastructure and devices. While newer terminals are required for multi-carrier operation, single-carrier terminals based on 1xEV-DO Release 0 or 1xEV-DO Revision A can operate on evolved EV-DO networks that support multi-carrier operation. 1xEV-DO Revision B offers end users richer services and improved user experience while lowering operator cost per bit. Multi-carrier EV-DO specifies up to a 20 MHz wide system with each carrier 1.25 MHz wide and terminals supporting one or more carriers. Operators can deliver Multi-carrier EV-DO based services via software upgrade to 1xEV-DO Revision A channel cards. Multi-carrier devices may operate in a single-carrier mode with 1x (IS-2000) or 1xEV-DO or a multi-carrier mode of operation with two or more EV-DO Revision A carriers. Multi-carrier EV-DO devices may support non-contiguous CDMA channel operation to maximize gains due to channel frequency selectivity and load balancing across carriers.

FIGURE 19

Centralized uplink control mechanisms in 1xEV-DO Revision A



3.4.1 Fundamental concepts

Fundamental concepts introduced in Multi-carrier EV-DO are:

1. channel aggregation via Multi-link Radio Link Protocol (ML-RLP);
2. symmetric and asymmetric modes of operation;
3. adaptive load balancing;
4. flexible duplex carrier assignment;
5. terminal battery life improvements (talk time and standby time improvements).

3.4.1.1 Channel aggregation

The radio link protocol (RLP) is an ARQ protocol that reduces the error rate at the physical and MAC layer and provides a lower error rate to higher layers in the protocol stack. Channel aggregation at the RLP layer, called multi-link RLP, allows achieving higher peak data rates utilizing multiple carriers on the forward link using 1xEV-DO-Revision A channel cards. Multi-link RLP is required when a terminal is assigned carriers on channel cards that do not communicate with each other and operate an independent scheduler.

3.4.1.2 Symmetric and asymmetric mode of operation

Multi-carrier EV-DO supports the following three modes of operation:

1. symmetric multi-carrier operation (feedback multiplexing mode);
2. basic asymmetric multi-carrier operation (basic feedback multiplexing mode);
3. enhanced asymmetric multi-carrier operation (enhanced feedback multiplexing mode).

In symmetric multi-carrier mode the number of forward CDMA channels is equal to the number of reverse CDMA channels. Asymmetric mode of operation results in reduced reverse link overhead as the pilot channels for the additional reverse link carriers are not transmitted. In basic asymmetric multi-carrier mode a single reverse CDMA channel may carry feedback channels for more than one forward CDMA channels using unique long codes for each feedback channel. The asymmetric mode of operation is also possible with fewer data carriers on the forward link than the reverse link. For each reverse link carrier, the corresponding forward link is used to transmit power control and ARQ signaling but may not be used for data transmissions. Such operation may be used for terminals uploading large amounts of data. Enhanced asymmetric multi-carrier mode is similar to the basic asymmetric multi-carrier mode with the exception that feedback channels for up to four forward CDMA channels are transmitted on a single reverse link using the same long code.

3.4.1.3 Adaptive load balancing

Channel assignment or de-assignment is a co-operative message based allocation between the access network and access terminals in order to achieve load balancing across carriers. Load balancing ensures that the network loading is uniform across carriers. Static load balancing is achieved by assigning each new access terminal to a set of carriers. Due to variable nature of application flows and bursty data sources, static load balancing cannot achieve uniform loading across carriers on shorter time scales. On the forward link the access network can achieve adaptive load balancing on a per packet basis. Similar fine load balancing is achieved on the reverse link by per packet carrier selection (of the assigned carriers) by the access terminal. The access network can assign all carriers that a terminal can support which permits the terminal to receive packet transmissions on the "best" carrier during the "best" time-slot.

On the reverse link terminals close to the base station can benefit from the higher data rates due to multi-carrier operation and as the distance (or path loss) from the base station increases the terminal data rate decreases. Since multi-carrier operation on the reverse link improves the reverse link transmit efficiency at high data rates multi-carrier usage at moderate distances from the base station allows the access terminal to continue operating using the spectrally efficient high capacity mode. This results in coverage improvements when transmitting at higher data rates.

3.4.1.4 Flexible duplex

Typical CDMA systems assign forward CDMA channels and reverse CDMA channels that have a fixed spacing and therefore access terminals are typically designed based on a fixed duplexer spacing. With flexible duplex spacing, any reverse CDMA channel from a band class can be coupled with any forward CDMA channel from that band class or with a forward CDMA channel from another band class subject to the capabilities of the access terminal. This also allows using a reverse CDMA channel from a paired spectrum with forward CDMA channels from both the paired spectrum as well as unpaired spectrum providing operators further flexibility in spectrum usage.

4 IMT-2000 CDMA DS, CDMA TDD and TDMA-SC

4.1 Technology overview

While there are a host of technologies competing to deliver commercial mobile broadband services, networks based on the well established 3rd Generation Partnership Project (3GPP)[18] family of standards – EDGE (Enhanced Data rates for Global Evolution), WCDMA (Wideband Code Division Multiplexed), HSPA (High Speed Packet Access) and HSPA+ (HSPA evolution) – offer an appealing way forward in terms of global acceptance, economies of scale and spectrum efficiency.

With Long Term Evolution (LTE) – the next evolutionary technology step for EDGE/WCDMA/HSPA networks – users will enjoy a superior experience with simplified technology for next-generation mobile broadband. LTE will enable even more demanding applications like interactive TV, mobile blogging, advanced games or professional services.

The development of the 3GPP technology track has been very significant. Within a decade, there has been a 1.000-fold increase in the supported data rates, for example. What is more, 3GPP technologies will continue to evolve and enhance their capability.

People can already browse the Internet or send e-mails using EDGE/WCDMA/HSPA-enabled notebooks, replace their fixed DSL modems with HSPA modems, and send and receive video or music using 3G phones.

EDGE/WCDMA/HSPA provides:

– an ecosystem of unrivalled breadth and depth, covering both traditional mobile terminals and personal consumer devices such as laptops, ultra mobile PCs, cameras, portable game consoles and music players;

– unmatched economies of scale that benefit all players in an ecosystem that serves nearly three billion subscribers;

– ever-improving performance, with commercially-proven transmission speeds of up to 14.4 Mbit/s today and up to 42 Mbit/s in the near future;

– highly economic urban and rural coverage, with up to 200 km cell range and measured speeds in excess of 2 Mbit/s at the cell border;

– a clearly defined and easily adopted evolution path.

Through an integrated approach, multi-mode terminals and global roaming agreements between operators, EDGE/WCDMA/HSPA subscribers get global coverage from day one. Using a single device, a subscriber might be able to get speeds of several Mbit/s over HSPA in downtown Johannesburg, 200 kbit/s over EDGE in the suburbs of Manila, and 40 kbit/s over General Packet Radio Service (GPRS) in rural parts of Vietnam.

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[18] The 3rd Generation Partnership Project (3GPP) is a collaboration between a number of telecommunications standards bodies from around the globe, including: ARIB (Japan), CCSA (China), ETSI (Europe), ATIS (North America), TTA (Korea) and TTC (Japan). 3GPP was established to produce globally applicable Technical Specifications and Technical Reports for evolving mobile networks. Further details can be found at www.3gpp.org

4.2 Examples of deployments using this standard

By November 2010, over 4.7 billion subscribers were using GSM/UMTS[19] – approaching 70% of the world's total 6.8 billion population[20]. Informa's World Cellular Information Service projects over 1 billion HSPA customers by 2012. 3G Americas President Chris Pearson states, "This level of wireless technology growth exceeds that of almost all other lifestyle-changing innovations"[21]. Clearly, GSM EDGE/UMTS has established global dominance. Although voice still constitutes most cellular traffic, wireless data worldwide now comprises more than 20% of average revenue per user (ARPU). In the United States of America, wireless data is more than 27% of ARPU for the three largest operators[22]. This number could easily double within three years, and operators across North and South America are confirming this growth with their reports of rising data ARPU.

HSPA has been commercially deployed by 365 operators in 150 countries by September 2010[23].

As of July 2010, 2579 HSPA devices have been launched by 235 suppliers[24].

According to Informa Telecoms & Media, there were 593 million HSPA subscribers in November 2010.The take-up of HSPA is faster than the initial growth of WCDMA, driven by the success of HSPA-enabled PC cards, USB modems and HSPA-capable phones. While it took almost three years for UMTS to exceed seven million subscribers, HSPA achieved this figure in 15 months.

For many remote or low-income areas, HSPA has become the fastest and cheapest way of providing people with access to broadband Internet services. In India's Tamil Nadu province, the Gramijyoti project has used HSPA technology to deliver e-learning and telemedicine services, provide useful information on weather and crop prices and enable locals to find and apply for jobs or set up an email account.

One of South Africa's poorest townships, Alexandra, was the setting for a similar project that involved an HSPA-based Internet café and business centre providing low-cost broadband and computer access to locals. Run by operator MTN, it also gave people access to career and health advice and information about local government services and education opportunities. The project was making a profit within two months of launching, and other South African townships have now approached MTN about setting up similar Internet cafes.

By 2009, HSPA is estimated to be the technology behind over 70% of mobile broadband connections, as illustrated in Fig. 20.

HSPA is built on the firm foundations of the 3GPP family – offering the broadband speeds users desire and the carrier-grade voice services they expect. HSPA can be built out using the existing GSM radio network sites and is a software upgrade of the installed WCDMA networks. Together with dual-mode terminals, this ensures nationwide coverage in most countries both for voice (GSM/WCDMA) and data (HSPA/EDGE).

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[19] Informa Telecoms & Media.

[20] United Nations Demographic Yearbook.

[21] 3G Americas press release of June 5, 2007.

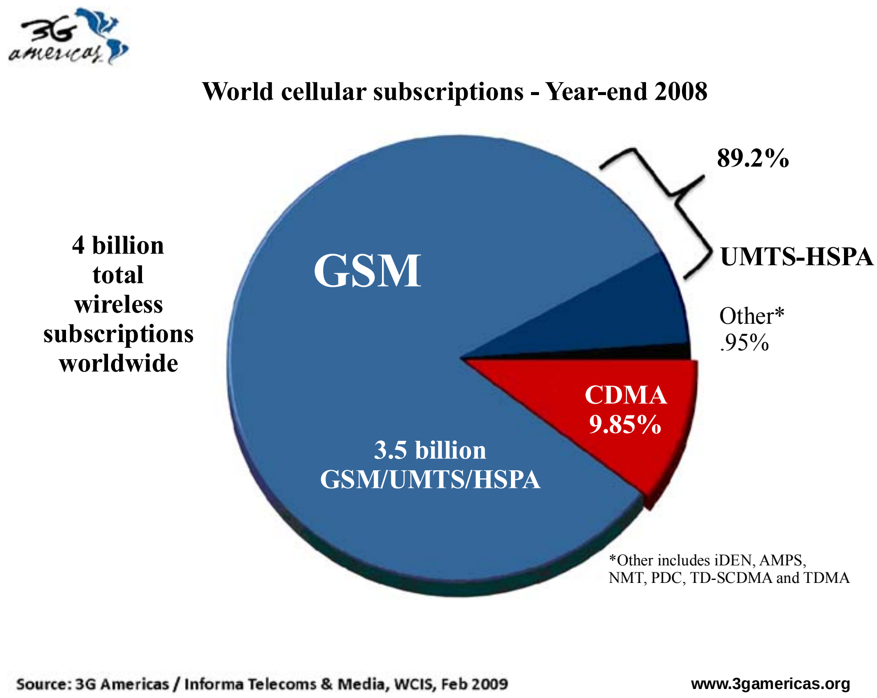
[22] http://www.chetansharma.com/usmarketupdateq309.htm

[23] Global mobile Suppliers Association (GSA).

[24] Global mobile Suppliers Association, http://www.gsacom.com/news/gsa_305.php4

FIGURE 20

Cellular subscription per mobile broadband technology 2008



BWA-20

Thanks to its heritage, HSPA operators have a single network – which offers multiple services – with a sound business case built on revenues from voice, SMS, MMS, roaming customers and mobile broadband.

The majority of WCDMA/HSPA networks are complemented with GSM/EDGE – which offers typical user data speeds of up to 300kbit/s – for service continuity in areas where WCDMA/HSPA coverage is not available, to ensure that users will receive a good experience of most 3G services. Out of the 191 HSPA-committed operators, 113 are also deploying GSM/EDGE, and 83 out of 147 commercially launched HSPA networks have also launched EDGE. Over 70% of HSPA devices also support GSM/EDGE.

4.3 Evolution to higher speeds and better performance

The 3GPP family of standards have undergone continuous evolution and improvement since their introduction in 1991 – with a 1 000-fold increase in peak data rates in the past few years, for example. It is worth noting that consecutive releases of the 3GPP standard are always backward-compatible with previous releases.

The 3GPP is a collaboration agreement that brings together a number of telecommunications standards bodies. The United States of America, Europe, Japan, Korea (Republic of) and China jointly formed the 3rd Generation Partnership Project and there are currently over 400 3GPP member companies and institutions.

3GPP defines GSM and WCDMA specifications for a complete mobile system, including terminal aspects, radio access networks, core networks and parts of the service network. Standardization bodies in each region have a mandate to take the output from the 3GPP and publish it in their region as formal standards.

3GPP specifications are structured in releases, as shown in Table 4.

TABLE 4

Progressive enhancements to 3GPP specifications

Version	Released	Info
Release 99	2000 Q1	Specified the first UMTS 3G networks, incorporating a WCDMA air interface
Release 4	2001 Q2	Added features including multimedia messaging service (MMS) and an all-IP core network
Release 5	2002 Q1	Added first phase of IP multimedia subsystem (IMS) and HSDPA
Release 6	2004 Q4	Added enhanced uplink (HSUPA), integrated operation with Wireless LAN networks, multimedia broadcast/multicast services (MBMS) and enhancements to IMS such as push-to-talk over cellular (PoC)
Release 7	2007 Q2	Added downlink multiple input multiple output (MIMO), further reduced latency, improved QoS and improvements to real-time applications like VoIP
Release 8	2008 Q3	Includes LTE (E-UTRA) and the evolved packet core (SAE) architecture and further enhancements of HSPA

WCDMA 3GPP Release 99 provides data rates of 384 kbit/s for wide-area coverage. However, as the use of packet data services increases, and new services are introduced, higher speed and greater capacity are required – at lower production cost.

WCDMA 3GPP Release 5 extended the specification with, among other things, a new downlink transport channel, the high speed downlink shared channel, which enhances support for high-performance packet data applications. The production cost per bit is reduced, since the enhanced downlink provides a considerable increase in capacity compared with Release 99. It also significantly reduces latency and provides downlink data rates of up to 14.4 Mbit/s.

This enhancement, which commonly goes under the abbreviation HSDPA (high speed downlink packet access), is the first step in the evolution of WCDMA.

There are quite a number of applications that benefit from an improved uplink, although a lot of traffic is downlink-oriented. These include the sending of large e-mail attachments, pictures, video clips and blogs. The key enhancement in WCDMA 3GPP Release 6 was a new transport channel in the uplink, enhanced uplink – also referred to as HSUPA (high speed uplink packet access) – which provides higher throughputs, reduced latency and increased capacity. Data rates of up to 5.8 Mbit/s can be provided with enhanced uplink.

Collectively, HSDPA and enhanced uplink are known as HSPA. HSPA evolution (also referred to as HSPA+) is introduced in 3GPP Release 7 and supports MIMO, 64-QAM (downlink) and 16-QAM (uplink) to further boost the peak data rate and capacity. HSPA evolution supports data rates up to 42 Mbit/s in the downlink and 11.5 Mbit/s in the uplink.

LTE, currently specified by 3GPP in Release 8, introduces orthogonal frequency-division multiplexing (OFDM/OFDMA) in the downlink and single carrier FDMA (SC-FDMA) in the uplink. LTE supports very high data rates, exceeding 300 Mbit/s in the downlink and 80 Mbit/s in the uplink. LTE will support channel bandwidths from approximately 1.25 MHz up to at least 20 MHz and operation in both paired and unpaired spectrum (FDD and TDD).

In addition to LTE, 3GPP is also defining an IP-based, flat network architecture. This architecture is defined as part of the System Architecture Evolution (SAE) effort. The LTE–SAE architecture and concepts have been designed for efficient support of mass-market usage of any IP-based service. The architecture is based on an evolution of the existing GSM/WCDMA core network, with simplified operations and smooth, cost-efficient deployment.

The 3GPP family of standards offers unrivalled breadth and depth, as well as unmatched economies of scale, to benefit all players in an ecosystem that currently serves nearly three billion subscribers.

For operators, technology choices made today will influence operations for many years to come. The 3GPP family of standards provides a future-proof choice – from an initial investment standpoint, economies of scale and the ability to extend and continuously enhance the solution.

Version	Name	Max uplink speed	Max downlink speed	Latency
Release 99	WCDMA	384 kbit/s	384 kbit/s	120 ms
Release 4	WCDMA	384 kbit/s	384 kbit/s	120 ms
Release 5	HSDPA	384 kbit/s	14 Mbit/s	80 ms
Release 6	HSPA	5.8 Mbit/s	14 Mbit/s	60 ms
Release 7	HSPA+	11.5 Mbit/s	42 Mbit/s	40 ms
Release 8	LTE	80 Mbit/s	300 Mbit/s	10 ms

4.4 Air interface

IMT-2000 CDMA DS specification includes enhanced features for High Speed Downlink Packet Access (HSDPA), Multiple Input Multiple Output Antennas (MIMO), higher order modulation (64-QAM) and improved L2 support for high data rates allowing for downlink packet-data transmission with peak data rates approaching 42 Mbit/s and simultaneous high-speed packet data and other services such as speech on the single carrier. In particular, features for enhanced uplink have been introduced, allowing for improved capacity and coverage, higher data rates than the current uplink maximum, and reduced delay and delay variance for the uplink. The addition of higher order modulation (16-QAM) for the enhanced uplink, allows for peak data rates up to 11 Mbit/s.

IMT-2000 CDMA TDD specification includes enhanced features for HSDPA and improved L2 support for high data rates, allowing for downlink packet-data transmission with peak data rates of 2.8 Mbit/s, 10.2 Mbit/s and 20.4 Mbit/s for the 1.28 Mchip/s, 3.84 Mchip/s and 7.68 Mchip/s modes respectively, and for simultaneous high-speed packet data and other services such as speech on the single carrier. Features for enhanced uplink have been introduced, allowing for improved capacity and coverage, higher data rates, and reduced delay and delay variance for the uplink. The addition of higher order modulation (16-QAM) for the enhanced uplink, allows for peak data rates up to 2.2 Mbit/s, 9.2 Mbit/s and 17.7 Mbit/s for the 1.28 Mchip/s, 3.84 Mchip/s and 7.68 Mchip/s modes respectively.

For efficient support of always-on connectivity whilst enabling battery saving in the UE and further increasing the air interface capacity, the specifications also include the continuous packet connectivity feature (CPC). Similar to the downlink, the improved L2 support for uplink is supported to allow efficient support of high data rates and reduced L2 overhead. For fast state transitions between different states, the specifications also include Enhanced CELL_FACH state. The CS voice services are supported over HSPA.

LTE supports scalable bandwidth operation below 5 MHz bandwidth options up to 20 MHz in both the uplink and downlink. The uplink radio access scheme is based on single carrier FDMA, more specifically, DFTS-OFDM. The sub-carrier spacing is 15 kHz. The baseline antenna configuration is MU-MIMO. The modulation scheme for the uplink is up to 16-QAM and optionally 64-QAM.

The downlink radio access scheme of LTE is based on conventional OFDM using cyclic prefix. The OFDM sub-carrier spacing is 15 kHz. In addition, there is also a reduced sub-carrier spacing of 7.5 kHz only for MBMS-dedicated cell. Single-user MIMO and multi-user MIMO with 2 and 4 transmit antennas are supported. Peak data rate of more than 300 Mbit/s can be achieved with 20 MHz bandwidth, MIMO and higher order modulation up to 64-QAM.

LTE FDD uses a frame structure Type 1, as depicted in Fig. 21. Frame structure Type 1 is applicable to both full duplex and half duplex FDD. Each radio frame is $T_f = 307\,200 \times T_s = 10$ ms long and consists of 20 slots of length $T_{slot} = 15\,360 \times T_s = 0.5$ ms, numbered from 0 to 19. A subframe is defined as two consecutive slots where subframe *i* consists of slots $2i$ and $2i+1$. For FDD, 10 subframes are available for downlink transmission and 10 subframes are available for uplink transmissions in each 10 ms interval. Uplink and downlink transmissions are separated in the frequency domain.

Frame structure Type 2 is applicable to TDD, as depicted in Fig. 22. Each radio frame consists of two half-frames of length $T_f = 153\,600 \times T_s = 5$ ms each. Each half-frame consists of eight slots of length $T_{slot} = 15\,360 T_s = 0.5$ ms and three special fields, DwPTS, GP, and UpPTS. The lengths of DwPTS and UpPTS are configurable subject to the total length of DwPTS, GP and UpPTS being equal to $30\,720 T_s = 1$ ms. Subframe 1 and 6 consists of DwPTS, GP and UpPTS, all other subframes are defined as two slots where subframe *i* consists of slots $2i$ and $2i+1$. Subframes 0 and 5 and DwPTS are always reserved for downlink transmission. Both 5 ms and 10 ms switch-point periodicity is supported. In case of 5 ms switch-point periodicity, UpPTS and subframes 2 and 7 are reserved for uplink transmission. In case of 10 ms switch-point periodicity, DwPTS exist in both half-frames while GP and UpPTS only exist in the first half-frame and DwPTS in the second half-frame has a length equal to $30\,720 T_s = 1$ ms. UpPTS and subframe 2 are reserved for uplink transmission and subframes 7 to 9 are reserved for downlink transmission.

