Chapter IX

EQUIPMENT AND NETWORKS

Contents

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Purpose of this chapter

Chapter 9 is intended to provide some guidance on the current trends in equipment and systems for developing networks. Given the enormous range of equipment now available, and the high rate of development, the contents can only be considered as a brief reference document for planning engineers who may not be familiar with the particular network elements considered. Detailed equipment descriptions and planning calculations are outside the scope of this chapter and are fully considered in the other publications to which references are made in the texts.

Outputs to be obtained

No specific outputs are expected from the material in this chapter except the promotion of an awareness among planning personnel of the possibilities offered by modern equipment and systems.

Inputs required

- Application notes included in parts of this chapter together with manufacturers' literature;
- ITU-T and ITU-R Recommendations;
- ITU manuals.

Chapter IX

EQUIPMENT AND NETWORKS

9.1 Review of subscriber terminal equipment

9.1.1 General and regulatory aspects

Terminal equipment to be connected to the telecommunication network varies in size and complexity, ranging from ordinary simple telephone sets to large PABX-systems.

The method of providing this equipment to subscribers as well as the necessary support in installation, maintenance and operational matters depends entirely on the regulatory situation of public telecommunication services in the different countries.

In an extreme case one can imagine a complete telecommunications service monopoly by a governmental department or PTT, which selects, rents, installs and maintains all terminal equipment.

At the other extreme a situation could exist in which the network operator either does not provide terminal equipment or provides it under the same and competitive conditions as the private sector, either by selling or by renting the equipment. In such a case there has to be an independent governmental body which takes care of type approval of any proposed terminal equipment to ensure its correct interworking with the telecommunications network.

Between these two extreme situations there may be cases where certain types of terminal equipment are available from the private sector (and possibly network operator), while others can be obtained only from the network operator.

The situation may also differ for the various public telecommunication networks, e.g. the Public Switched Telephone Network, ISDN applications, the Telex Network, Mobile networks and Packet Switched Public Data Networks.

There is a general global tendency to liberalise the provision of terminal equipment, and this matter together with its regulatory aspects has to be considered in other sections of the development plan, dealing with organisation, tariffs and financial aspects.

9.1.2 Inventory of the existing situation

An inventory has to be made of the existing situation with regard to:

a) the different categories and types of terminals currently used in the network;
b) the conditions for their connection to the network (e.g. type approval, purchase or lease from network operator or private sector, installation and maintenance).

9.1.3 Identification of potential new services and associated terminal equipment in the existing and new network structures

New network structures such as mobile networks and ISDN will require new types of terminals such as mobile telephones, fax machines group 4, teletex, and other ISDN-connectable terminals and it should be indicated how provision of such equipment could be arranged, such as mentioned in the previous paragraph, by purchase or lease, either from the network operator and/or from the private sector.

Some possible new services and associated terminal equipment are listed as follows:

a) New facilities for analogue terminals:
   - a range of new telephone sets with different degrees of sophistication;
   - different types of cordless telephones;

- a range of supplementary equipment to telephone sets, such as home meters, additional ringers, automatic answering sets, etc.

b) Public telephone sets of different degrees of sophistication (coin and phone card operated).

c) New facsimile service, group 4, at 64 kbit/s via ISDN.

d) Teletex service and its associated equipment.

e) Mobile telephone service on different networks (analogue and/or digital), and the associated range of terminal equipment.

f) Paging service and the associated paging terminal equipment.

g) Videotex service and its terminal equipment (telephone with video terminal).

h) Videophone (telephone with moving image) via ISDN, and its associated terminal equipment.

i) ISDN-PABXs.

j) Different types of terminal adapters (TA), for modem-type devices and X.21 or X.25 operation.

Other types of services such as mixed-mode)text code and facsimile coded transmission) and sketchphone (still picture communication) and their associated terminal equipment could be considered as possible candidates for terminal equipment to be provided by the network operator.

9.1.4 Future policy for terminal equipment

Finally, based on the previous review of existing and possible new types of terminal equipment to be expected in the network, a policy should be defined for the future arrangements for provision, installation and maintenance of terminal equipment.

The regulatory aspects associated with such proposals should also clearly be formulated.

9.2 Planning and provision of local networks

9.2.1 General

The provision of local networks, even excluding the subscriber stations, absorbs a significant proportion of the total investment in telecommunication facilities - estimated at an average of about 30% - while the running costs of this part of the network are by no means negligible if an adequate quality of service is to be maintained.