IMT-2000 TDMA-SC provides two bandwidth options for high-speed data, both using TDMA technology. The 200 kHz carrier bandwidth option (EDGE) utilizes 8-PSK modulation with hybrid ARQ and achieves a channel transmission rate in dual-carrier mode of 1.625 Mbit/s while supporting high mobility. A second 1.6 MHz bandwidth is provided for lower mobility environments that utilize binary and quaternary offset QAM modulation with hybrid ARQ. This 1.6 MHz bandwidth option supports flexible slot allocation and achieves a channel transmission rate of 5.2 Mbit/s.

Additional information on IMT-2000 CDMA DS, IMT-2000 CDMA TDD, and IMT-2000 TDMA-SC can be found in Recommendation ITU-R M.1457. The complete set of the 3GPP Specifications can be found at www.3gpp.org

FIGURE 21

Frame structure Type 1

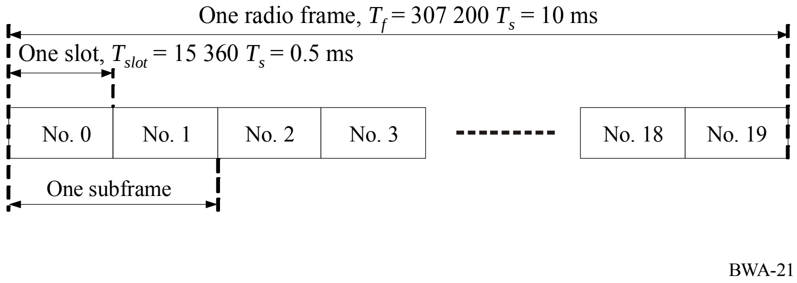
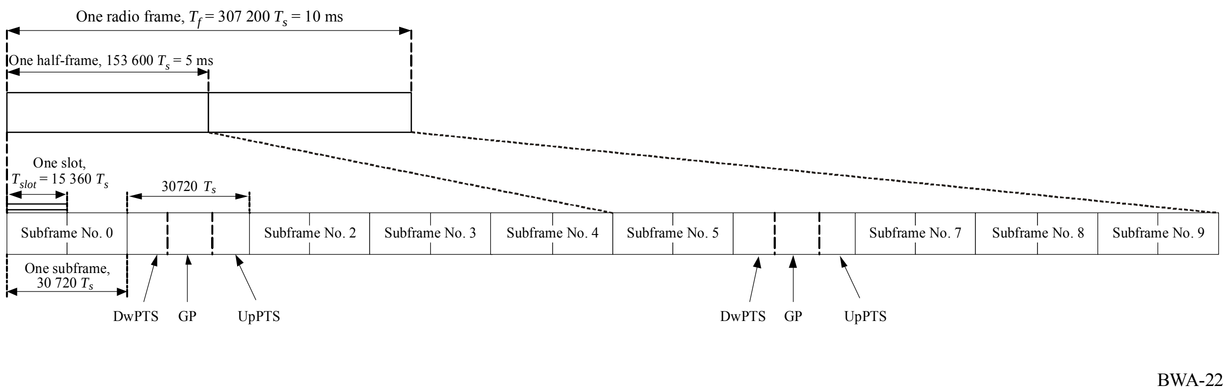


FIGURE 22

Frame structure Type 2

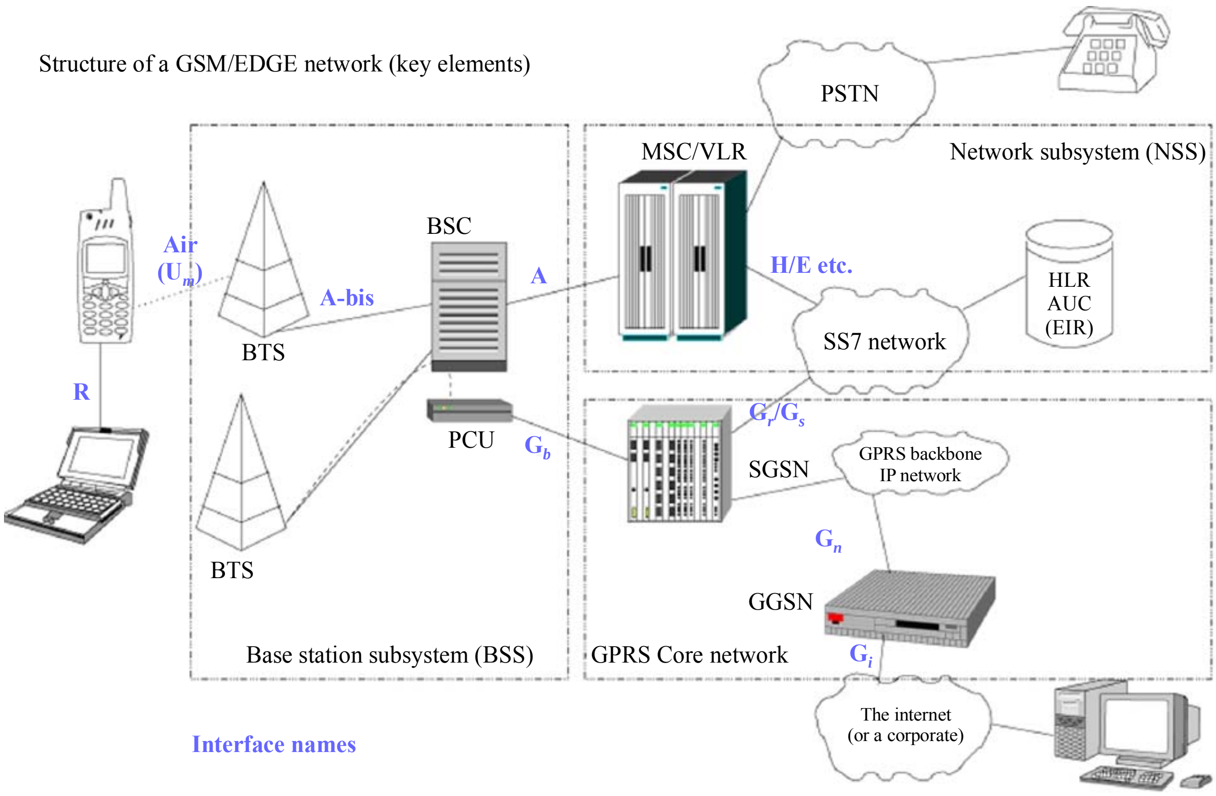


4.5 WCDMA / HSPA system architecture

One of the advantages of WCDMA and HSPA is that they use a system architecture common to both. Figure 23 shows a typical example of a core network technology (in this case, a GSM/EDGE network), which provides both circuit-switched and packet-switched connectivity between mobile users and fixed voice and data networks:

FIGURE 23

Typical core network



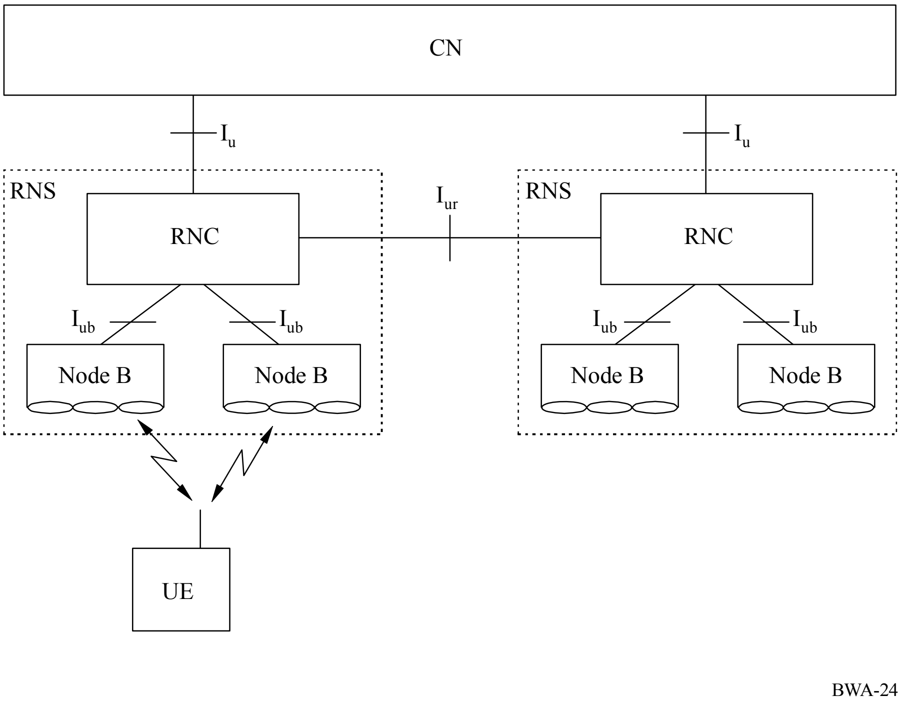
Key:
BTS Base transmitter station
BSC Base station controller
PCU Packet control unit
MSC Mobile switching centre
HLR Home location register
VLR Visitor location register
SGSN Serving GPRS support node
U_m, A-bis, A, G_b, G_r, G_s, G_n, G_i,
various interface protocols

BWA-23

WCDMA/HSPA technologies utilize the existing packet data elements of the core network, which separate the data packets at the base station controller and direct them through a PCU to a packet network (shown as GPRS core network in Fig. 23). This re-use of existing infrastructure also extends to the security, authentication and other management elements of the core network, which support the commercial operation of a mobile network. The overall architecture of the radio access network is shown in Fig. 24.

FIGURE 24

WCDMA/HSPA overall architecture



The architecture of this radio interface consists of a set of radio network subsystems (RNS) connected to the CN through the Iu interface. An RNS consists of a radio network controller (RNC) and one or more entities called Node B. Node B is connected to the RNC through the Iub interface. Each Node B can handle one or more cells. The RNC is responsible for the handover decisions that require signalling to the user equipment (UE). The RNCs of the RNS can be interconnected through the Iur interface. Iu and Iur are logical interfaces, i.e. the Iur interface can be conveyed over a direct physical connection between RNCs or via any suitable transport network.

4.6 LTE System architecture

The radio access network architecture for LTE consists of the evolved UTRAN NodeBs (eNBs). eNBs host the functions for radio resource management, IP header compression and encryption of user data stream, etc. eNBs are interconnected with each other and connected to an evolved packet core (EPC).

The LTE radio access network consists of eNBs, providing the user plane (PDCP/RLC/MAC/PHY) and control plane (RRC) protocol terminations towards the UE. The eNBs are interconnected with each other by means of the X2 interface. The eNBs are also connected by means of the S1 interface to the EPC more specifically to the mobility management entity (MME) by means of the S1-MME and to the serving gateway (S-GW) by means of the S1-U. The S1 interface supports a many-to-many relation between MMEs / serving gateways and eNBs.

The LTE radio access network architecture is illustrated in Fig. 25.

The main functions of each node are summarized in Fig. 26 where yellow boxes depict the logical nodes, white boxes depict the functional entities of the control plane and blue boxes depict the radio protocol layers.

FIGURE 25

Overall architecture

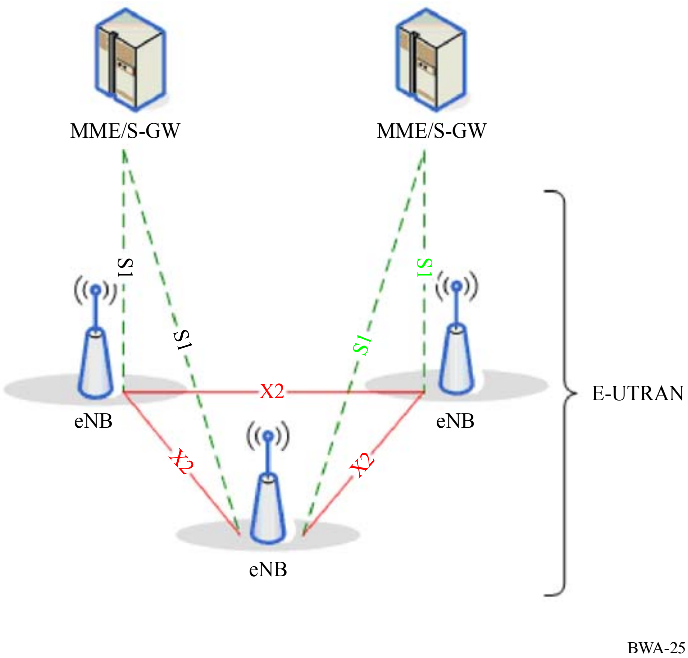
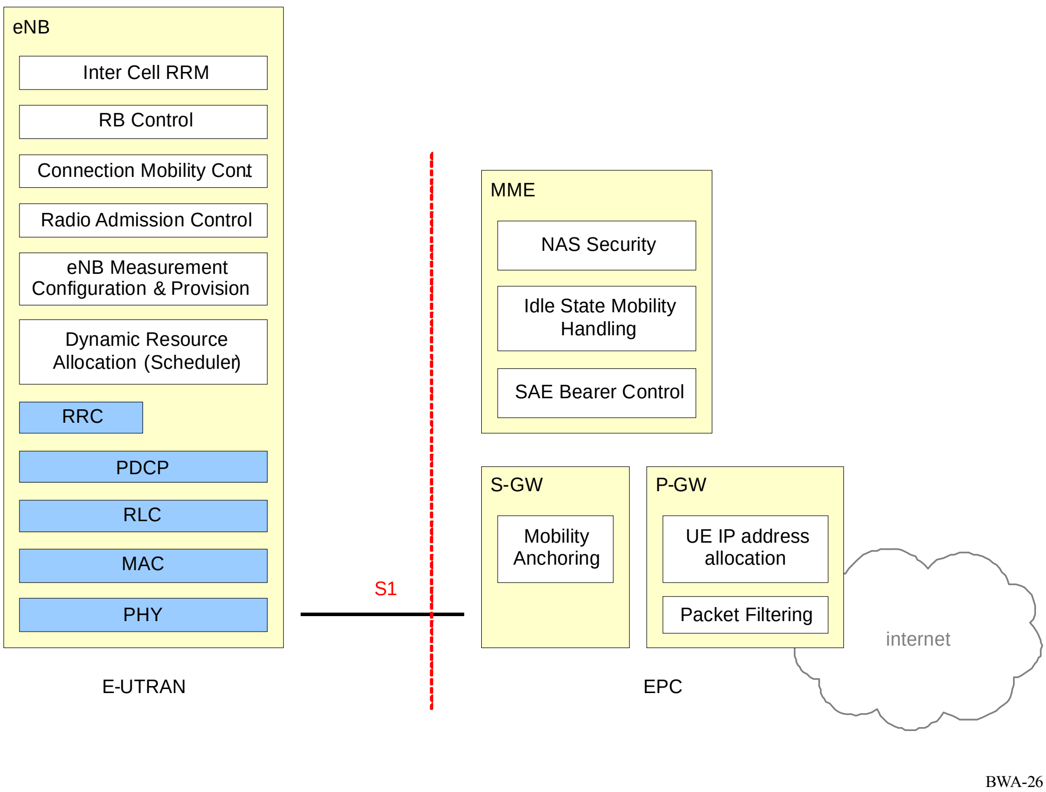


FIGURE 26

Overall architecture of the LTE system

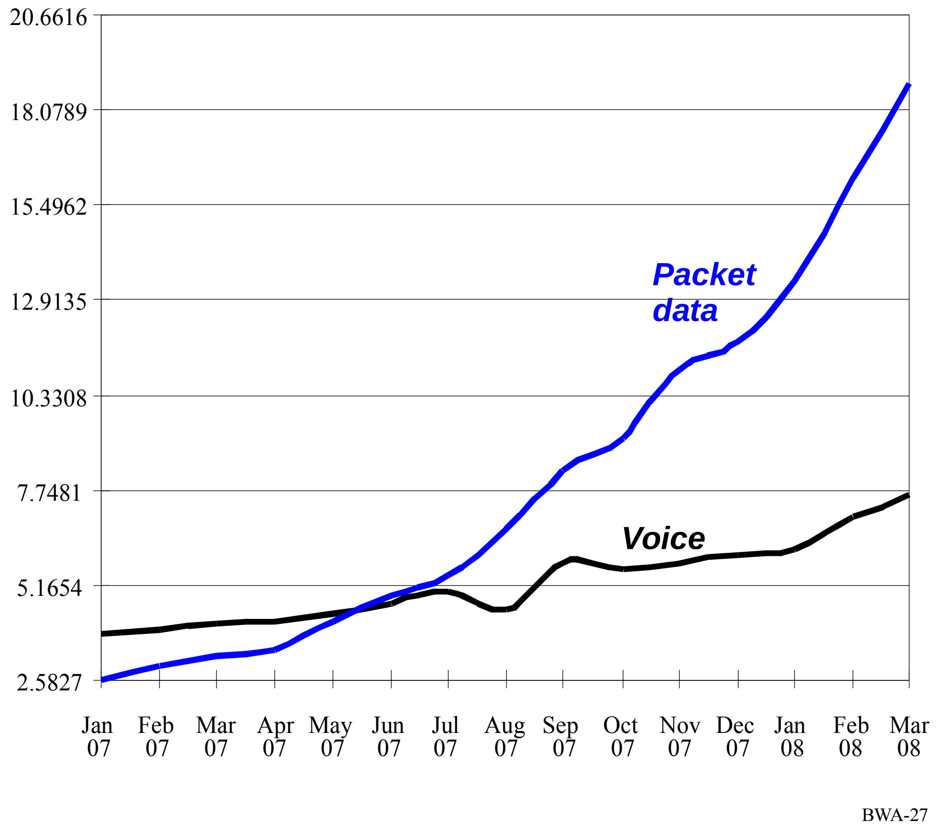


4.7 Deployments and trends

Based on one leading UMTS/HSPA infrastructure vendor's statistics, Fig. 27 compares the rapid growth in wireless data traffic compared to voice traffic. By the end of 2007, the volume of data traffic, indicated in gigabit per RNC per hour, exceeded voice traffic.

FIGURE 27

UMTS/HSPA Voice and data traffic*



* Based on leading infrastructure vendor statistics.

The key for operators is enhancing their networks to support the demands of consumer and business applications as they grow, along with offering complementary capabilities such as IP-based multimedia. This is where the 3GSM family of wireless-data technologies is the leader. Not only does it provide a platform for continual improvements in capabilities, but it does so over huge coverage areas and on a global basis bringing economies of scale.

Another driver for broadband data growth beyond mobile applications is the use of HSPA/LTE BWA networks as alternatives to wireline networks where running wire or fibre is problematic. This includes developing economies, as well as remote areas. For example, Telstra is extending its HSPA network to remote mining locations and oil production platforms[25].

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25 Telstra presentation "HSPA as an Open Eco-System Today – Telstra Next G Network", 2008.

5 Ultra Mobile Broadband

5.1 Introduction

The general philosophy of ultra mobile broadband (UMB)™[26] design is to provide significantly higher data rates while lowering the cost per bit of the system. This is done primarily by utilizing wider bandwidths and advanced multiple antenna techniques. Other main areas of performance improvements include better spectral efficiency, lower latency, improved battery life, as well as higher capacity and enhanced user experience for delay sensitive applications such as VoIP.

The specifications for the IMT-2000 CDMA Multi-Carrier Ultra Mobile Broadband system can be found at this location, http://www.3gpp2.org/Public_html/specs/index.cfm

UMB provides a unified system design that supports full and half duplex FDD modes with scalable bandwidth and can operate in a mixed network with synchronous as well as asynchronous access points (APs). The system is designed for robust mobile broadband access and is optimized for high spectral efficiency and short latencies using advanced modulation, link-adaptation and multi-antenna transmission techniques.

Features necessary for mobile operation (such as handoff, power control, inter-sector interference management) are integrated into the design. Adaptive coding and modulation with turbo or LDPC codes and synchronous hybrid ARQ (H-ARQ) are used to achieve high spectral efficiency. Sub-band scheduling provides enhanced performance on both the forward link (FL) and the reverse link (RL) by enabling multi-user diversity gains for latency sensitive traffic. H-ARQ transmission and processing timelines are optimized for short retransmission latency as well as a large number of channel dimensions, to support latency sensitive applications as well as a practical processing timeline.

UMB is based on an OFDMA FL with advanced multi-antenna techniques including closed loop precoding, multi-input multi-output (MIMO) and space-division multiple access (SDMA). The UMB RL makes use of OFDMA with the possibility of quasi-orthogonal multiplexing of access terminals (ATs) when multiple receive antennas are available at the APs. Other RL enhancements include interference management through fast power control based on interference caused to the neighbour sectors. Fractional frequency reuse (FFR) is used to further improve edge data rates and handoff performance. Particular attention has been given to a seamless support of full mobility, through fast and efficient FL and RL handoffs.

Other enhancements include low power consumption in the active state based on selected interlace mode which allows for sleep between transmissions and is suited for low rate latency sensitive traffic such as VoIP, and semi-connected mode which allows long sleep intervals between data bursts and is suited for latency tolerant traffic. UMB also features multi-carrier operation that enables improved peak rates and trunking efficiency of a system with higher bandwidth, by combining multiple physical carriers.

5.2 Ultra mobile broadband numerology

OFDM symbol numerology is optimized to maintain low overhead while achieving good performance over the range of delay and Doppler spreads observed in mobile wide area networks. Tone spacing is fixed to 9.6 kHz for all bandwidth allocations, with four options for the cyclic prefix duration which can be chosen based on deployment and propagation conditions.

[26] Ultra Mobile Broadband™ and (UMB™) are trade and service marks owned by the CDMA Development Group (CDG).

Five different FFT sizes are defined to support bandwidth allocations in the range from 1.25 MHz to 20 MHz as indicated in Table 5. The number of guard tones can be chosen in units of 16 allowing for about 150 kHz granularity of spectrum allocation. Time-domain windowing is employed to reduce OoB emissions with low processing complexity and overhead.

TABLE 5

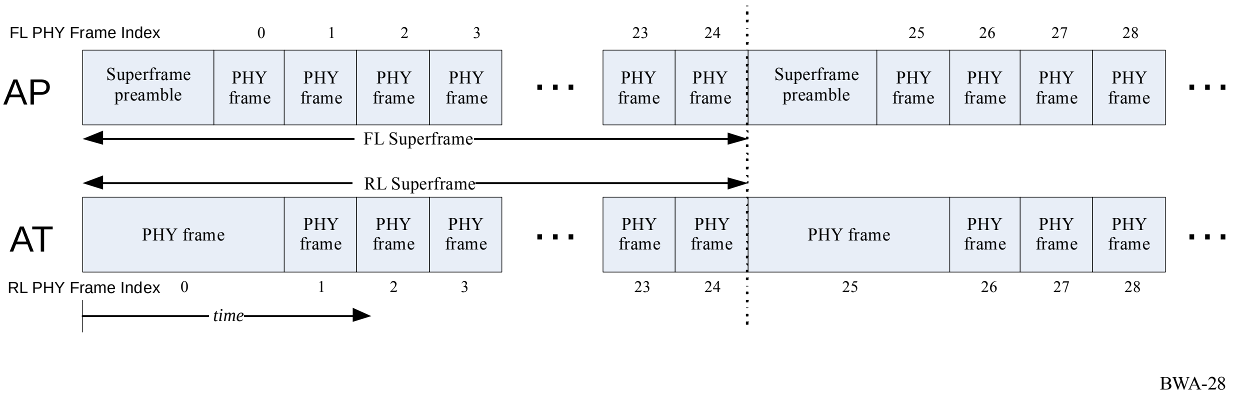
OFDM Symbol numerology

Parameter	**128 pt FFT**	**256 pt FFT**	**512 pt FFT**	**1 024 pt FFT**	**2 048 pt FFT**
Sampling rate (Mcps)	1.2288	2.4576	4.9152	9.8304	19.6608
Tone spacing (kHz)	9.6				
Bandwidth (MHz)	≤ 1.25	1.25 – 2.5	2.5 – 5	5 – 10	10 – 20
Guard tones	depends on bandwidth				
Cyclic prefix (μs)	6.51, 13.02, 19.53, 26.04				
Windowing duration (μs)	3.26				
Total OFDM symbol (μs)	113.93 (corresponds to cyclic prefix of 6.51μs)				

A FL superframe consists of a superframe preamble followed by 25 physical layer (PHY) frames as shown in Fig. 28. Superframe preamble and each PHY frame consist of 8 OFDM symbols. The superframe preamble carries acquisition pilots and primary overhead channels needed for initial system acquisition, time frequency synchronization and AP configuration discovery. A RL superframe consists of 25 PHY frames where the first frame spans 16 OFDM symbols to account for superframe preamble on the FL, while the remaining 24 frames span 8 OFDM symbols, see Fig. 28.

FIGURE 28

Superframe structure



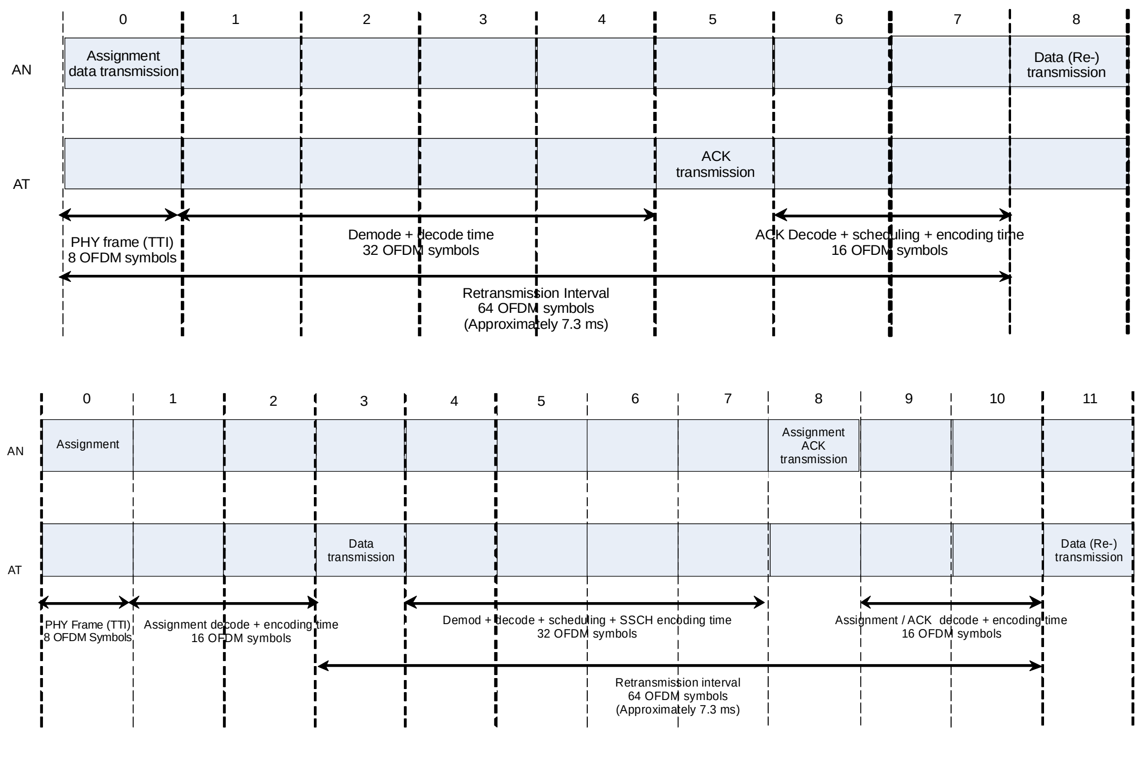
UMB supports a half-duplex mode which is designed to support duplexer free operation at the AT. The sequence of FL and RL frames is therefore divided into two half-duplex interlaces so that every even FL frame (and every odd RL frame) belongs to one half-duplex interlace and every odd FL frame (and every even RL frame) belongs to the other half-duplex interlace. A duplexer free AT will be assigned one of the two half-duplex interlaces in a semi-static fashion while a full duplex AT can be scheduled on both interlaces at any time. Half-duplex mode offers all the benefits of full-duplex mode, in terms of peak rates as well as link budget to full-duplex ATs, while supporting low cost duplexer free ATs on the same channel, at the expense of a small guard time (close to 78 μs) inserted between the adjacent PHY frames. This mode of operation is particularly attractive for broadband deployments in band classes with a relatively small spacing between FL and RL channels.

5.3 H-ARQ timelines

UMB makes use of synchronous H-ARQ on the FL as well as the RL. While certain features of asynchronous H-ARQ are supported by UMB resource management framework, synchronous H-ARQ is designed to handle most scenarios due to its low resource management overhead. The default H-ARQ timelines use 8 interlaces on both FL and RL as shown in Fig. 29. On FL, acknowledgment is sent five PHY frames after the data packet transmission and retransmission occurs after eight PHY frames. RL shows a similar H-ARQ timeline with RL resource assignment taking place three PHY frames prior to the packet transmission.

FIGURE 29

Forward and reverse Link H-ARQ timelines



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Both the FL and RL feature H-ARQ retransmission latencies of approximately 7.3 ms. Both FL and RL support the extended frames which consist of a sequence of three PHY frames carrying one data packet. Extended frames have the same retransmission latency as regular frames and therefore are well suited to manage low latency applications such as VoIP. Extended frames are particularly useful on the RL as they allow for an increased packet size when the ATs spectral efficiency is limited by link budget constraints thereby avoiding the MAC overhead penalty associated with very small packets. UMB also features an optional 6 interlace FL timeline which allows for retransmission latency of around 5.5 ms.

5.4 Forward link traffic channel

UMB features various traffic resource structures and resource multiplexing modes. Distributed resource channel (DRCH) is designed to maximize frequency and interference diversity. DRCH channels rely on a common pilot channel for channel estimation. An alternative to DRCH is the block resource channel (BRCH) which consists of a contiguous block of 16 tones over a PHY frame (8 OFDM symbols). Each BRCH channel (also referred as tile) hops within a larger set of contiguous tones (subband) thereby providing frequency and interference diversity across H-ARQ transmissions, and within an H-ARQ transmission for assignment sizes larger than one tile.

The discussion focuses on BRCH which makes use of forward dedicated pilot channel (F-DPICH) to support local channel and interference estimation. Note that local interference estimation allows us to take advantage of interference variations inherent in the presence of time and/or frequency selective fading and FL power control. Additionally the F-DPICH facilitates implementation of multi-antenna techniques such as precoding and SDMA, where spatial signaling, used for data transmission on every BRCH channel, is applied to pilot modulation symbols and is therefore transparent to the AT. F-DPICH symbols which populate a pre-defined pattern on the time-frequency grid. Three pilot patterns are shown in Fig. 30. Format 0 is the default pilot pattern, which is used while transmitting to users capable of supporting up to three spatial streams. Format 1 is used to support users with high delay spread channels and Format 2 is used to support four spatial streams.

Channel and interference estimation is performed within every tile. The interference level is roughly constant across a tile in a synchronous system. The different pilot patterns provide enough “looks” to capture time and frequency selectivity by trading-off pilot overhead with channel sampling needed to support MIMO and high delay spreads. The pilot pattern indicated as part of resource assignment. F-DPICH overhead is identical for SIMO and MIMO, and is 14.06% for Format 0 and 18.75% for Formats 1 and 2.

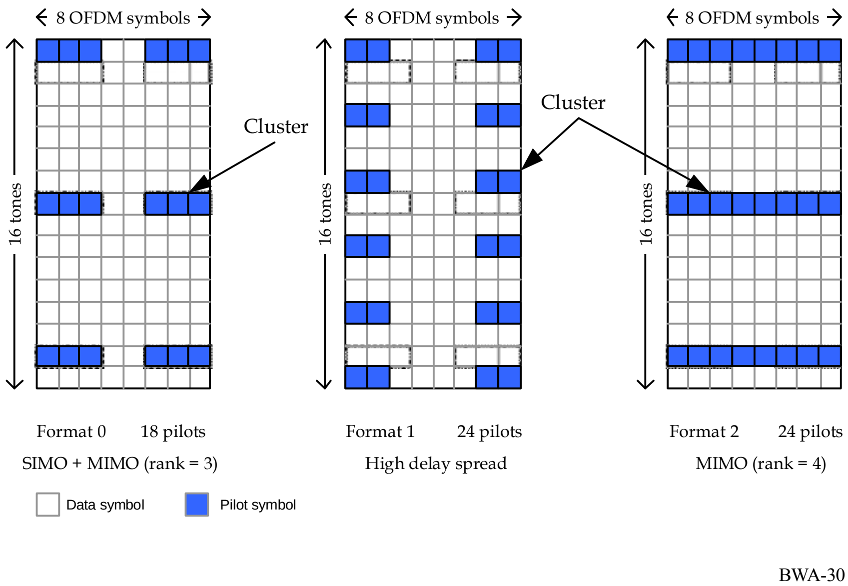
As shown in Fig. 30, F-DPICH consists of a set of contiguous pilot clusters. Each cluster consists of 3 or 4 symbols. The former can support up to third order of spatial multiplexing while the latter can support up to fourth order spatial multiplexing. The orthogonal sequences associated with different effective antennas are defined by the columns of the DFT matrix of size 3, 2 and 4 for Format 0, 1 and 2 respectively.

5.5 MIMO design

UMB features two MIMO modes namely single codeword (SCW) and multi-codeword (MCW) MIMO. As the name suggests, SCW MIMO interleaves a single coded packet over multiple transmit streams (spatial dimensions). A typical receiver makes use of linear minimum mean square error (MMSE) filtering to separate multiple streams that are subsequently multiplexed and decoded. SCW MIMO operation requires closed loop channel quality and rank feedback from the receiver. Conversely MCW MIMO transmitter generates multiple independently encoded streams (layers) and requires a successive interference cancellation receiver for the best performance. MCW MIMO mode requires multiple channel quality values corresponding to different layers. While SCW MIMO is well suited for a wide range of channel conditions in terms of channel to interference ratio (*C*/*I*), MCW MIMO is more efficient at high *C*/*I* values and in the presence of spatially correlated channels. The UMB MIMO design offers flexibility of switching between the two modes based on channel conditions, feedback requirements and AT capabilities.

FIGURE 30

F-DPICH structures



5.6 Closed loop precoding and SDMA

A unified RL feedback structure supports closed loop MIMO, precoding and SDMA. Precoding is based on a codebook which consists of up to 64 precoding matrices. Each precoding matrix defines a set of beams that correspond to different MIMO streams (SCW) or layers (MCW). The AT feeds back a precoding index that identifies a precoding matrix, selected by the AT based on FL channel measurements. In SCW mode, channel quality feedback captures the data rate that can be achieved with precoding while the rank value reflects the MIMO rank and therefore the number of columns of the precoding matrix (beams) to be used for different streams. In MCW mode, per-layer channel quality feedback identifies the data rate to be used by different layers corresponding to columns of the precoding matrix.

SDMA is enabled by a codebook that is structured as a set of SDMA clusters of precoding matrices. The clusters are defined so as to ensure low level of co-channel interference between FL transmissions corresponding to precoding matrices chosen from different clusters. An AT that reports the precoding index from a certain cluster computes a channel quality backoff. This backoff accounts for the co-channel interference incurred when another AT is receiving a FL transmission with precoding matrix chosen from another cluster which is compatible with the former cluster. The backoff is fed back to the AP in the form of differential channel quality. It is subsequently used by the AP to decide between single user (precoded) MIMO and SDMA, and to determine the corresponding data rates. UMB supports the concept of downloadable codebooks. This allows UMB to support different antenna configurations and propagation conditions. The air interface supports mechanisms to identify the existing codebooks, and enables the AT to acquire new ones as needed.

5.7 Handoff design

UMB design supports fast cell switching to minimize the outage of low-latency traffic caused by handoffs in a high mobility system. This is achieved at a relatively low signaling overhead, which is especially important when frequent handoffs are used either to obtain fast fading gains at pedestrian speeds, or to support seamless connectivity at high vehicular speeds. Key elements of handoff design in UMB are fast RL control signaling to indicate request handoff to the target and forward link signaling to assign FL or RL traffic channel thereby completing FL or RL handoff. Moreover, fast handoff group selection, whereby an AT may choose to receive simultaneous transmissions from more than one sector, can be employed to improve the cell edge user performance.

Fast handoff requests by an AT are possible due to the CDMA control segment, which provides statistical multiplexing for contention based channels such as access, FL/RL handoff indications, RL bandwidth request etc. An AT can point to any AP currently within its Active Set by sending FL and/or RL handoff request in the next available CDMA control segment, which typically repeats every ~7.3 ms. Each AP monitors potential handoff requests from all ATs that have the given AP in the Active Set. The Active Set of an AT is updated on a slower time scale but in a proactive manner, based upon the FL channel quality. The handoff is completed when the AT receives the resource assignment from the target AP via the FL shared control channel. This mechanism allows for handoff signaling latencies on the order of 8 ms. An additional component of the FL handoff latency depends upon the backhaul delay associated with context transfer from the source to the target AP. Small handoff latencies are essential to ensure robust mobility support in universal reuse deployments.

Furthermore, the UMB handoff design allows for an AT to be served by different APs on the FL and RL thus achieving the best AP selection on each link. To this end UMB provides a mechanism for RL channel measurement at the AP and for reporting to the AT. Specifically, an AT transmits the RL pilot (R-PICH) on the RL CDMA control segment and various APs in the Active Set measure reverse channel quality and report the measurements back to the AT via the pilot quality indication channel (F-PQICH) transmitted as part of the FL control segment. ATs make use of F-PQICH reports to make RL handoff decisions.

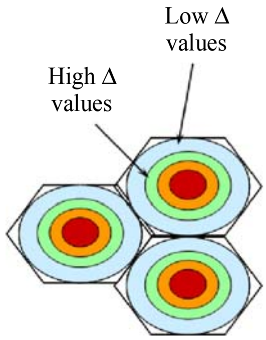
5.8 Interference management

Tight control of RL intercell interference level is essential for reliable support of QoS applications, and to ensure stable network operation in deployments with universal frequency reuse. UMB features two complimentary mechanisms of interference management: regular and fast interference management. Regular interference management functions on the timescale of several tens of ms and targets loaded networks where multiple ATs share bandwidth at any time. The idea of regular interference management is depicted in Fig. 31. Since ATs that are located close to the AP boundary are the main contributors to other cell interference, these ATs should operate at a lower receive power (at the target AP) and use a smaller share of time-frequency resources, subject to fairness constraints. Since resource management is centralized at the AP scheduler, the scheduler needs to identify ATs within its coverage that are responsible for an excessive interference level, and allocate a smaller amount of RL resources to these ATs. In UMB every AP indicates an excessive level of RL interference through the other sector interference (OSI) channel broadcast as part of the superframe preamble (every 23.7 ms). Each AT combines OSI values broadcast by different APs along with a measure of the relative RF distance of these APs to generate a transmit power spectral density (p.s.d.) estimate. The p.s.d estimate is then fed back to the serving AP.

The p.s.d. estimate is used by the AP scheduler to optimize the RL throughput subject to fairness and QoS constraints. This distributed closed loop interference management enables tight control of RL interference to a desired target level, while achieving a desired tradeoff between throughput and fairness.

FIGURE 31

Regular interference management



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The above approach to interference management is well suited for loaded networks where statistical averaging of RL interference contributions from several users results in a stable total interference level, even though the transmit p.s.d. of users is updated relatively slowly. In practice, broadband networks may see dominant interference contributions from just a few users, and high variability of interference due to bursty traffic such as web browsing, gaming, instant messaging etc. In these scenarios, the user experience is mainly determined by packet latency. Thus it is important to ensure a high burst rate while maintaining good control on other sector interference and also facilitate interference avoidance between adjacent APs.

In UMB, this is addressed by the fast interference management. The AP controls interference generated by the ATs served in neighbor APs by sending a fast other sector (FOSI) indication. FOSI values are sent for every RL frame and every RL sub-zone (a sub-zone spans 128 or 64 tones depending on the AP configuration). When the AT receives the FOSI indication from an AP within its Active Set corresponding to a subband/frame pair that the AT transmitted, the AT reduces its transmit p.s.d. by a certain amount. Likewise the AT increases its transmit p.s.d. if no FOSI is observed in response to the AT's transmission. The transmit p.s.d. is updated at every instance of the AT's transmission, hence every 7.3 ms for every scheduled interlace, and any change in transmit p.s.d. level is reported to the serving AP as part of in-band (MAC) header.

This closed loop operation is complemented by an "open loop projection" setting for the initial p.s.d. which is based on the RF distance to the closest non-serving AP versus the serving AP. The rationale behind this scheme is to start with a conservative setting of the initial p.s.d. level based on open loop projection and allow for a fast ramping in p.s.d. and rate until FOSI reports are triggered by the neighboring APs. This way ATs located far enough from cell boundaries can quickly ramp up to fairly high data rates while ATs that are causing excessive interference settle at a suitable p.s.d. level. Furthermore the AP can reassign an AT to a different subband whenever AT reports p.s.d. reduction caused by FOSI activity in an adjacent cell on its current assignment. This form of interference avoidance proves to be particularly effective in broadband systems where an AT located close to the cell edge needs only fraction of the total available bandwidth for efficient operation.

5.9 Fractional frequency reuse

While UMB is designed to deliver robust operation in deployments with universal frequency reuse, frequency planning could be used to enhance coverage and QoS at cell boundaries. Traditionally, sector-based fractional frequency reuse is used in interference limited systems to improve the channel *C/I* and thereby improving link reliability at the cell edge. The resulting channel quality improvement, however, comes with the cost of bandwidth reduction, which is not necessarily a good capacity tradeoff.

User based fractional frequency reuse (FFR) in UMB enables ATs with different channel conditions to enjoy different reuse factors while being served by the same AP. A small fraction of bandwidth and power resources can be assigned to the ATs that benefit from interference reduction achieved by reuse. In UMB, FL FFR is enabled by the synchronized hopping of different FL sub-zones in different APs, and by the channel feedback sent by each AT. RL FFR is enabled by synchronized hopping of different RL sub-zones, and by the long-term RL interference measurements performed at the AP.

A variation of user-based FFR uses power tiering among groups of tones, and manages the assignment of users to different groups of tones. This essentially eliminates cell poor coverage regions without compromising system capacity. Unlike traditional (sector-based) frequency reuse schemes which completely shut off unused tones in one sector, this variation uses all tones in all sectors; the FL scheduler assigns users closer to the base station to tones with lower power, while the cell-edge users are scheduled to tones with higher power. The same concept applies to multi-carrier deployments where different carries are transmitted at different power levels, and an AT makes use of inter-frequency handoff to move to a suitable carrier depending on its channel conditions.

In UMB, inter-frequency handoff is facilitated by inter-frequency pilots called beacons. A beacon pilot is a low-rate sequence of tones that that carries AP identity as well as frequency (carrier) index. Beacons for all active carriers are embedded in every active carrier. These out of band pilots impose a very low overhead and enable low complexity detection of AP signal strength on different carriers without actually re-tuning receive chains to those carriers. Thus, beacons enable inter-carrier handoffs without service interruption.