This high average expenditure is typical of networks in a rapid stage of development - in terms of increasing the telephone penetration rate as quickly as possible. It is not however typical of the situation in many developing countries, in which priority for the often limited financial resources has had to be given to providing the national trunk network for example and the development of the local networks is confined to catering for immediate needs by simple extensions. The local networks in these cases usually consist of overhead construction, which adds to the already high running costs due to the increased fault liability.

In view of these high investment and operational costs, it is seen that the savings to be made as a result of rational and timely planning could be considerable. Comparatively recent developments in both transmission and switching techniques (optical fibre cables and digital switching) have both simplified the tasks of the planner and enabled more efficient local networks to be realised.

The planning required can be broadly divided into:

- long-term planning, which provides the framework for decisions concerning long-term investments;
- extension planning (provision planning), which determines the final structure of the local networks and is usually of a shorter-term nature than development planning.

As both the above aspects are fully considered in References [1] and [2], only a résumé of the most important points is given in the following sections.

Although rural networks can be considered as a type of local network, they are not included in this section - in which only urban and metropolitan networks are examined. Rural networks are described in section 9.5, which deals with the often specialised transmission and distribution systems peculiar to these networks.

The local networks, urban and metropolitan, considered in the following text consist of the main and subscriber distribution cables between the local exchange MDF and the subscriber's premises, and the inter-exchange, or junction, network between the local exchanges (including local transit and combined exchanges).

As for all parts of the telecommunication network, the local facilities are likely to see some radical changes in the future. Some of the possibilities are briefly considered in §9.2.7 at the end of this section. Subscriber demand and traffic forecasting for local networks, in particular metropolitan networks, are considered in some detail in Chapter 6. The optimisation of metropolitan networks is considered in Chapter 7.

9.2.2 Structure of local networks

The traditional local network consists of the junction network linking the local exchanges together with the subscribers' line networks providing the (usually) 2-wire connections between the MDFs of the local exchanges and the subscriber's premises.

Two basic types of subscribers' line network can be distinguished.

a) Rigid networks

In a rigid network all conductors are extended from one cable section to the next by jointing, i.e. all pairs are rigidly connected between the MDF and the distribution point (DP) near the subscriber's premises - giving a star configuration. Rigid networks are economical for low subscriber density areas and for areas where the subscriber lines are short - i.e. in the immediate service areas of a local exchange. The disadvantages arise from the work involved when the joints have to be re-arranged, so that a large number of spare pairs has to be provided.

b) Flexible networks

In this type of network the connection between the MDF and DP is divided into sections via one or more flexibility points - the cross connection points (CCP). The main cable connects the MDF to the CCP and distribution cables connect the CCP to the DPs. Any pair on the DP side can be connected to any pair on the exchange side of the CCP so that the smaller distribution cables from the DPs can be combined into a larger main cable to the exchange, in which fewer spare pairs are required. This is the main advantage of flexible networks, other advantages being that sections of the network can be developed independently and that fault location is much easier. In addition the pair utilisation factor, in both the main and distribution cables, is much higher so that the necessity for relief cables can be delayed. The jointing procedure, when relief cables are required, is also simplified as terminals are available at the CCP and MDF.

Except in the immediate service areas of the local exchanges, urban local networks are usually constructed as flexible networks.

c) Junction networks

As far as the junction network is concerned, its typical structure obviously depends on the traffic between the local exchanges. The structures therefore vary between simple star and fully intermeshed networks.

Until comparatively recently, junction networks were realised using loaded audio cables connecting 2-wire exchanges. With the advent of digital switching and transmission, these networks are now implemented on a 4-wire basis - with a corresponding improvement in the transmission plan, as far as losses are concerned. The loaded cables have been replaced by various PCM multiplex systems using unloaded pairs, radio-relay and optical fibre cables as the transmission media.

Economies in the subscribers' line network can now be made by the use of remote line units (RLU) and remote switching units (RSU) in the feeder network, a concept which leads to the so-called ring network in which RLUs can be located at the CCPs and eliminate the main subscriber cables for example. Security is built-in to this type of network by the provision of bi-directional transmission round the loop; if one direction suffers a failure, half the traffic continues to be routed in the reverse direction. This concept was considered in Chapter 5 (Target Network).

d) Future structures

As discussed in §9.2.7, and in Chapter 5, further developments will radically change the structure of both the feeder network (including the present concept of the junction network) and the subscriber distribution network. The introduction of SDH for example will result in a flexible, multi-service infrastructure based on optical fibre transmission at high bit-rates with distribution via add/drop multiplexers and digital cross-connect units. The distribution network itself could consist of optical fibre using passive components and handling both conventional telephony and broadband services.

9.2.3 Development planning of local networks

Development, or long-term, planning aims to provide the framework for decisions concerning long-term investments and for the detailed planning of particular projects (extension planning).