5.10 Conclusion

UMB is an advanced air interface that meets the needs of the broadband wireless users for high data rates as well as providing excellent capacity in both mobile and non-mobile environments. Bandwidths can be from 1.25 to 20 MHz. On the FL and with a 20 MHz bandwidth, UMB can provide up to 288 Mbit/s with a 4 x 4 MIMO configuration and up to 152 Mbit/s with a 2 x 2 MIMO configuration. On the RL and with a 20 MHz bandwidth, UMB can provide up to 75 Mbit/s with a single layer and 151 with a 2 layer quasi-orthogonal RL.

6 Harmonized IEEE and ETSI radio interface standards, WiMAX, for broadband wireless access (BWA) systems including mobile and nomadic applications in the mobile service

6.1 Overview of the radio interface

The IEEE standard 802.16 (including the 802.16e-2005 amendment), and ETSI HiperMAN standards define harmonized radio interfaces for the OFDM and OFDMA physical layers (PHY) and MAC (Media Access Control)/DLC (Data Link Control) layer. The ETSI BRAN HiperMAN targets nomadic applications, while the IEEE 802.16 standard also targets full vehicular applications.

The use of frequency bands below 6 GHz provides for an access system to be built in accordance with this standardized radio interface to support a range of applications, including full mobility for enterprise and residential applications in urban, suburban and rural areas. The interface is optimized for dynamic mobile radio channels and provides support for optimized handover methods and a comprehensive set of power saving modes. The specification could easily support both generic internet-type data and real-time data, including applications such as voice and videoconferencing.

This type of system is referred to as a wireless metropolitan area network (WirelessMAN in IEEE and HiperMAN in ETSI BRAN). The word "metropolitan" refers not to the application but to the scale. The architecture for this type of system is primarily point-to-multipoint, with a base station serving subscribers in a cell a range up to several km. Users can access the network via several types of terminals, e.g. handheld phones, smart phone, PDA, handheld PC and notebooks in a fixed or mobile environment. The radio interface as defined by WiMAX defined profiles supports a variety of channel bandwidths, from 3.5 MHz to 20 MHz for operating frequencies below 6 GHz. The use of orthogonal frequency-division multiplexing (OFDM) and orthogonal frequency-division multiple access (OFDMA) improves spectral efficiency due to combined time/frequency scheduling and flexibility when managing different user devices with a variety of antenna types and form factors. It brings a reduction in interference and tolerance to multipath for user devices with omnidirectional antennas and improved NLoS capabilities that are essential when supporting mobile subscribers in both indoor and outdoor environments. Sub-channelization defines sub-carriers that can be allocated to different subscribers depending on the channel conditions and data requirements on a user-by-user basis. This gives the service providers more flexibility in managing the bandwidth and transmit power, and leads to a more efficient use of resources, including spectrum resources.

The radio interface supports a variety of channel bandwidths and operating frequencies, providing a peak DL spectral efficiency of up to 3.5 bit/s/Hz in a single receive and transmit antenna (SISO) configuration and 7 bit/s/Hz with a (2 x 2) MIMO configuration.

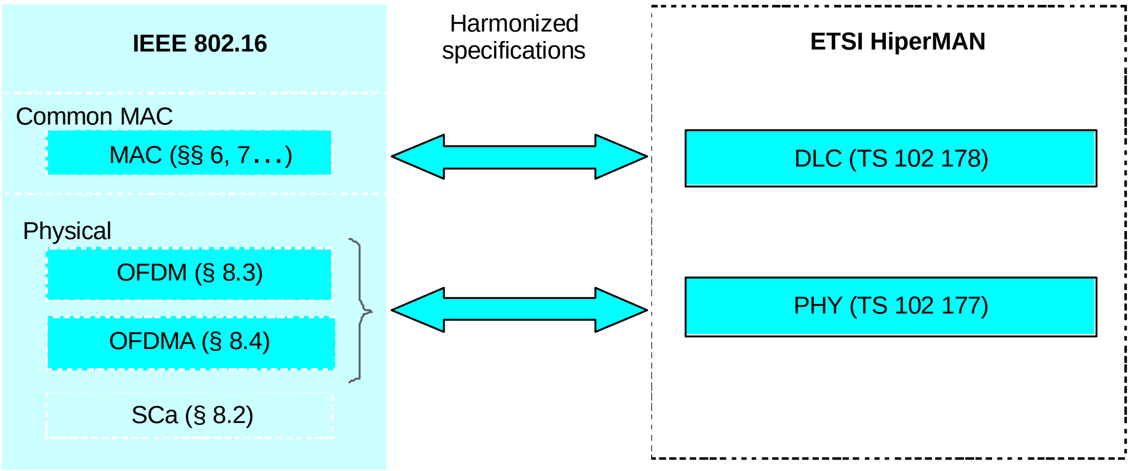
The radio interface includes PHY as well as MAC/DLC. The MAC/DLC is based on demand-assigned multiple access in which transmissions are scheduled according to priority and availability. This design is driven by the need to support carrier-class access to public networks, through supporting various convergence sub-layers, such as internet protocol (IP) and Ethernet, with full quality-of-service (QoS).

The harmonized MAC/DLC supports the OFDM and OFDMA PHY modes.

Figure 32 illustrates pictorially the harmonized interoperability specifications of the IEEE WirelessMAN and the ETSI HiperMAN standards, which include specifications for the OFDM and OFDMA physical layers as well as the entire MAC layer, including security.

FIGURE 32

BWA standards harmonized for interoperability for frequencies below 6 GHz



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The WiMAX Forum™, IEEE 802.16 and ETSI HiperMAN define profiles for the recommended interoperability parameters. IEEE 802.16 profiles are included in the main standards document, while HiperMAN profiles are included in a separate document. The Telecommunications Technology Association (TTA) defines profile for wireless broadband (WiBro) service which is referred to WiMAX Forum profiles.

TTA maintains a standard TTAS.KO-06.0082/R3 for WiBro service, which is portable internet service in Korea. The standard is a subset of IEEE 802.16-2009.

6.2 Detailed specification of the radio interface

6.2.1 IEEE 802.16/WiMAX

IEEE Standard for local and metropolitan area networks Part 16: Air interface for fixed and mobile broadband wireless access systems

IEEE 802.16 is an air interface standard for BWA. The base standard, IEEE 802.16-2004, address fixed and nomadic systems only. The amendment IEEE 802.16e-2005 enables combined fixed and mobile operation in licensed frequency bands below 6 GHz. The current IEEE 802.16 (including the IEEE 802.16e-2005 amendment) is designed as a high-throughput packet data radio network capable of supporting several classes of IP applications and services based on different usage, mobility, and business models. To support such diversity, the IEEE 802.16 air interface is designed with a high degree of flexibility and an extensive set of options. The WiMAX technology, based on the IEEE 802.16 Air Interface standard, enables flexible network deployment and service offerings. Some relevant key standard features are described below:

Throughput, spectral efficiency and coverage

Advanced multiple antenna techniques work with OFDMA signaling to maximize system capacity and coverage. OFDM signaling converts a frequency selective fading wideband channel into multiple flat fading narrow-band subcarriers and therefore smart antenna operations can be performed on vector flat subcarriers. Major multiple antenna technique features are listed here:

– 2^{nd}, 3^{rd} and 4^{th} order MIMO and spatial multiplexing (SM) in uplink and downlink;
– adaptive MIMO switching between spatial multiplexing/space time block coding to maximize spectral efficiency with no reduction in coverage area;
– UL (uplink) collaborative spatial multiplexing for single user device transmit antenna devices;
– advanced adaptive beamforming and null steering.

QPSK, 16-QAM and 64-QAM modulation orders are supported both in uplink and downlink. Advanced coding schemes including convolution encoding, CTC, BTC and LDPC along with chase combining and incremental redundancy hybrid ARQ and adaptive modulation and coding mechanism, enables the technology to support a high performance robust air link.

Support for mobility

The standard supports BS and MS initiated optimized hard handover for bandwidth-efficient handover with reduced delay achieving a handover delay less than 50 ms. The standard also supports fast base station switch (FBSS) and Marco diversity handover (MDHO) as options to further reduce the handover delay.

A variety of power saving modes is supported, including multiple power saving class types sleep mode and idle mode.

Service offering and classes of services

A set of QoS options such as unsolicited grant service (UGS), real-time variable rate, non-real-time variable rate, best effort and extended real-time variable rate with silence suppression (primarily for VoIP) to enable support for guaranteed service levels including committed and peak information rates, minimum reserved rate, maximum sustained rate, maximum latency tolerance, jitter tolerance, traffic priority for varied types of internet and real time applications such as VoIP.

Variable UL and DL subframe allocation supports inherently asymmetric UL/DL data traffic.

Multiple OFDMA adjacent and diversified subcarrier allocation modes enable the technology to trade off mobility with capacity within the network and from user to user. OFDMA with adjacent subcarrier permutation makes it possible to allocate a subset of subcarriers to mobile users based on relative signal strength.

Sub-channelization and MAP-based signaling schemes provide a mechanism for optimal scheduling of space, frequency and time resources for simultaneous control and data allocations (multicast, broadcast and unicast) over the air interface on a frame-by-frame basis.

Scalability

The IEEE 802.16 standard is designed to scale to different channel bandwidths from 1.25 to 28 MHz to comply with varied worldwide requirements. Current WiMAX profiles support several channel bandwidths ranging from 3.5 MHz to 20 MHz.

Scalable physical layer based on the concept of scalable OFDMA enables the technology to optimize the performance in a multipath fading mobile environment, characterized with delay spread and Doppler shift, with minimal overhead over a wide range of channel bandwidth sizes. The scalability is achieved by adjusting the FFT size to the channel bandwidth while fixing the subcarrier frequency spacing.

Reuse planning

IEEE 802.16 OFDMA PHY supports various subcarrier allocation modes and frame structures such as partially used sub-channelization (PUSC), fully used sub-channelization (FUSC) and advance modulation and coding (aka adjacent multi-carrier) (AMC). These options enable service providers to flexibly perform wireless network reuse planning for a spectrally efficient reuse factor of 1, a more interference robust reuse factor of 3 or optimal fractional reuse deployment scenarios.

In the case of reuse factor 1, although system capacity is increased, users at the cell edge and sector boundary may suffer from low connection quality due to co-channel interference. Since in OFDMA, users operate on sub-carriers, which only occupy a small fraction of the channel bandwidth, the cell edge and sector boundary interference problem can be easily addressed by reconfiguration of the sub-carrier usage and reuse factor within frames (and therefore the notion of fractional frequency reuse) without resorting to traditional frequency planning. In this configuration, the full load frequency reuse factor 1 is maintained for centre users[27] with better link connection to maximize spectral efficiency while fractional frequency reuse is achieved for edge users[28] to improve edge-user connection quality and throughput. The sub- carrier reuse planning can be adaptively optimized across sectors or cells based on network load, distribution of various user types (stationary and mobile) and interference conditions on a per-frame basis. All the cells/sectors can operate on the same RF frequency channel and no conventional frequency planning is required.

Duplexing

Time-division duplex (TDD), frequency-division duplex (FDD) and half frequency division duplex (H-FDD) are all supported by the standard. TDD provides the ability for adaptation to varied DL to UL ratios for improved spectral efficiency in contiguous spectrum blocks with data-oriented traffic which by its nature will tend to be asymmetric. TDD also assures channel reciprocity for more accurate monitoring of propagation path quality. With FDD and H-FDD profiles can be supported to fit spectrum assignments consisting of paired channels.

Security sublayer

IEEE 802.16 provides support for mutual device/user authentication using IETF EAP, flexible key management protocol using PKMv2, strong traffic encryption with AES-CCM, control and management plane message protection using AES based CMAC or MD5-based HMAC and security protocol optimizations for fast handovers.

Standard

The IEEE standard is available in electronic form at the following address:

http://www.ieee802.org/16/published.html

Information regarding the WiMAX system profiles can be found at:

http://www.wimaxforum.org/resources/documents/technical/release

6.3 IEEE 802.16 Air interface for broadband wireless access

A Wireless MAN based on the IEEE 802.16 air interface standard is configured much the same way as a traditional cellular network with strategically located base stations using a point-to-multipoint architecture to deliver services over a radius up to several kilometers depending on frequency,

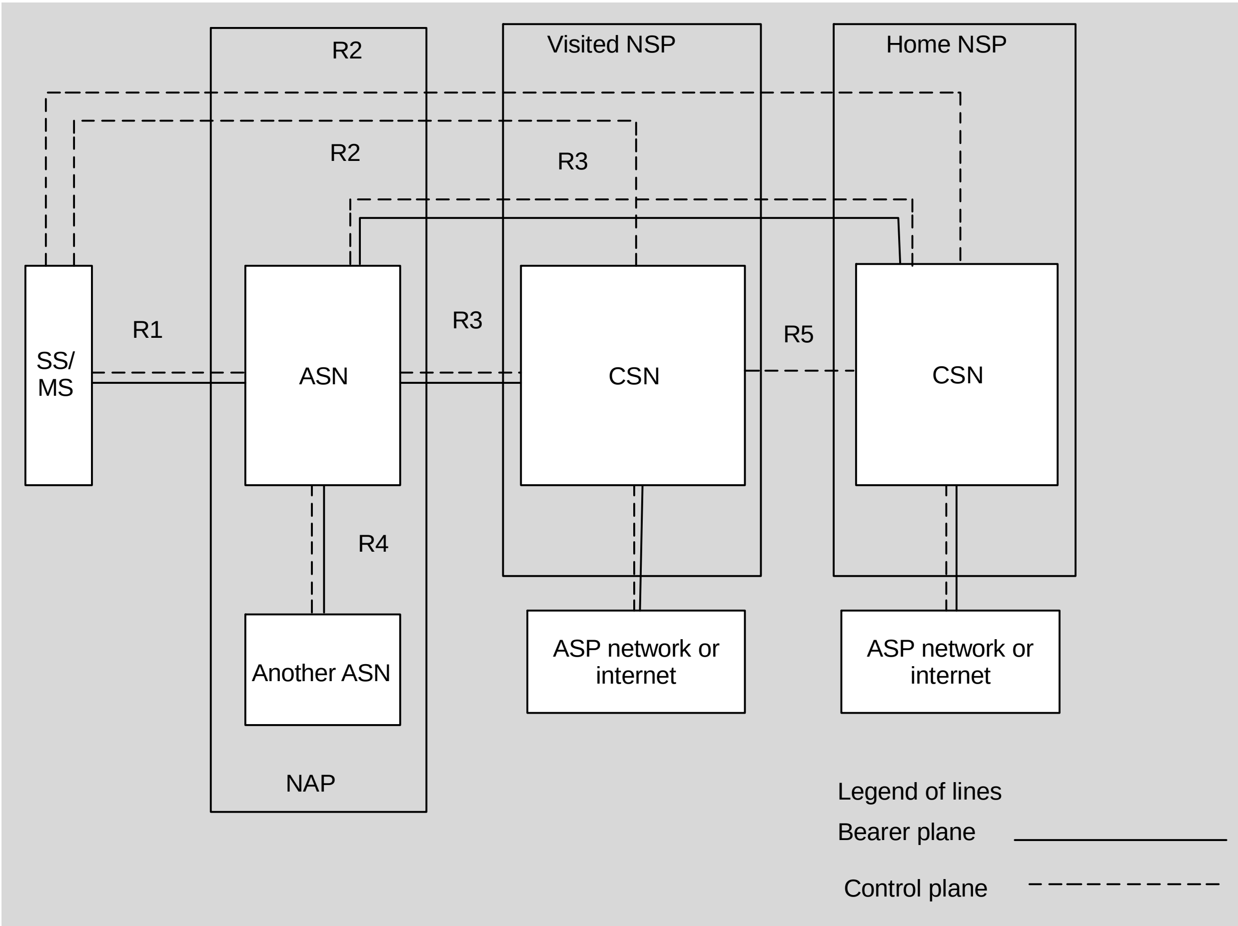
[27] Users who are located towards the middle of a sector, far from the adjacent sectors.

[28] Users who are located towards the edges of a sector, close to adjacent sectors.

transmit power and receiver sensitivity. Base stations are typically backhauled to the core network by means of fibre or point-to-multipoint microwave links to available fibre nodes or leased lines from an incumbent wire-line operator. The range and NLoS capability make the technology cost-effective.

6.3.1 WiMAX system architecture

The mobile WiMAX system architecture network reference model is depicted in the figure below.



BWA-§6.3.1

SS/MS – Client system

ASN – Access service network

CSN – Connectivity (Core) service network

ASP – Application service provider

R1, R2 etc. – Reference points

NAP – Network access provider

NSP – Network service provider

The following salient points are worth noting about this architecture:

– End-to-end all all-IP architecture not encumbered by any legacy system conformance requirements or limitations.

– Supports IP (IPv4 and IPv6) based packet switched (PS) services.

– Support Ethernet and IP convergence sublayer based services for stationary, portable and fully mobile WiMAX deployments – and simple IP and mobile IP services.

– Defines 3 major functional groups:

1. Mobile station (MS) that represents a WiMAX-enabled user device.
2. ASN that terminates the WiMAX radio link and provides radio access network (RAN) functions.
3. CSN that is a representation of an IP core network based on IETF standardized protocols for various core network functions such as mobility, AAA, address management, policy management, naming service etc.

– Defines two functional entities for the ASN – Base station (BS) and ASN gateway (ASN-GW); one or more instance of each together comprise an ASN. Interconnections within and across ASNs are IP-based links – the architecture does not put any limitations on ASN topologies and accommodates flexibility for a number of different access topologies – Flat, hierarchical, Relay, Femto etc.

– Defines CSN as a set of functions that may be subsumed in existing IP core networks or in new WiMAX-specific core networks.

– Defines interoperability reference points and protocols and procedures across these reference points. Network IOT (NWIOT) test procedures have been defined to test for interoperability conformance across these reference points.

– Defines the notions of a NAP and NSP that allows different deployment models to be realized:

a) access and core networks deployed by the same operator;
b) access network deployed by one operator and shared by 2 or more operators only offering core network services (MVNO model);
c) core network operator offering WiMAX service over ASNs deployed by 2 or more NAPs (ASN aggregation).

– Supports home and visited (roaming) connectivity scenarios.

– End-to-end capabilities such as:

a) OTA provisioning for mobile WiMAX devices;
b) pre-provisioned and dynamically provisioned QoS;
c) Radio Resource Management (RRM) in the ASN;
d) password and SIM based authentication;
e) emergency services and lawful interception support.

– Supports interworking with 3GPP (GERAN, UMTS and SAE networks), 3GPP2 and DSL networks based on IP protocols.

– Support for mobile Internet connectivity as well as advanced IP services such as multicast broadcast service (MCBCS), location based services (LBS), IP multimedia services (IMS).

– Support for new, innovative, metered mobile Internet IP services based on universal services interface (USI).

The WiMAX Forum has initially focused upon four main spectrum bands for certification of interoperability and conformance to the IEEE 802.16 standard:

– 2.3-2.4 GHz

– 2.496-2.690 GHz

– 3.4-3.6 GHz

– 5.725-5.850 GHz.

The WiMAX Forum certified products are available for use in these and other frequency bands. The following table provides a complete list of WiMAX Forum profiles.

Band Class Group	Uplink MS Transmit Frequency (MHz)	Downlink MS Receive Frequency (MHz)	Channel Bandwidth (MHz)	Duplex Mode
1.A	2 300-2 400	2 300-2 400	8.75	TDD
1.B	2 300-2 400	2 300-2 400	5 and 10	TDD
2.D	2 305-2 320, 2 345-2 360	2 305-2 320, 2 345-2 360	3.5, 5 and 10	TDD
2.E	2 345-2 360	2 305-2 320	2 x 3.5, 2 x 5 and 2 x 10	FDD
2.F	2 345-2 360	2 305-2 320	5 (Uplink), 10 (Downlink)	FDD
3.A	2 496-2 690 #	2 496-2 690 #	5 and 10	TDD
3.B	2 496-2 572 #	2 614-2 690 #	2 x 5 and 2 x 10	FDD
4.A	3 300-3 400 #	3 300-3 400 #	5	TDD
4.B	3 300-3 400 #	3 300-3 400 #	7	TDD
4.C	3 300-3 400 #	3 300-3 400 #	10	TDD
5L.A	3 400-3 600	3 400-3 600	5	TDD
5L.B	3 400-3 600	3 400-3 600	7	TDD
5L.C	3 400-3 600	3 400-3 600	10	TDD
5.D	3 400-3 500	3 500-3 600	2 x 5, 2 x 7 and 2 x 10	FDD
5H.A	3 600-3 800 #	3 600-3 800 #	5	TDD
5H.B	3 600-3 800 #	3 600-3 800 #	7	TDD
5H.C	3 600-3 800 #	3 600-3 800 #	10	TDD
6.A	1 710-1 770	2 110-2 170	2 x 5 and 2 x 10	FDD
6.B	1 920-1 980	2 110-2 170	2 x 5 and 2 x 10	FDD
6.C	1 710-1 785	1 805-1 880	2 x 5 and 2 x 10	FDD
7.A	698-862	698-862	5, 7 and 10	TDD
7.B	776-787	746-757	2 x 5 and 2 x 10	FDD
7.C	788-793, 793-798	758-763, 763-768	2 x 5	FDD
7.D	788-798	758-768	2 x 10	FDD
7.E	698-862	698-862	5, 7 and 10 (TDD) 2 x 5, 2 x 7 and 2 x 10 (FDD)	TDD/FDD
7.G	880-915	925-960	2 x 5 and 2 x 10	FDD
8.A	1 785-1 805, 1 880-1 920, 1 910-1 930, 2 010-2 025, 1 900-1 920	1 785-1 805, 1 880-1 920, 1 910-1 930, 2 010-2 025, 1 900-1 920	5 and 10	TDD

Equipment that is WiMAX Forum Certified is the only equipment proven interoperable with other vendor's equipment that is also WiMAX Forum Certified. For network operators, this interoperability yields more options, the flexibility of deploying broadband wireless systems from multiple vendors, and the knowledge that all products deployed, if certified, will interoperate seamlessly, thereby reducing the overall investment risk and creating a price-competitive marketplace.