The output of this type of planning consists of the dimensioning and optimisation of the local network(s) covering the following principal aspects:

- determination of the number of exchanges in the network;
- determination of their locations;
- definition of their boundaries;
- design and implementation of the subscriber line network (main cables and distribution cables);
- definition of the optimum structure of the junction network.

For long-term planning, the above have to be specified in terms of time and cost, in other words the problem is to find the least cost network development over the planning period which satisfies a specified demand and quality of service. In particular, the timing for the opening of new exchanges and the growth of each exchange area are important for this type of planning.

The main factors to be considered when finding the optimum configuration are:

- the subscriber demand;
- the traffic demand;
- the cost of the three main elements of the network; exchanges, junction network and subscriber network;
- service criteria such as grade of service, compliance with transmission plan, satisfaction of demand, etc.;
- constraints such as natural or man-made obstacles on cable routes;
- consideration and influence of existing plant.

As already mentioned, the object is to find the least-cost configuration of the local network at a given time and Figure 9.1 below shows an example of this concept in terms of the number of exchanges in a particular case. In the general case, the cost corresponds to the optimum location and boundaries of the exchanges for a given number.

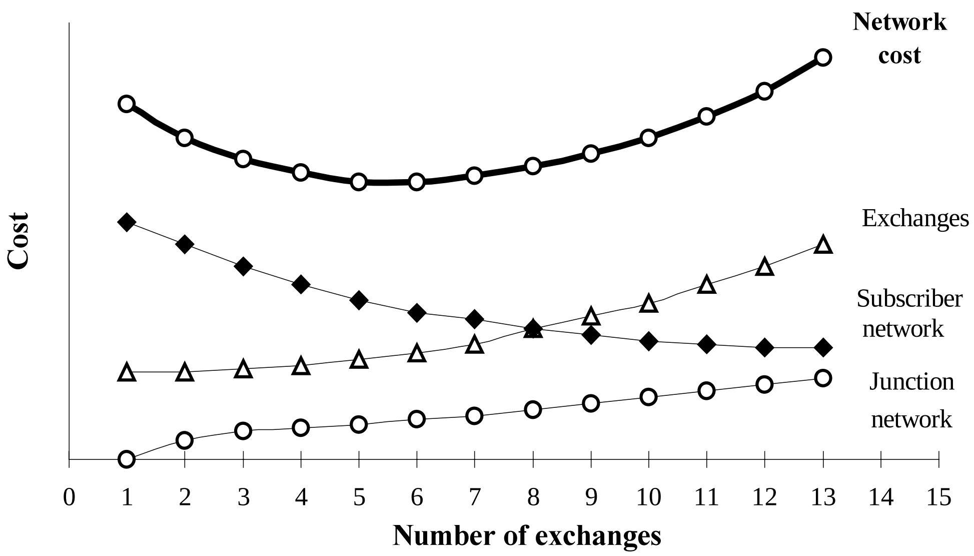

Figure 9.1 : Example of network cost variations

The influence of the factors listed above is examined in more detail as follows:

a) Subscriber demand

It is obvious that the subscriber density and, above all, its distribution defines the subscriber network required for a particular configuration, as well as the optimisation of the exchange locations and service areas. In addition, the provision of subscriber networks absorbs a significant proportion of the total network cost and, as will be seen from Figure 9.1, the subscriber network cost is heavily influenced by the number of exchanges.

Both the exchange and junction network costs will of course increase as a result of an increase in subscriber density but these increases will not be in direct proportion as the exchange start-up costs remain unchanged and the junction network would operate at a higher efficiency. The result of an increase in subscriber demand on the typical characteristics of Figure 9.1 for example would be a displacement of the minimum point to the right - which would not however correspond to an equivalent increase in the number of exchanges.

In view of the strong influence of the subscriber demand on the network costs, it is important that this demand is calculated, or assessed, with some accuracy and regularly updated. The methods for calculating the subscriber demand are given in Chapter 6, with an emphasis on separating the subscriber categories and establishing a comprehensive database for computer manipulation.

b) Traffic demand

The traffic demand and its distribution determine the dimensions and configuration of the junction network and thus influence the costs of both the junctions and the local exchanges.

An increase in traffic causes a significant increase in the cost of the junction network with a slight increase in the exchange costs and an unchanged cost of the subscriber network. This shifts the optimum cost-point slightly to the left in Figure 9.1. Thus, although there is obviously an overall increase in the network costs, the influence of the traffic demand on the minimum cost analysis is not as significant.