Work is also underway to extend the mobile WiMAX profiles for other frequency bands identified for mobile service allocations, such as the 700 MHz band.

6.4 ETSI standards

The specifications contained in this section include the following standards for BWA, the last available versions being:

– ETSI TS 102 177 v1.3.2: Broadband Radio Access Networks (BRAN); HiperMAN; Physical (PHY) Layer.

– ETSI TS 102 178 v1.3.2: Broadband Radio Access Networks (BRAN); HiperMAN; Data Link Control (DLC) Layer.

– ETSI TS 102 210 v1.2.1: Broadband Radio Access Networks (BRAN); HiperMAN; System Profiles.

Abstract: The HiperMAN standard addresses interoperability for BWA systems below 11 GHz frequencies, to provide high cell sizes in non-line-of-sight (NLoS) operation. The standard provides for FDD and TDD support, high spectral efficiency and data rates, adaptive modulation, high cell radius, support for advanced antenna systems, high security encryption algorithms. Its existing profiles are targeting the 1.75 MHz, 3.5 MHz and 7 MHz channel spacing, suitable for the 3.5 GHz band.

The main characteristics of HiperMAN standards, which are fully harmonized with IEEE 802.16, are:

– all the PHY improvements related to OFDM and OFDMA modes, including MIMO for the OFDMA mode;

– flexible channelization, including the 3.5 MHz, the 7 MHz and 10 MHz raster (up to 28 MHz);

– scalable OFDMA, including FFT sizes of 512, 1 024 and 2 048 points, to be used in function of the channel width, such that the subcarrier spacing remains constant;

– uplink and downlink OFDMA (sub-channelization) for both OFDM and OFDMA modes;

– adaptive antenna support for both OFDM and OFDMA modes.

Standards: All the ETSI standards are available in electronic form at:
http://pda.etsi.org/pda/queryform.asp, by specifying in the search box the standard number.

6.5 IMT-2000 OFDMA TDD WMAN

A technology conforming to a subset of the 802.16 specifications has been added to the IMT-2000 family. The parameters of this sixth interface are given in Table 6.

TABLE 6

OFDMA TDD WMAN parameters and capabilities, TDD mode

Parameter / Capability	Value				IEEE 802.16 Subclause
Duplex method	TDD				8.4.4
Physical layer mode	OFDMA				8.4
System channel bandwidth	5 MHz	10 MHz	8.75 MHz	7 MHz	8.4.1
FFT size	512	1 024	1 024	1024	
Frame duration	5 ms		5 ms	5 ms	8.4.5.2
Transmit transition gap (TTG)	105.714 µs		87.2 µs	188 µs	8.4.5.2
Receive transition gap (RTG)	60 µs		74.4 µs	60 µs	8.4.5.2
Modulation, downlink	QPSK, 16-QAM, 64-QAM				8.4.9.4.2
Modulation, uplink	QPSK, 16-QAM				8.4.9.4.2
Forward error correction coding	Convolutional Coding and Convolutional Turbo Coding				8.4.9.2.1; 8.4.9.2.3 excluding 8.4.9.2.3.5
Encryption	AES-CCM, AES Key Wrap, 128-bit keys				11.9.14
Authentication	EAP				11.8.4.2
Privacy key management	PKMv2				7.2.2
Management message integrity protection	CMAC				7.5.4.4

OFDMA TDD WMAN parameters and capabilities, FDD mode

Parameter / Capability	Value			IEEE 802.16 Subclause
Duplex method	FDD			8.4.4
Physical layer mode	OFDMA			8.4
System channel bandwidth (uplink/downlink)	5 MHz	10 MHz	7 MHz	8.4.1
FFT size	512	1 024	1 024	
Frame duration	5 ms			8.4.5.2
Modulation, downlink	QPSK, 16-QAM, 64-QAM			8.4.9.4.2
Modulation, uplink	QPSK, 16-QAM			8.4.9.4.2
Forward error correction coding	Convolutional coding and convolutional turbo coding			8.4.9.2.1; 8.4.9.2.3 excluding 8.4.9.2.3.5
Encryption	AES-CCM, AES Key Wrap, 128-bit keys			11.9.14
Authentication	EAP			11.8.4.2
Privacy key management	PKMv2			7.2.2
Management message integrity protection	CMAC			7.5.4.4

6.6 Examples of deployments using this standard

The year 2008 marked the advent of OFDMA-based WiMAX for mobile services. Building on WiMAX deployments for fixed services beginning in 2006, mobile WiMAX quickly gained favor with operators in developing and developed countries as a truly next generation broadband mobile technology. Within less than two years, there are over 500 WiMAX deployments underway in more than 140 countries. A recent Infonetics Report[29] predicts 140 million WiMAX subscribers in 2013. WiMAX is the first commercially available technology with the features and capacity to simultaneously support fixed, nomadic, portable, and mobile usage models for enterprise and consumers.

Another driver for broadband data growth beyond mobile applications is the use of WiMAX networks as alternatives to wireline networks where running wire or fibre is problematic or too complex. This includes developing economies, as well as remote areas. For example, Packet One Networks in Malaysia deployed a Mobile WiMAX network that attracted over 100.000 subscribers in just over a year of service. P1's Network will extend broadband coverage to 50% of the Malaysian population by 2010, more than doubling the country's pre-WiMAX broadband penetration rate.

[29] Infonetics Research Q209 Report: WiMAX equipment, devices, and subscriber market share forecast and research Report.

ANNEX C

PUBLICATIONS ON BWA

1 Overview

The following sections provide a non-exhaustive list of relevant publications on BWA. Summaries are provided for ease of reference.

2 ITU-R Publications

2.1 Resolutions

Resolution 229 (WRC-03) – Use of the bands 5 150-5 250 MHz, 5 250-5 350 MHz and 5 470-5 725 MHz by the mobile service for the implementation of wireless access systems including radio local area networks

2.2 Recommendations

Recommendation ITU-R M.1450 – Characteristics of broadband radio local area networks

Summary: This Recommendation lays out the technical requirements for the use of these bands by the mobile service for the implementation of WAS, including RLANs.

Recommendation 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

Summary: This Recommendation provides the e.i.r.p density and power flux density limits on RLANs, as well as operational constraints and interference mitigation techniques. The Recommendation also provides the methodology and parameters to be used for sharing studies.

Recommendation ITU-R M.1457 – Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-2000 (IMT-2000)

Summary: This Recommendation provides specifications of the radio interfaces (terrestrial and satellite) for IMT-2000 third generation mobile devices.

Recommendation ITU-R M.1651 – A method for assessing the required spectrum for broadband nomadic wireless access systems including radio local area networks using the 5 GHz band

Summary**:** This Recommendation provides a method for assessing the required spectrum for broadband nomadic wireless access (NWA) systems including radio local area networks (RLANs). Annex 1 of this Recommendation gives a general description of RLANs, the deployment scenarios, an overview of the method for estimating the required spectrum as well as an example calculation in the 5 GHz band.

Recommendation ITU-R M.1652 – Dynamic frequency selection (DFS) in wireless access systems including radio local area networks for the purpose of protecting the radiodetermination service in the 5 GHz band

Summary: This Recommendation and its annexes provide the DFS requirements (performance, detection, operational, response) and procedures for the protection of the radiodetermination service. The annexes also provide details on the characteristics of radiolocation systems and the parameters and methodology for the probability of detection of these systems by wireless access systems including radio local area networks.

Recommendation ITU-R M.1653 – Operational and deployment requirements for wireless access systems including radio local area networks in the mobile service to facilitate sharing between these systems and systems in the Earth exploration-satellite service (active) and the space research service (active) in the band 5 470-5 570 MHz within the 5 460-5 725 MHz range

Summary: This Recommendation lays out the technical requirements (power spectral density, transmitter power, e.i.r.p limits, etc.) for indoor and outdoor operation of WAS including RLANs for sharing. The Recommendation also provides the technical characteristics of EESS and SAR systems.

Recommendation ITU-R M.1739 – Protection criteria for wireless access systems, including radio local area networks, operating in the mobile service in accordance with Resolution 229 (WRC-03) in the bands 5 150-5 250 MHz, 5 250-5 350 MHz and 5 470-5 725 MHz

Summary: This Recommendation provides protection criteria for wireless access systems, including radio local area networks (WAS/RLAN), operating in accordance with Resolution 229 (WRC-03) for the purposes of carrying out compatibility studies with services or applications from which WAS/RLAN systems are to be protected.

Recommendation ITU-R M.1801 – Radio interface standards for broadband wireless access systems, including mobile and nomadic applications, in the mobile service operating below 6 GHz

Summary: This Recommendation recommends specific standards for broadband wireless access in the mobile service. These specific standards are composed of common specifications developed by standards development organizations (SDOs). Using this Recommendation, manufacturers and operators should be able to determine the most suitable standards for their needs.

Recommendation ITU-R RS.1632 – Sharing of the band 5 250-5 350 MHz between the Earth exploration-satellite service (active) and wireless access systems (including radio local area networks) in the mobile service

Summary: This Recommendation provides the technical characteristics of various EESS systems and the results of three sharing studies between spaceborne active sensors and high speed RLANs. The Recommendation also provides the results of a study between RLANs and altimeters.

2.3 Reports

Report ITU-R M.2034 – Impact of radar detection requirements of dynamic frequency selection on 5 GHz wireless access system receivers

Report ITU-R M.2039-1 – Characteristics of terrestrial IMT-2000 systems for frequency sharing/interference analyses

Summary: This Report provides the baseline characteristics of terrestrial IMT 2000 systems for use in frequency sharing and interference analysis studies involving IMT 2000 systems and between IMT 2000 systems and other systems.

Report ITU-R M.2116 – Characteristics of broadband wireless access systems operating in the land mobile service for use in sharing studies

Summary: This Report provides characteristics for a number of terrestrial broadband wireless access (BWA) systems, including mobile and nomadic applications, operating, in the mobile service for use in sharing studies between these terrestrial BWA systems and other fixed or mobile systems.

Report ITU-R SM.2012 – Economic aspects of spectrum management

Summary: This Report is intended for use by administrations of both developing and developed countries in their development of strategies on economic approaches to national spectrum management and to the financing of this activity. In addition, the Report presents a discussion of the benefits of strategic development and the methods of technical support for national spectrum management. These approaches not only promote economic efficiency but can also promote technical and administrative efficiency.

2.4 Handbooks

Handbook on Land Mobile (including Wireless Access) – Volume 1 – Fixed Wireless Access (2nd Edition)

Summary: This Volume on Fixed Wireless Access describes the basic principles, access requirements, technology criteria, deployment planning and technical descriptions of typical systems, http://www.itu.int/publ/R-HDB-25/enDeployment of IMT-2000 Systems.

Supplement 1 to the Handbook on Deployment of IMT-2000 Systems.

Summary: This Handbook addresses a variety of issues - service requirements and applications trends, systems characteristics, technologies, standards, spectrum, regulations – related to the deployment of IMT-2000 systems, http://www.itu.int/pub/R-HDB-46.

ANNEX D

TECHNICAL ASPECTS OF SPECTRUM DEPLOYMENT

1 Introduction

This Annex addresses fundamental technical aspects of adjacent channel interference and the implications for BWA deployments. The use of common band plans and fixed cross-over points between FDD and TDD operations significantly reduces the possibility of interference while simplifying the complexity of the equipment and the analysis of interference conditions. Both base station-to-base station and mobile-station to mobile-station interference scenarios are analyzed and general guidelines are given in terms of requirements for guard bands, band-pass filters, and geographical separation. Analysis would need to be conducted for specific deployment situations according to the guidelines provided here, particularly for those situations using a band plan unique to one operator. The analyses here provide examples and general guidance.

2 Fundamental technical considerations

Modern broadband technologies can support various functionalities, such as different channel bandwidths (e.g. 1.25 MHz to 20 MHz), adaptive modulation and coding schemes (e.g. modulations such as QPSK to 64-QAM, turbo coding and LDPC, and any combination of these depending on the propagation conditions), different duplexing access schemes (FDD and TDD), and adaptive antenna systems including MIMO. However, some technical limitations still prevail as a result of the physical characteristics of radio technologies.

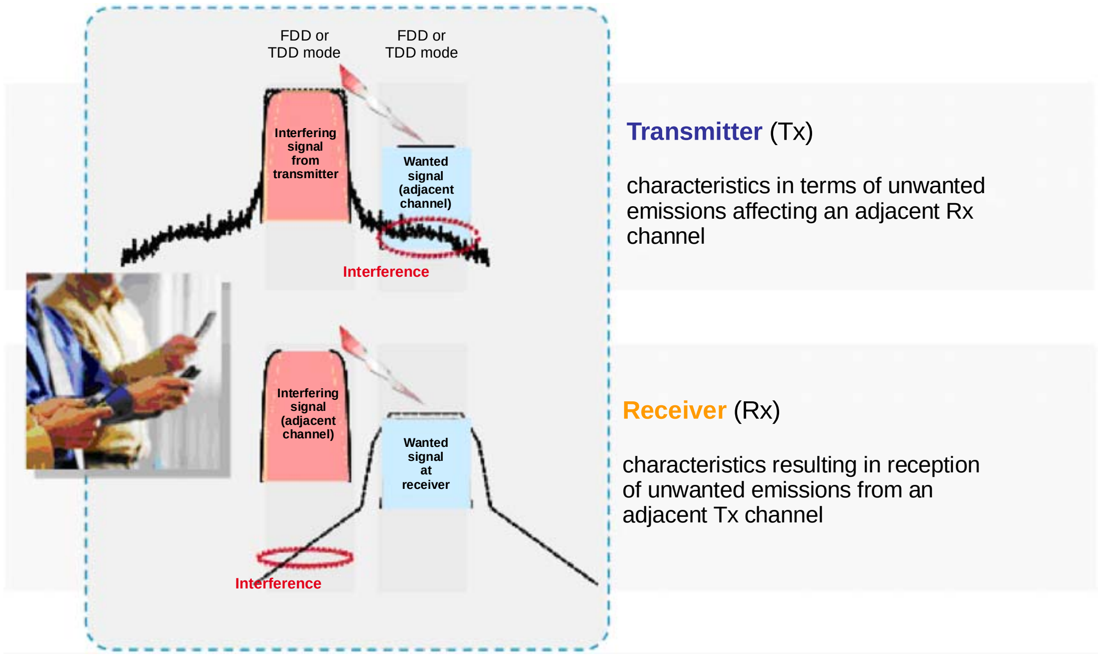
One such limitation is that the receivers of mass market terminal devices cannot discriminate between the required signal and the unwanted emissions from front-end non-linearities or from a transmitter being operated on an immediate adjacent channel as depicted in Fig. 33 (transmitter interference). Similarly, the selectivity properties of the broadband receiver will always receive signals in the adjacent transmit channel (receiver interference). These types of interference are shown in red in Fig. 33.

Figure 33 shows the two fundamental types of interference. Figure 34 shows the more complete case of a broadband deployment consisting of an FDD system with a TDD system operating in the center gap between the uplink and downlink blocks of the FDD system. The red arrows show the direction of each case of interference, with the thicker arrows denoting those cases of interference – i.e., base to base and mobile to mobile - that require greater care to mitigate.

The thin arrows, which denote base station to mobile station and mobile station to base station interference scenarios exist for situations between two FDD systems, two TDD systems or one FDD and one TDD system adjacent to each other. Today’s FDD and TDD systems have similar parameters; hence, this scenario is not specific to FDD/TDD coexistence. The base-to-mobile and mobile-to-base scenarios are typically planned for by conventional frequency planning and technology design, so that a minimal number of special precautions are needed except in unusual circumstances. The right hand computer can have a problem if it is too close to the TDD cell. In this case, it is limited to the one user. But, if the left hand computer is too close to the TDD cell, it can take out the entire cell.

FIGURE 33

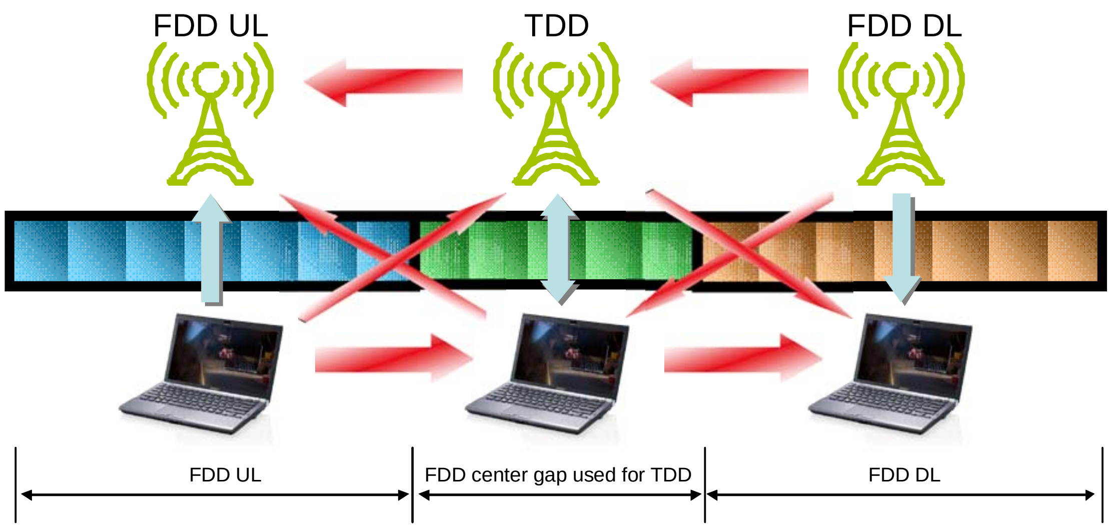
Illustration of adjacent channel interference



BWA-33

FIGURE 34

Interference situations between different duplex access schemes



Abbreviations: FDD: Frequency-division duplex; TDD: Time-division duplex;
UL: Up link transmission direction; DL: Down link transmission direction.

BWA-34

The only approach to reduce the interference between broadband base stations using FDD and TDD while serving the same geographic area is to increase the isolation between the two systems by implementing:

– additional filtering in both receivers and transmitters[30], and / or

– guard bands, or restricted channels.

Two reports have shown[31] that a guard band of 5 MHz or a restricted channel has to be considered at each FDD-TDD boundary together with additional filtering, beyond that of the current specifications in 3GPP. Such measures are a compromise between the cost of system implementation and the cost of spectrum for guard bands. The studies such as those referenced here are made with a specific set of operating conditions and different sets of conditions could result in either more or less guard band. While reducing RF power per base station is an option, doing so would necessitate additional base stations to meet coverage requirements, thereby increasing the potential for interference. The model in Fig. 34 will also apply if FDD and TDD are interleaved within a band.

Similar guard band and additional filtering considerations need to be taken into account between two TDD deployments operating in adjacent frequencies in the same or adjacent areas unless their uplink / downlink subframes are synchronized and phase aligned. Such measures avoid the overlap of uplink/downlink time slots (phase alignment may not always be possible because the up/down ratio may be different depending on the offered services and the time of day).

The model in Fig. 34 may also be used for the analysis of TDD-TDD in adjacent bands. Indeed, the left side of Fig. 34 applies in the TDD uplink and right-hand side applies to the TDD downlink.

It should be noted that filtering is used conceptually here. In practice, filters cannot be applied after a power amplifier. What is intended here is cleaner RF spectrum, which generally doesn't include RF filtering in modern implementations.

Alternatives exist beyond filtering and guard bands in the frequency domain but they need to be purposely designed for each specific deployment. One example is guard band in the time domain, where the FDD channel is still slotted in a manner to coordinate with the TDD transmissions. Uplink beam forming techniques could also be used to improve isolation. Cell sitting is also a consideration where the location of the FDD cell can guarantee some minimum isolation between the TDD and FDD cells.

3 Overarching aspects of base stations and terminal devices

3.1 Interference scenarios and filter requirements

To reach mass-market scale, BWA equipment is manufactured based on the ITU recommended standards. For that reason, base stations, but more importantly, most mobile terminals devices, are produced to these standards with state of the art radio frequency filters of small size that operate within the frequency bands and arrangements defined by ITU-R Recommendations, such as Recommendation ITU-R M.1036 for IMT systems. The inherent filter characteristics, and the combination of different filters, enable the base stations and terminal devices to scale across a band, thereby supporting spectrum efficiency.

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[30] While filtering may help, this generally is difficult for equipment that has already been deployed.

[31] See for example CEPT Report 19 and ECC Report 131.

The design of filters will be based on the fixed frequency boundaries between FDD and TDD systems as specified in harmonized frequency arrangements. For example, the implementation of FDD filters is based on fixed filter design with band pass characteristics for the base station receive sub-band and the terminal receive sub-band, whereas the implementation of a TDD filter, in many cases, is fixed for the band or sub-band used. (Again, note that a sub-band refers to a contiguous range of frequencies for FDD uplink, for FDD downlink, or for TDD operation, within a band plan.)

Notably, these filters will facilitate the coexistence situation by suppressing unexpected interference where the FDD and TDD access schemes are separated in frequency and the base stations and terminals are used according to the harmonized sub-band partitioning. The technical limitations are mainly due to a tradeoff between the spectral rolloff capabilities of the radio frequency filters and the restrictions in power consumption, size and weight. The technical requirements dictate the need for supporting a large bandwidth, while keeping insertion loss low and the out of band rejections high.

The use of filters to improve performance presents many challenges. It assumes that the TDD and FDD operation have defined frequency bands, not interspersed. Most modern systems have filtering processes that are implemented at baseband as well as at RF. Generally, RF filtering is applied for a whole band of operation, not sub-bands. Switching sub-band filters in and out as needed for a device that could support both FDD and TDD is also problematic due to its complexity. Further, in addition to the insertion loss mentioned above, there is usually ripple associated with a RF filters that have good sideband rejection. In addition, much FDD equipment is already deployed and is retrofitted with difficulty. It should be noted that the Minimum Performance Standards for TDD and FDD devices are generally set by the group developing the specifications such as 3GPP, 3GPP2, and IEEE.

If countries implement band plans that are not internationally harmonized, specially designed additional filtering for both FDD and TDD systems would be required[32]. Furthermore, when different countries that share a common border adopt different band plans, the following four interference scenarios could occur. Scenarios 1 and 2 could be managed by bilateral agreements as they relate to the deployment of base stations, which are generally in fixed sites; however, scenarios 3 and 4 below would require country-specific terminal implementations to avoid adjacent interference. International roaming could still be problematic:

1. the upper part of the FDD UL block would be subject to an international situation of co-channel interference cross borders (base station TDD Tx -to- base station FDD Rx);
2. the upper part of the FDD DL block would be subject to an international situation of co-channel interference cross borders (base station FDD Tx -to- base station TDD Rx);
3. the upper part of the FDD UL block would be subject to a national situation of adjacent interference (mobile FDD Tx -to- mobile TDD Rx);
4. the upper part of the FDD DL block would be subject to a national situation of adjacent interference (mobile TDD Tx -to- mobile FDD Rx).

With regard to scenarios 3 and 4, it should be noted that the terminal radio frequency filters are designed to function within specific frequency bands. Country-specific spectrum arrangements would require the design and production of country-specific terminal devices, thereby increasing the potential for interference when foreign terminals operate in a country as well as when that country’s terminal devices are operated abroad. Terminals with mass-produced filters would not be

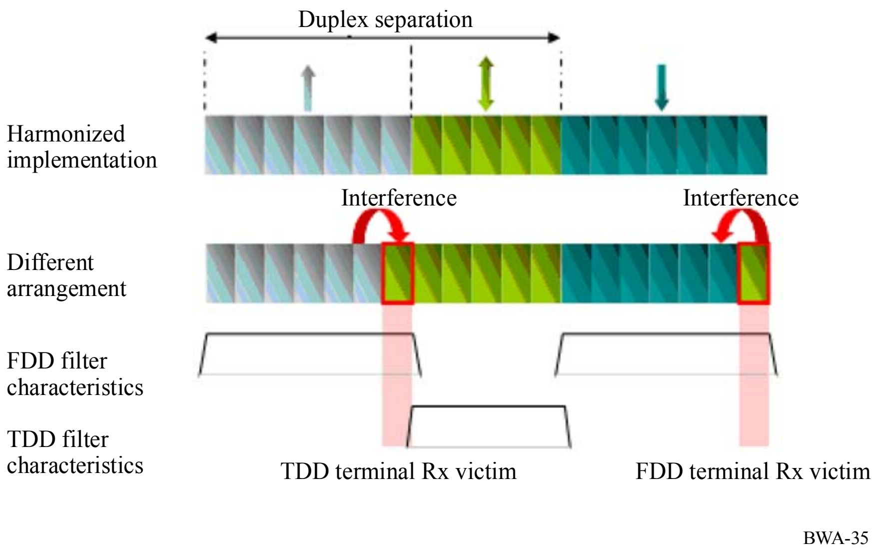
[32] International band plans for IMT devices can be found in Recommendation ITU-R M.1036. See also Report ITU-R M.2030 for guard band requirements.

able to manage unexpected interference generated by terminals with filters designed to operate on different band plans.

Therefore, the adoption of unique national spectrum arrangements is likely to lead to interference issues or cost, especially when terminal devices operate in close proximity. This is illustrated in Fig. 35. Such interference situations could occur in any environment, for example, in homes, offices, conference centers, bus and train stations, on buses and trains, underground stations, at events, sports arenas, hospitals, etc.

FIGURE 35

Risks of interference created by implementing non-harmonized frequency arrangements



4 Base station to base station aspects

4.1 Filters and guard bands

Several studies in ITU-R have analyzed the need for guard bands between FDD and TDD deployed in the same geographical area, using adjacent channels (see Reports ITU-R M.2030, ITU-R M.2045, ITU-R M.2113 and ITU-R M.2146). Similar studies in Europe have been used to determine the appropriate conditions for the band 2 500-2 690 MHz, where both FDD and TDD may be deployed. In particular, adjacent channel interference from one base station transmitting at the same time as another one is receiving on the immediate adjacent channel has been studied in detail, as it is assumed that this is the most difficult case to manage.

The overall conclusion of the ITU-R studies is that even with a 10 MHz frequency separation between the edge of the transmit band and the edge of the receive band (i.e. guardband), base station to base station interference will be excessive, unless additional measures are taken[33]. Provided that additional filters are applied to the base stations, both for the receiving base station

[33] Report ITU-R M.2030 specifically states that based on the existing specifications and minimum coupling loss (MCL) assumptions, even a guardband of 5 MHz and 10 MHz will not remove the problem.

and the transmitting base station, it is possible to operate FDD and TDD in the same area with only a 5 MHz frequency separation. These filters need to improve selectivity and reduce adjacent channel leakage of base stations of the order of 50 dB. CEPT Report 19 defines the block edge mask (BEM) for TDD and FDD coexistence and the adjacent channel leakage is derived from the BEM. ECC Report 119 is a more general description of FDD/TDD coexistence in 2 600 MHz band. Moreover, based on the same scenario and calculations, interfering base stations with less than 100 m separation distance may also require specific site engineering even if additional filters are applied. Special care is needed in the case of tower sharing and/or the presence of nearby reflective objects (e.g., a large building). In some configurations, where tower sharing is impractical due to interference, more antenna towers may be needed.

The above results on frequency separation between FDD and TDD access schemes apply equally to scenarios with two TDD systems in the same area that do not have coordinated uplink and downlink transmissions, i.e. scenarios where base station to base station interference will be present. Therefore, in the case of unpaired operation, the uplink and downlink sub-frames of adjacent base stations operating in the vicinity of each other (of the same or different technology), must be time-aligned (i.e. frames starting at the same time), and the two systems should be frame-synchronized (i.e. the frames of the two systems have the same length and the same uplink to downlink ratio) to a common source and have a common break point between the uplink and downlink.

4.2 Geographic separation to avoid co-channel interference

Interference will result from co-channel operations under different TDD and FDD allocations on either side of a geographical border separating different countries or regions. In this case there will be co-channel interference from a base station on one side of the border to one on the other side, as the first is transmitting on a channel that is being used simultaneously for receiving by the other base stations. The same type of interference will of course result for the case of two TDD networks on either side of the border that do not have coordinated uplink and downlink transmissions. As the base stations antennas are generally placed at a height of 30 m or more, the interference may be excessive even at very large distances, due to the fact that filtering is not an option in a co-channel case. For example, in a deterministic, worst case situation, the required propagation loss to suppress the interference would be in the order of 180 dB, which corresponds to about 75 km separation. To derive this value, it is assumed that base stations in transmitting and receiving mode are operating on opposite sides of a border. The operating frequency is 2 600 MHz.

The parameters used in the calculation are the following:

Operating frequency: 2 600 MHz

Interfering base station

Radio frequency power (e.i.r.p.)	58 dBm
Antenna height	30 m
(Antenna directed towards the border)	

Victim base station receiver

Antenna gain	17 dBi
Feeder loss	2 dB
Antenna height	30 m
(Antenna directed towards the border)	

Maximum tolerable interference level –109 dBm (6 dB below noise)[34]

Required path loss 58 + 17 – 2 + PL(dB) = –109 dBm → PL = 182 dB

The study is relevant for the following three co-channel scenarios:

BS FDD Tx to BS TDD Rx;

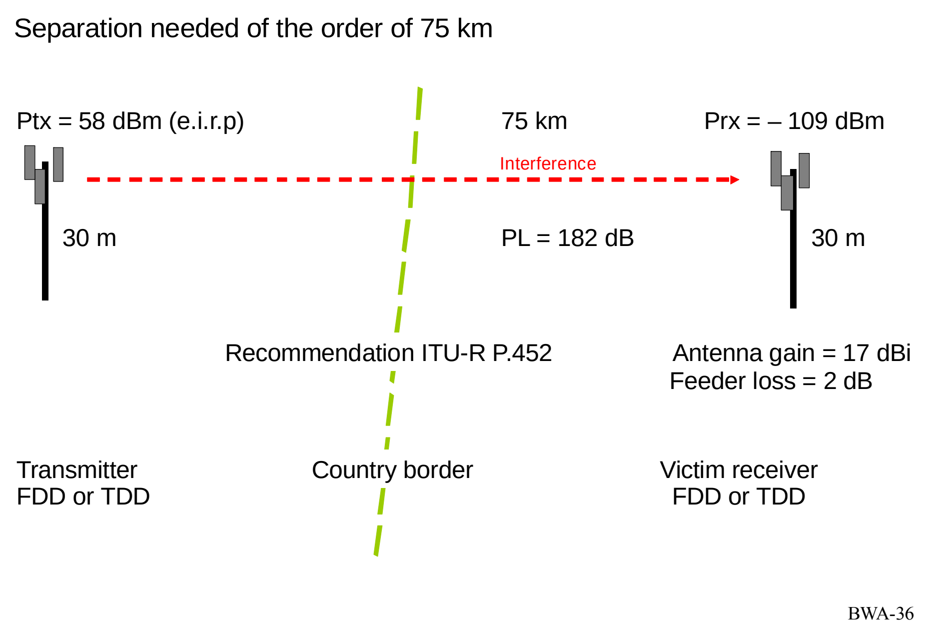
BS TDD Tx to BS FDD Rx, and

BS TDD Tx to BS TDD Rx (unsynchronized).

Recommendation ITU-R P.452 – Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz, for the frequency 2 600 MHz is used to derive the separation distance needed given the path loss. The results indicate a need for a separation distance of the order of 75-80 km. This is illustrated in Fig. 36.

FIGURE 36

Base station to base station interference



If both systems turn their antennas away from the border, assuming an antenna front to back ratio of 25 dB, the result would be a path loss (PL) of about 182 – 50 = 132 dB. Again, using Recommendation ITU-R P.452, a separation distance of the order of 30 km would be required.

However, antenna directivity will not always protect neighboring cells without causing coverage gaps. This is exacerbated since RF coverage does not follow geographic borders.

Thus, for the co-channel scenarios described above, a "corridor" of approximately 15-35 km would be needed on each side of the border, unless mitigation methods, such as reducing the transmitted power, are introduced.

[34] This value is from ITU-R Report M.2039. Noise is calculated over 3.84 MHz (UMTS). Noise figure 5 dB and –6 dB *I/N* requirement (the difference for a LTE channel is ~0.5 dB).

4.3 Guidance for performing calculations for specific deployment situations

For specific deployment situations, more detailed analyses should be done taking into consideration the variables in the configuration and parameters of the deployment, as well as the corresponding propagation model.

Recommendation ITU-R M.1825 – Guidance on technical parameters and methodologies for sharing studies related to systems in the land mobile service, gives guidance to perform sharing studies related to systems in the land mobile service. It establishes a list of parameters, that characterize a system to assist in sharing studies, provides information on the methodologies that can be used for sharing analyses involving the land mobile service and describes mitigation techniques that can improve spectrum sharing. It also contains a list of relevant ITU-R Recommendations, Reports and Handbooks.

The ITU-R Handbook – Terrestrial land mobile radiowave propagation in the VHF/UHF bands, provides guidance on those concepts that are necessary to understand how radiowave propagation principles are applied to the design of terrestrial land mobile radio systems. In particular its Chapter 4 addresses modelling techniques for outdoor radio propagation predictions, which are broadly subdivided into site-general, empirically-based models and more deterministic, site-specific models.

Recommendation ITU-R P.452 is the appropriate propagation model for predicting interference between terrestrial stations in the frequency range from about 700 MHz up to above 6 GHz when the distance between the transmitter and receiver is longer than 1 km. Recommendation ITU-R P.1411 could be used for short paths up to about 1 km, while Recommendation ITU-R P.1546 can be used for frequencies from 30 to 3 000 MHz and for time percentages down to 1%.

Recommendation ITU-R P.452 must be used with a terrain profile. Hypothetical terrain can be used to be representative of the case under consideration, but each profile must be specific; there is no mode in which Recommendation ITU-R P.452 can be used for an "average" profile.

If it is considered necessary to use Recommendation ITU-R P.452 with representative terrain profiles, it is suggested that these are obtained from a global database of actual terrain heights for different global locations, in order to sample the variation of radio-meteorological parameters, and for different terrain types representative of the scenarios under consideration.

The models implemented in Recommendation ITU-R P.452 take into account whether the path is line-of-sight (LoS) or non-line-of-sight (NLoS), its general location anywhere in the world, and the specific geometry of the path. The complete method predicts the basic transmission loss not exceeded for a percentage of an average year in the range 50% to 0.001%.

As a general guideline, the analysis above should be performed for deployments following different band plans for FDD and TDD operation. That is, a harmonized band plan will address most spectrum sharing issues through the associated standardized specifications; however, any deviation from the standard band plan will require additional considerations to minimize the possibilities of interference. Interference will result if base stations are operating TDD and FDD modes according to different band plans at geographical borders. The normal needed separation distances may be of the order of 75 km. It is thus beneficial to harmonize spectrum arrangements within a geographical region.

5 Mobile to mobile station aspects

Mobile station to mobile station interference will appear between closely located and simultaneously operated terminals, i.e. if operated in the same conference or meeting room or other densely populated places. The interference may be of the same order magnitude as of the wanted signal but will be less static than in the case of base station to base station situation due to the mobility of terminal devices. For terminal device to terminal device, using a TDD scheme, the interference cannot be efficiently managed between operators without synchronization and identical uplink/downlink phasing. An individual operator would also need to synchronize the network to avoid intra system interference between terminal devices.

With regard to the mass-market aspect where mobile devices are produced in tens of millions, if different frequency arrangement deployments were to be used, the mobile to mobile device interference cannot be expected to be adapted to all specific national circumstances.

Typically BWA mobile devices are manufactured to operate within specific band plans. Therefore, as discussed earlier, from a technical and economical point of view, the FDD mobile device duplex filter cannot adapt to a multitude of frequency arrangements. As a result, FDD terminal devices cannot discriminate between wanted and unwanted emissions, especially when terminal devices are operated in close proximity to each other.

One of the more common usages of mobile broadband communication is indoors where mobile devices will be operated in close vicinity. The following examples (see Figs 37a) and 37b)) look at potential interference within a meeting room.

– Base station (urban) radio frequency power 55 dBm
– Distance between base stations 350 m
– Distance to "wanted" user 200 m
– Path loss (urban): –116 dB[35]
– Path loss building –10 dB
– Resulting received power –71 dBm
– Transmit power of interfering terminal devices: 23 dBm[36]
– Distance between "unwanted and the "wanted" terminal: within 3 m
– Path loss (LoS): –50 dB
– Activity factor 12.5% one to one user[37]: –12 dB
– Adjacent channel suppression: –30 dB
– Resulting interference level: –69 dBm.

The example shows a −2 dB SINR value (signal −71 dBm and interference −69 dBm). The decrease in SINR (unless close to antenna) will reduce the throughput (possibly to zero in cell-edge case). Using a "link to system interface" for this SINR value it gives ~20% throughput capacity compared to maximum capacity. Assuming a second mobile station at 3 m, it would cause a 3 dB higher SINR value, which would further reduce the throughput capacity by ~40%. A few dB variations can be assumed due to antenna mismatch and/or body shielding; the wanted user would be losing 60–80% of the capacity.

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[35] The propagation model used here is Extended Hata Urban model, with base station height 30 m, mobile station height 1.5 m, frequency 2 570 MHz and 200 m is the propagation loss ~116 dB.

[36] While automatic power control will attempt to reduce the mobile station transmit power, at cell edge it could be 23 dBm.

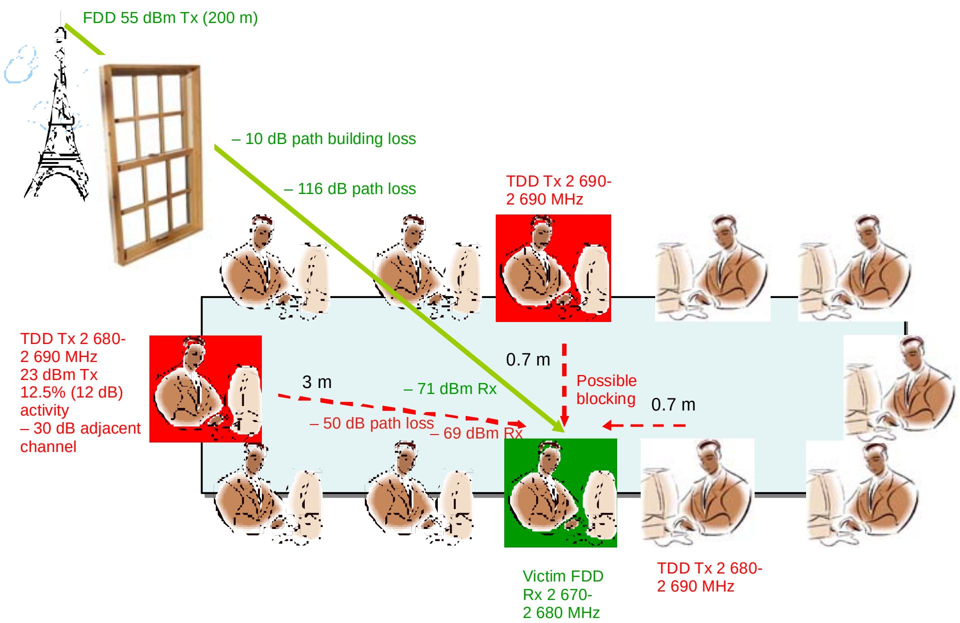
[37] Refers to the probability of two users colliding. CEPT Report 119 defines block edge masks for terminals in 2 600 MHz band. The Report analyzes the probability of packet collision. The used assumption is that the interferer transmits 2.5 ms per 20 ms period. This gives an activity factor of 12.5%.

It should be noted that the exact scenario details can have a big effect. As an example, for Fig. 37a), if the TDD system uses 1 out of 8 slots (like GSM), and the FDD system is CDMA voice, then if the victim has margin, the victim system will compensate, but at cell edge, communications will fail. If the mobile station starts receiving errors, it will ask for more power from the cell until it overcomes this. If the loss of 1/8 of the reception is impacting 12.5% of every CDMA frame, then error correction and interleaving will also be impacted (error correction will succeed if 1 in 8 frames are impacted, but possibly not if 12.5% of every frame is impacted). Furthermore, if the FDD has a data system, and the timing happens to be just wrong, the TDD bursts could land on top of frame ACK bits or other transmissions which have very little coding and would probably be blocked. This would cause serious degradation.

In addition, outage may also occur from activities from the closest meeting participants when the wanted user will experience 100% capacity loss. The previous example uses a propagation loss figure for 3 m, i.e., that any meeting participant within this range can cause capacity degradation. A meeting participant with a shorter distance will give a higher interference level, that level may be sufficiently high to saturate the victim receiver giving a 100% capacity loss. In this example this would correspond to the meeting participant 0.7 m away from the victim user.

FIGURE 37a

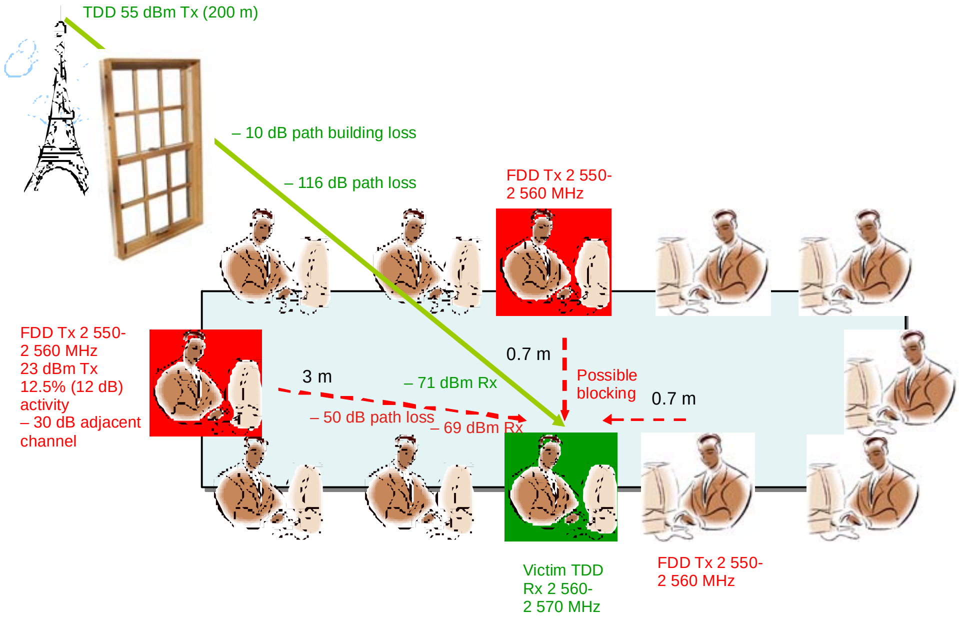
FDD victim in meeting room



BWA-37a

FIGURE 37b

TDD victim in meeting room



BWA-37b

6 Summary of guidelines

Based on the arguments in favor of a more orderly approach with regard to the spectrum arrangements:

– To take advantage of mass-market deployments, the internationally harmonized frequency arrangements offer significant clear advantages to end-users, wireless operators and administrations.

– If FDD and TDD systems are used in a band, a common FDD-TDD frequency boundary should be used internationally to reduce the potential of interference, and reduce the complexity, size and cost of the equipment; otherwise national band plans increase market fragmentation and lead to limited consumer choice.

– Interference between TDD and FDD systems should be analyzed with the particular characteristics of the intended systems. A frequency separation (typically 5 MHz) between FDD and TDD systems operating in the same geographical area is always required for a normal operating radio frequency power. Furthermore, in the examples considered, additional filters of the order 50 dB are necessary for both receiver and transmitter when applying a frequency separation of 5 MHz between FDD and TDD operations; the same applies between unsynchronized TDD operations. Without filters, the frequency separation needs to be more than 10 MHz. Consequently it will not be spectrum efficient to have a large number of sub-bands between which this type of frequency separation needs to be applied. Therefore, the number of cross-over points between FDD and TDD or unsynchronized TDD operations should be kept to a minimum for reasons of spectrum efficiency.

– When there are deployments following different band plans for FDD and TDD operation, the interference situation should be analyzed, since interference will result if base stations are operating TDD and FDD modes according to different band plans at geographical borders under a multitude of FDD/TDD arrangement situations. The needed separation distances may be of the order of 75 km. It is thus beneficial to harmonize spectrum arrangements within a geographical region.

– A common band plan should be adopted internationally, otherwise considering mass market terminal devices under a multitude of arrangements, there would be many situations where users are coming close to each other. In such situations and where the interference situation cannot be managed, users would experience significant capacity loss which would be unacceptable for quality and real time services.

– Time coordination between adjacent operators may be a practical alternative to a geographical or spectral separation when TDD is used by both operators.

ANNEX E

MODULATION TECHNIQUES IN BROADBAND RLANs

1 Introduction

RLAN systems are being deployed all over the world. There are several major standards for broadband RLAN systems and Table 6 provides an overview of these.

Broadband RLAN systems make it possible to move a computer within a certain area such as an office, a factory, and SOHO with high data rates of more than 20 Mbit/s. As a consequence of the great progress in this field, computer users are demanding free movement with bit rates equivalent to those of conventional wired LANs such as 10BASE-T Ethernet.

This Annex presents features of the modulation techniques used in the standards listed in Table 6.

2 Physical layer to realize high bit rate and stable wireless networks

The broadband radio channel is known to be frequency selective, causing inter-symbol interference (ISI) in the time domain and deep notches in the frequency domain. A possible method to realize a high bit rate, wireless access system under frequency selective fading channels is to shorten the symbol period. A second way is to use bandwidth efficiently by multi-level modulation. The third way is to employ multicarrier modulation. The first and second solutions show serious drawbacks in multipath environments. In the first solution, as the symbol period decreases, ISI becomes a severe problem. Therefore, equalization techniques will be necessary. The second solution reduces the symbol distance in the signal space and hence the margin for thermal noise or interference is decreased, leading to intolerable performance degradation for high bit rate, wireless access systems. The third solution, the multicarrier method, is to increase the symbol period in order to compensate for ISI resulting from multipath propagation. As promising methods for multipath countermeasures, the first solution of single carrier with equalizer and the third solution using multicarrier methods (OFDM) are discussed below.

3 Single carrier with equalizer

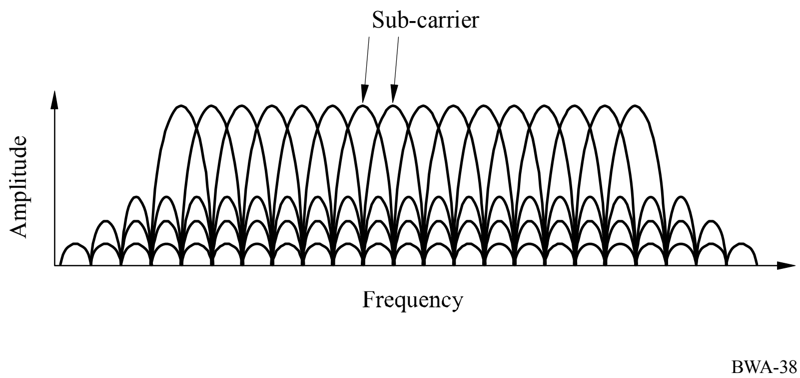
In radiocommunications, the transmission is affected by the time-varying multipath propagation characteristics of the radio channel. To compensate for these time-varying characteristics, it is necessary to use adaptive channel equalization. There are two main groups into which adaptive equalizers can be subdivided; the least mean square (LMS) equalizer and the recursive least squares (RLS) equalizer. The LMS algorithm is the most commonly used equalization algorithm because of its simplicity and stability. Its main disadvantage is its relatively slow convergence. LMS converges in 100-1 000 symbols. A faster equalization technique is known as an RLS method. There exist various versions of RLS with somewhat different complexity and convergence trade-off. RLS is more difficult to implement than LMS, but converges in fewer symbols compared with LMS methods. Although much research has been conducted on RLS and LMS equalizers in the cellular systems, RLS and LMS are still a research topic in the points of fast convergence, stability and complexity for high bit rate wireless access applications.

4 Multicarrier OFDM

With multicarrier transmission schemes the nominal frequency band is split up into a suitable number of sub-carriers each modulated by QPSK modulation, etc., with a low data rate. In general, when dimensioning a multicarrier system, the maximum path delay should be shorter than the symbol time. An OFDM modulation scheme is one of the promising multicarrier methods. The power spectrum of this modulation is shown in Fig. 38. The development of fast and power saving LSIC and effective algorithms, Fast Fourier Transform (FFT) for signal processing today allows a cost-effective realization of OFDM schemes. The advantages of this system are given by a satisfactory spectral efficiency and in the reduced effort for equalization of the received signal. In the case of limited delay spread (<~300 ns) of the multipath signals it is possible to dispense with an equalizer.

FIGURE 38

Spectrum of OFDM



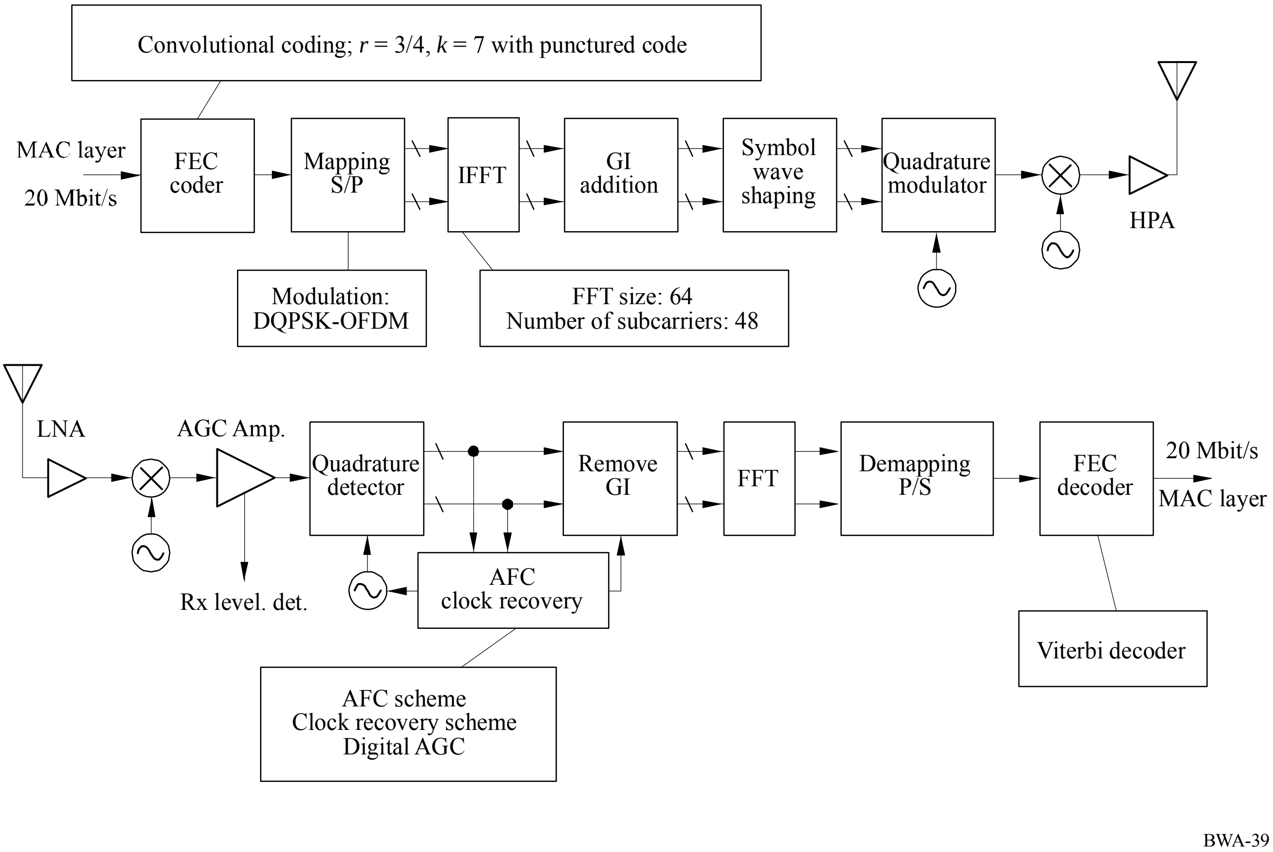
The multicarrier transmission scheme employed with OFDM causes envelope fluctuation like additive white Gaussian noise and the effect on the interference environment is negligible.

5 Configuration of OFDM system

A simplified block diagram of an OFDM transmitter and receiver is shown in Fig. 39. In this example the data to be transmitted are coded by convolutional coding ($r = 3/4$, $k = 7$) and serial-parallel (S/P) converted and the data modulates the allocated subcarrier by DQPSK modulation. In the IEEE 802.11a and HIPERLAN/2 standards, data rates from 6 to 54 Mbit/s can be offered by using various signal alphabets for modulating the OFDM sub-carriers and by applying different puncturing patterns to a mother convolutional code. BPSK, PSK, 16-QAM and 64-QAM modulation formats are used. An IFFT of the modulated sub-symbols generates the OFDM signals. GI signals are added to the output signals of the IFFT. The GI added OFDM signals are shaped by roll-off amplitude weighting to reduce outband emission. Finally, the OFDM signals modulate IF. At the receiver side, received signals are amplified by the AGA and converted to the baseband signals. At this stage, frequency error due to instability of the RF oscillators is compensated by AFC and the timing of packet arrival is detected. After this synchronization processing, the GI signals are removed and the OFDM signals are de-multiplexed by the FFT circuit. The output signals of the FFT circuit are fed to the de-mapping circuit and demodulated. Finally, a Viterbi decoder decodes the demodulated signals.

FIGURE 39

Configuration of DQPKS-OFDM with convolutional coding



6 Computer simulation

Major simulation parameters and the OFDM symbol format are shown in Table 7 and Fig. 40, respectively. Figure 41 shows that to achieve the packet error rate of 10%, the required E_b/N_0 is about 20 dB under the frequency selective fading channel with 300 ns delay spread. The proposed physical layer approach allows us to use this high bit rate RLAN system not only in indoor areas but also outdoor areas forming parts of locations such as universities, factories, and shopping malls, etc.

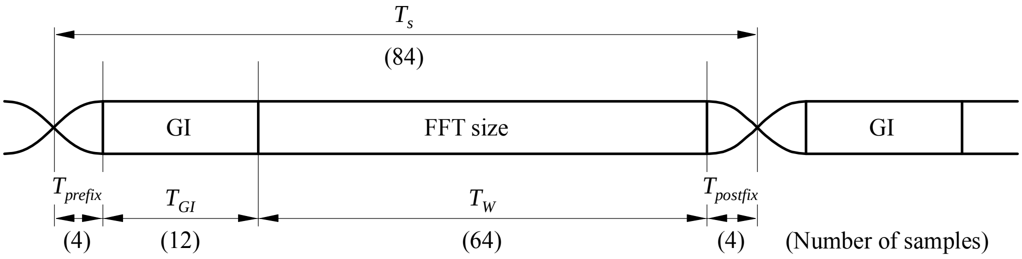
TABLE 7

Major simulation parameters

Raw data rate	26.6 Mbit/s
Modulation/detection	DQPSK/differential detection
FFT size	64 samples
Number of subcarriers	48
GI	12 samples
Number of T_{prefix} samples	4 samples
Symbol duration (T_s)	84 samples (= 3.6 µs)
Carrier frequency offset	50 kHz (10 ppm at 5 GHz)

FIGURE 40

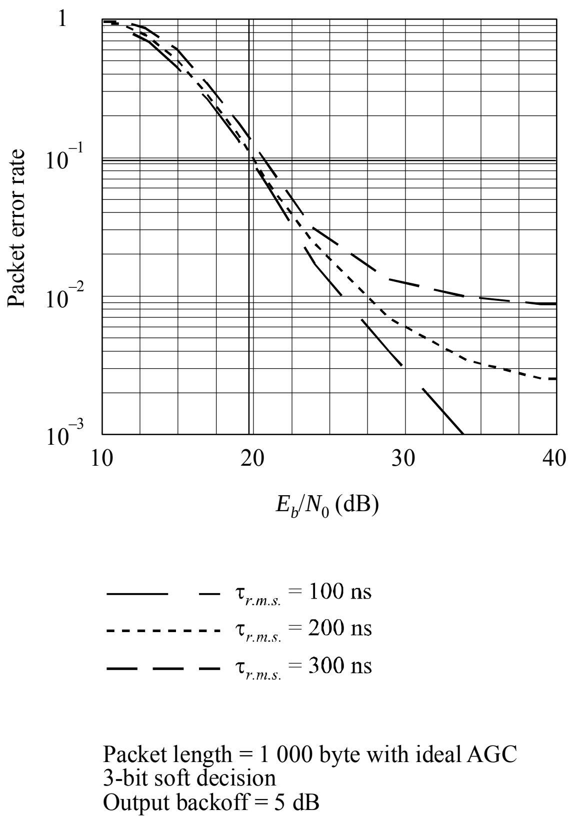
OFDM symbol forma



BWA-40

FIGURE 41

Packet error rate vs E_b / N_0



BWA-41

ANNEX F

REMOTE ACCESS TECHNIQUES IN RLANs

1 Introduction

One of the most beneficial usages of RLANs is that the RLAN terminals can be used without any additional operation at other company offices where they move. In order to realize such usage, it is very important to establish network techniques to virtually connect the RLAN terminals that are in other offices (other subnetworks) to their own subnetwork.

There are several approaches to support such remote access for RLAN terminals.

In the following sections, these techniques will be explained, and compared in the aspects of service performance and system composition.

2 Remote access techniques

2.1 Dial-up connection

Currently, the simplest way to connect a terminal from a remote place is a dial-up method. It does not need a LAN environment, but it is possible wherever the telephone network is available, using a modem or an ISDN adapter. Normally, the user sets up a telephone line in his home office, and connects a modem to a dial-up server. A mobile PC with a modem card can be connected to the home network server by a public wired or wireless telephone. In this connection PPP [IETF, 1994a], or ARA is mainly used.

On the other hand, the dial-up method has the following restrictions:

– additional software is necessary on mobile terminals;
– the network interface changes;
– communication bit rate is low;
– connection fee is generally expensive.

2.2 Dynamic Host Configuration Protocol

Dynamic Host Configuration Protocol (DHCP) [IETF, 1993] is a technique using a new network address at a remote network. DHCP is originally a protocol for the auto-configuration of terminal network interfaces. It enables mobile RLAN terminals to connect to the home network via the Internet by searching for a DHCP server and obtaining a new address.

For DHCP, the following restrictions exist:

– additional software is necessary on mobile RLAN terminals;
– only TCP/IP is available;
– it is unavailable for networks with private IP addresses.

2.3 Mobile IP

Mobile IP [IETF, 1996] is a technique that supports terminal mobility in networks. In mobile IP, IP packets transmitted to a mobile RLAN terminal are encapsulated by a home agent into other IP packets, and are forwarded to the foreign agent. In this way, the mobile RLAN terminal can be used at the home network. Because mobile IP works on the Internet, communication cost is low even for international communication.

However, the following are its restrictions:

– additional software is necessary on mobile RLAN terminals;

– only TCP/IP is available;

– it is unavailable for networks with private IP addresses.

2.4 Virtual Local Area Network

Recent advances in virtual local area network (VLAN) allow us to construct subnetworks or LAN segments independent of physical network topology, by using switching hubs, ATM switches, or routers. The main purpose of VLAN is to adopt the following independently of the physical locations:

– unified administration;

– security;

– private IP address or multi-protocol;

– broadcast.

Some of them allow us to construct wide area VLANs, which are also called Internet VPNs [IETF, 1994b]. The wide area VLAN is a very recent technique and the standardization works are now under study in the IETF. In this technique, VLAN functions are necessary on remote network routers, or mobile RLAN terminals themselves.

When the function is on a router, advance registration is necessary. This means that access to Intranet is available only in limited remote networks. When the function is on a mobile RLAN terminal, additional software is necessary.

2.5 Mobile Virtual Local Area Network

Among the various mobile environment requirements, the mobile VLAN technique was developed to support the following features:

– low-cost communication;

– no operation for connection at the RLAN terminal;

– multi-protocol, private IP address;

– ubiquitous communication;

– high security.

In mobile VLAN, the MAC frame transmitted by a mobile RLAN terminal moves to a remote network. Next, it is encapsulated into an IP packet by the server at the remote network. The IP packet is then transferred to its home network (MAC over IP). Then the server at the home network de-encapsulates the received IP packet to the original MAC frame. Therefore, the mobile RLAN terminal can use the home network environment at the remote network.

Mobile VLAN has such functions as terminal location registration, address resolution, authentication, and recognition of disconnection. In order to connect with no operation at the RLAN terminal, all of these functions are performed on the network side.

3 Evaluation

Table 8 summarizes the serviceability of the techniques mentioned-above. The mobile VLAN realizes low-cost communication, connection with no operation at a RLAN terminal, support for multi-protocols, and ubiquitous communication without losing other technical advantages.

The mobile VLAN system is considered the most promising to support RLAN terminal mobility.

TABLE 8

Comparison of the mobility support techniques

	Mobile VLAN	**Dial-up connection**	**DHCP**	**Mobile IP**	**Wide area VLAN (in router)**
Transport network	Internet	PSTN ISDN	Internet	Internet	Internet
Communication cost	Low	High	Low	Low	Low
Network interface modification	No	Yes	No	No	No
Network address modification	No	No	Yes	No	No
Additional software on terminal	No	Yes	Yes	Yes	No
Multi-protocol	Available	Unavailable	Unavailable	Unavailable	Available
Private IP address	Available	Available	Unavailable	Unavailable	Available
Ubiquitous communication	Available	Available	Available	Available	Unavailable

References

IETF [1993] Dynamic Host Configuration Protocol, RFC1541, 1531. Internet Engineering Task Force (IETF).

IETF [1994a] The Point-to-Point Protocol, RFC1661, 1548. Internet Engineering Task Force.

IETF [1994b] Generic Routing Encapsulation, RFC1701. Internet Engineering Task Force.

IETF [1996] INTERNET draft. IP Mobility Support Rev. 17. Internet Engineering Task Force.

APPENDIX 1 TO ANNEX F

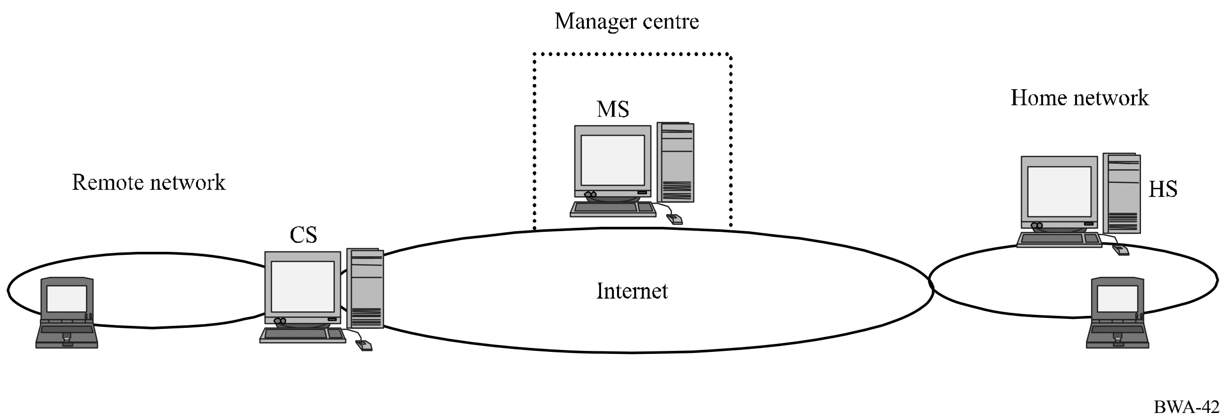
OUTLINE OF MOBILE VLAN SYSTEM

1 System composition

The functions needed for the mobile VLAN techniques are address resolution, terminal authentication, location registration for recognition of disconnection, and MAC frame encapsulation/de-encapsulation. The first two factors, i.e. address resolution and terminal authentication, are necessary over the entire network. The location registration function is required only in remote networks. The MAC frame encapsulation/de-encapsulation is necessary in both home networks and remote networks. Consequently, the usage of three kinds of servers may be proposed: the management server (MS), the home server (HS), and the client server (CS), as shown in Fig. 42. One MS serves the whole network. It manages terminal authentication data and terminal location data, and resolves addresses. One HS is located in one home network, where it encapsulates and forwards MAC frames for mobile terminals. One CS is located in one remote network, where it recognizes mobile terminals, requests terminal authentication to the MS, establishes connection to the HS, and encapsulates MAC frames.

FIGURE 42

System composition of mobile VLAN



2 Major techniques of mobile Virtual Local Area Network

In this section, the major techniques of mobile VLAN are introduced based on sequence charts.

2.1 Terminal authentication, location registration, connection

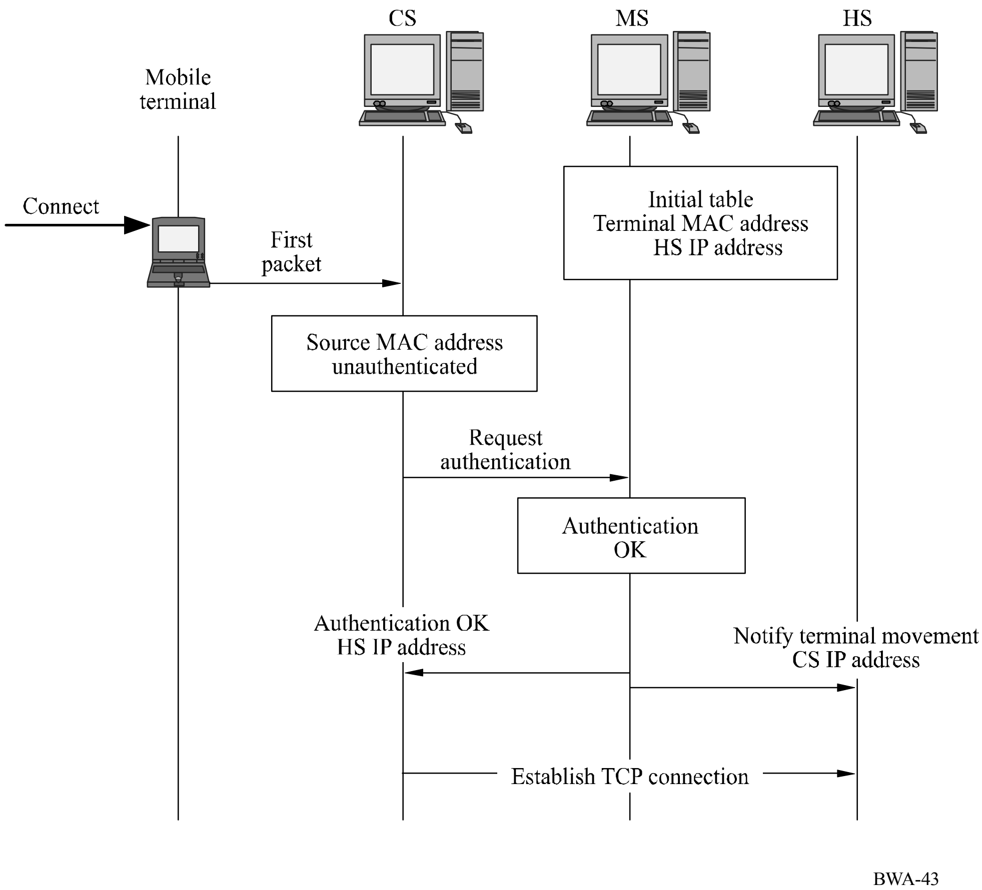
MAC addresses and the corresponding HS IP addresses have to be registered in advance in the MS. IP addresses of all HSs and CSs are also registered. TCP connections to all HSs and CSs are established. The mobile terminal can be connected to remote networks that are connected to the CSs. After connection, when the terminal sends a packet, e.g. an ARP, the CS captures the packet as a MAC frame. The CS sends the source MAC address to the MS, and the MS authenticates that the terminal is from the corresponding home network.

Upon authentication, the MS registers the terminal location, and notifies the CS and corresponding HS of terminal movement. Then, the CS establishes a TCP connection for MAC frame forwarding to the HS.

Because the destination HS differs depending on the source address of the MAC frame, a CS can belong to many HSs.

FIGURE 43

Sequence chart for terminal authentication, location registration and connection

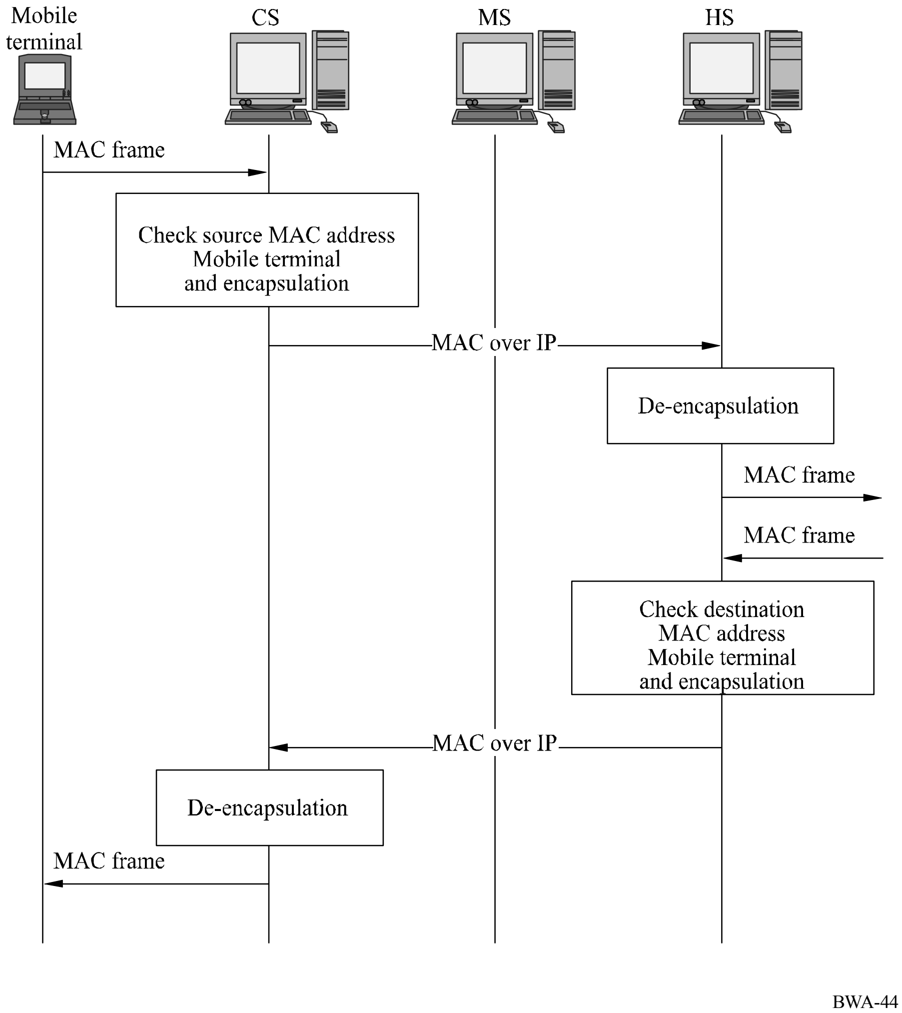


2.2 Encapsulation / de-encapsulation

After TCP connection is established, the CS captures MAC frames with source MAC address of the mobile terminal, and the HS captures MAC frames with destination MAC address of the mobile terminal. Then they encapsulate MAC frames into IP packets. If they receive encapsulated MAC frames via the TCP connection, they de-encapsulate them and transmit extracted MAC frames to the LAN. If a MAC frame for another mobile terminal is captured, they encapsulate it again and send it to the corresponding CS. In this way, many CSs can belong to one HS.

FIGURE 44

Sequence chart for encapsulation/de-encapsulation

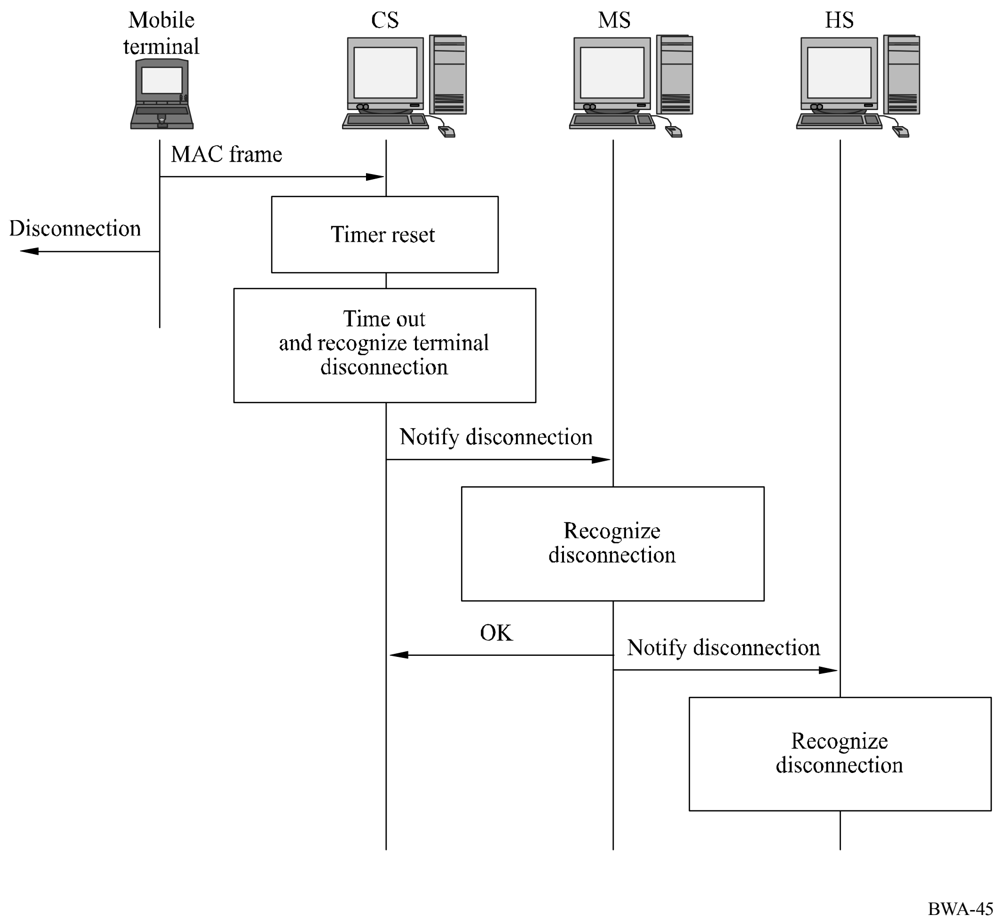


2.3 Recognition of terminal disconnection

The CS has a timer, and if reception of MAC frames from the mobile terminal stops for a certain period, it recognizes this as disconnection.

FIGURE 45

Sequence chart for terminal disconnection



ANNEX H

USER DEMOGRAPHICS AND NEEDS

This section examines trends and deployment, and then demonstrates the rapid growth of wireless data.

Trends

Users are adopting wireless data across a wide range of applications, including e-mail, social networking, game downloads, instant messaging (IM), ringtones, and video. Wireless data in enterprise applications like group collaboration, enterprise resource planning (ERP), customer relationship management (CRM), and database access is also gaining acceptance. The simultaneous adoption by both consumers, for entertainment-related services, and businesses, to enhance productivity, increases the return-on-investment potential for wireless operators.

A number of important factors are accelerating the adoption of wireless data. These include increased user awareness, innovative "feature phones", powerful smartphones, and global coverage. But two factors stand out: network capability and applications. Most BWA systems support a wide range of applications, including standard networking applications and those designed for wireless. Meanwhile, application and content suppliers are optimizing their offerings or, in many cases, developing entirely new applications and content to target the needs and desires of mobile users.

Computing itself is becoming more mobile, and notebook computers and smartphones are now prevalent. In fact, all mobile phones are becoming "smart," with some form of data capability, and leading notebook vendors are now offering computers with integrated IMT-2000 capabilities together with WiFi. Modems are available in multiple formats including USB devices, PC Cards and Express cards.

Computer manufacturers are also experimenting with new form factors, such as ultra-mobile PCs, "netbook" computers and mobile Internet devices (MIDs). Lifestyles at home and at work are increasingly mobile with more people traveling more often for business, for pleasure or in retirement. Meanwhile, the Internet is becoming progressively more intertwined with people's lives providing communications, social networking, information, enhancements to memberships and subscriptions, community involvement, and commerce. Wireless access to the Internet in this environment is a powerful catalyst for the creation of new services. It also provides operators and other third-party providers with many new business opportunities.

As data constitutes a rising percentage of total cellular traffic, it is essential that operators deploy spectrally efficient data technologies that meet customer requirements for performance-especially because data applications can demand significantly more network resources than traditional voice services. Operators have a huge investment in spectrum and in their networks; data services must leverage these investments. It is only a matter of time before today's more than 3 billion cellular customers start taking full advantage of data capabilities. This adoption will offer tremendous opportunities and the associated risks to operators as they choose the most commercially viable evolutionary path for migrating their customers. The BWA evolutionary paths provide data capabilities that address user needs and deliver ever-higher data throughputs, lower latency, and increased spectral efficiency.

Although wireless data has always offered a tantalizing vision of always-connected mobile computing, adoption has been slower than that for voice services. In the past several years, however, adoption has accelerated thanks to a number of key developments. Networks are much more capable, delivering higher throughputs at lower cost. Awareness of data capabilities has increased, especially through the pervasive success of short message service (SMS), wireless e-mail, downloadable ringtones, and downloadable games. Widespread availability of services has also been important.

The features found in cellular telephones are expanding at a rapid rate and today include large color displays, graphics viewers, still cameras, movie cameras, MP3 players, IM clients, e-mail clients, push-to-talk over cellular (PoC), downloadable executable content capabilities, and ever more powerful browsers. All these capabilities consume data.

Meanwhile, smartphones, which emphasize a rich computing environment on a phone, represent the convergence of the personal digital assistant, a fully capable mobile computer, and a phone, all in a device that is only slightly larger than the average cellular telephone. Many users would prefer to carry one device that "does it all." Smartphones, originally targeted for the high end of the market, are now available at much lower price points and thus affordable to a much larger market segment. ABI Research predicts that the smartphone market, which was 10% of the total market in 2007, will become 31% of the market in 2013[38]. This number may be conservative as the success of advanced smartphones demonstrates the latent user demand for devices that enable rich multimedia and communications capabilities.

As a consequence, this rich network and device environment is spawning the availability of a wide range of wireless applications and content. Because of its growing size – and its unassailable potential – application and content developers simply cannot afford to ignore this user need. And they aren't. Consumer content developers are already successfully providing downloadable ringtones and games. Enabled by IMT network capabilities, downloadable and streaming music and video are not far behind. In the enterprise space, all the major developers now offer mobilized "wireless-friendly" components for their applications. A recent article in Network Computing surveyed major enterprise application vendors, including IBM, Oracle, Salesforce.com, SAP, and Sybase and found comprehensive support for mobile platforms from each of these vendors[39].

Acting as catalysts, a wide array of middleware providers are addressing issues such as increased security, for example, virtual private networks (VPNs), switching between different networks (for example, WLANs to IMT), session maintenance under adverse radio conditions, and policy mechanisms that control application access to networks.

A number of other powerful catalysts are spurring wireless-data innovation. Pricing for unlimited[40] usage has declined substantially for both laptop and handset plans, thus encouraging greater numbers of users to adopt data services. Operators are seeing considerable success with music sales. New services such as video sharing are being enabled by IMS, which will also facilitate FMC and seamless communications experiences that span cellular and WiFi networks. Meanwhile, users are responding enthusiastically to location-based services, banks are letting their account holders manipulate their accounts using handheld devices, and users have an increasing number of mobile options for real-time travel information and manipulation of that information.

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38 One in Three Handsets Will Be a Smartphone by 2013", March 2008, http://www.wirelessweek.com/article.aspx?id=158452

39 RYSAVY, Peter. [May, 2007] Reach Me if You Can. See: http://www.rysavy.com/Articles/2007_05_Mobile_Applications.pdf

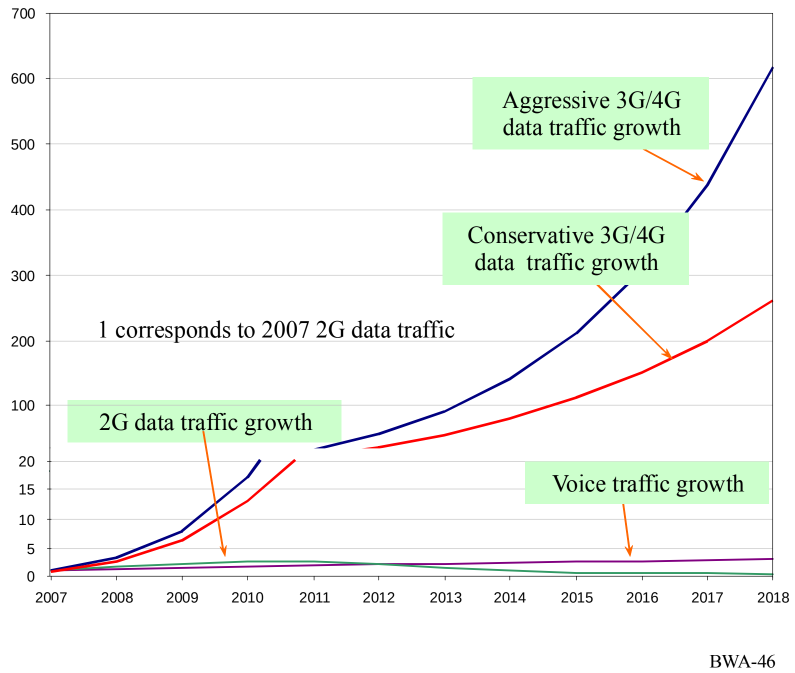
40 Typically, some restrictions apply.

In the enterprise space, the first stage of wireless technology adoption was essentially to replace modem connectivity. The next was to offer existing applications on new platforms like smartphones. But the final, and much more important, stage is where jobs are reengineered to take full advantage of continuous connectivity. Selective tactical adoption of mobile applications such as wireless e-mail is a good starting point for many organizations. However, companies that carefully adopt mobile applications in a more strategic fashion across multiple business units are finding they can significantly increase their competitiveness.

Over time, data demands are expected to grow significantly. Figure 46 shows a leading operator's assessment of data demands on its network.

FIGURE 46

Operator assessment of growth in data demand on relative basis*



*   Source: 3G Americas member company contribution.

Figure 46 is consistent with growth in mobile-broadband data consumption presented in a Report from Value Partners[41]. The Report projects for European countries 1 GByte/user/month using conservative assumptions, 8 GBytes/user/month with medium assumptions, and 30 Gbytes/user/month with aggressive assumptions.

A final factor accelerating adoption of mobile/wireless technologies is environmental considerations, where enhanced communications technologies facilitate business interaction with fewer face-to-face meetings, and make it easier for workers to either telecommute or stay involved

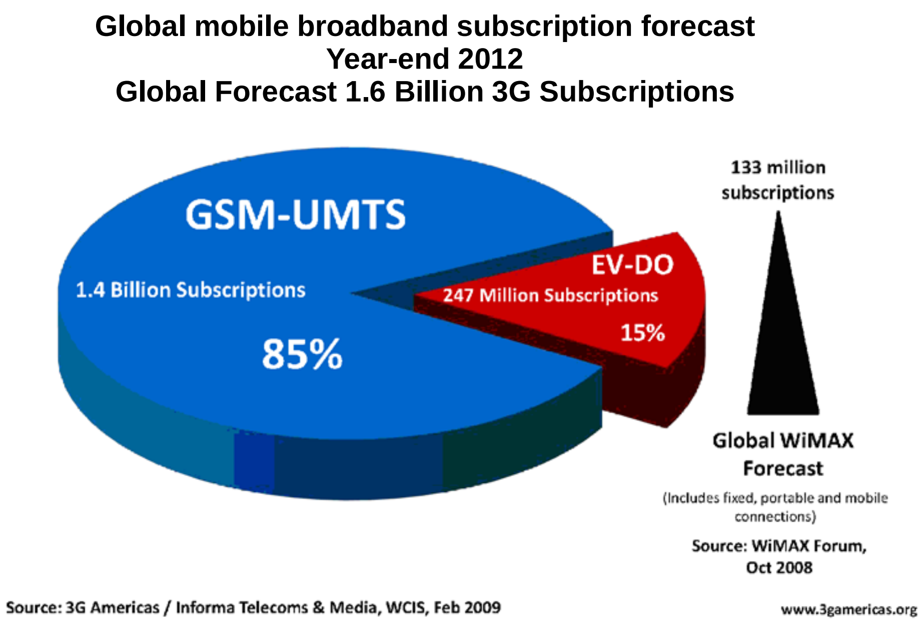
41 Value Partners, "Getting the Most Out of the Digital Dividend – Allocating UHF Spectrum to Maximise the Benefits for European Society", March 2008, http://www.valuepartners.com/VP_pubbl_pdf/PDF_Comunicati/notizie%20e%20idee/2008/Spectrum-Getting-the-most-out-of-the-digita-dividend-2008.pdf

with work projects as they conduct their personal affairs. With huge energy costs and pollution from fossil fuels, mobile broadband may increasingly be viewed as a "green" technology, and there is even a website, http://www.green4g.com, that promotes this cause.

The key for operators is enhancing their networks to support the demands of consumer and business applications as they grow, along with offering complementary capabilities such as IP-based multimedia.

FIGURE 47

Global mobile broadband subscriptions forecast 2012



BWA-47

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Throughout this Handbook hyperlinks have been used for the convenience of those reading an electronic version of the Handbook; however, the address (URL) of the hyperlinks is not visible to those reading a paper copy. This appendix lists the URLs of the hyperlinks used in this Handbook.

ITU-D: "Guidelines on the Smooth Transition of Existing Mobile Networks to IMT-2000 for Developing Countries (GST)" produced by ITU-D SG2 Q.18-1/2 (Strategy for migration of mobile networks to IMT-2000 and beyond), ITU-D Publication 2005.

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