Methods for traffic forecasting are given in Chapter 6.

c) Exchange costs

These costs consist of those for the switching equipment itself together with the costs of the accommodation, power supplies and land. The exchange costs influence the optimum configuration as, in addition to representing a high proportion of the total network cost, they change significantly with the number of exchanges.

d) Junction network costs

The influence of the junction network on the definition of the optimum configuration is not, in general, significant. As the number of exchanges decreases it is obvious that the cost of the junction network will increase.

e) Cost of subscriber network

This includes the cost of the infrastructure such as ducts, CCPs, DPs, etc. as well as the cables and other transmission media - when used as pair-gain systems for example. The influence of this part of the network is significant as far as the number and location of the exchanges and their boundaries are concerned.

With the increasing use of remote digital switching stages, the cost of the subscriber networks can be significantly reduced in many cases, typically in extended networks with relatively isolated but important groups of subscribers.

f) Grade of service

The influence of the grade of service is the same, i.e. negligible, as that of the junction network and traffic demand.

g) Transmission plan

This affects both the junction network and the subscriber network so that the influence is the same as that described for these networks. It should be noted that in a fully digital network the transmission losses (loudness ratings) are determined entirely by the subscriber network. In this type of network the 4-wire points are brought close to the subscriber.

h) Satisfaction of demand

In optimisation exercises it is usually assumed that the demand is automatically satisfied - with the implication that there is no limitation on the funds necessary to achieve this. In the more practical case of restricted funds the “optimum” configuration becomes that which maximises the total income, so that priorities for the subscriber categories to be served have to be established for example.

j) Constraints due to existing network

As far as the exchanges and junction network are concerned, a decision has to be made between retaining them in service at maximum utilisation or discarding them. The decision is obviously influenced by the technology and serviceability of these components. In any case, the cost has to be balanced against the advantages of optimising the network using new equipment.

In the case of the subscriber line network it is obvious that the existing CCP and service areas will heavily influence the definition of the optimised network. Clearly, it is not desirable to have to change the service areas during the planning period if this can be avoided. The network development should therefore be planned to avoid these changes.

From the above it is seen that the long-term planning, i.e. effectively defining the dimensioning and optimisation of the local network over a given time period, can be complicated given the many interrelated factors involved. While the problem can, in theory, be resolved manually it is much more suited to resolution by computer provided that a realistic model can be devised to take account of the factors listed above. This subject is considered in Chapter 7 of this document together with the methods for forecasting the subscriber and traffic demands which form essential input information. This input information also has to include the marginal costs of the switching and transmission equipment to be used as well as accurate topographical maps on which the subscriber distribution, exchange boundaries, cable runs, etc. can be superimposed.

9.2.4 Extension planning

As already indicated, extension (or provision) planning is generally of a shorter-term nature than development planning which, in the case of local networks, provides the outline on which extension planning and its component projects are based. It should be remembered however that, in some cases, the extension of certain network components (for example duct systems) has to be envisaged for similar periods as those covered by development planning.

The provisioning periods can be calculated on an idealised economic basis, as described for example in Reference [1], but in practice it has been found convenient to standardise these periods as far as possible as the small economic penalty is outweighed by the administrative advantages. According to information provided by many administrations, the minimum provisioning period is five years, with a maximum of about 20 years for duct systems. A relatively long period is, in any case, desirable to minimise service interruptions.

Although extension planning can, and should, cater for the unexpected such as premature saturation of an area, non-linear growth of subscriber numbers, etc., it should always be considered in the context of the overall development of the network.

The following text gives the principal factors which affect extension planning.

a) Transmission requirements

With the decline in 2-wire switching and physical junctions, the attenuation and loop resistance characteristics required are now largely confined to the subscriber line network and are determined by the local exchange requirements, the subscribers telephone instrument and the limiting subscriber line lengths as defined in the national transmission plan. The conductor sizes must obviously be adequate for a major proportion of the subscriber lines to meet these requirements but it is recommended that, in the interests of standardisation, the number of different conductor diameters is limited (ideally) to two - for example 0.4 mm and 0.6 mm.

b) Subscriber and traffic forecasts

Updated demand forecasts are obviously essential for extension planning - in particular for the subscriber network for which these forecasts should preferably be entered on density maps. These maps should show both the present and forecast subscriber distributions. A commonly used type of density map consists of a grid overlaid on the topographical map of the area concerned, the grid consisting of squares with 200-400 m sides into which the subscriber quantities are entered. This type of grid can also be used to (manually) derive the optimum location for an exchange and to define new service areas as described in Reference [1].

As extension planning is often stimulated by urban and other civic development, usually beyond the control of the telecommunication administration, it is essential to maintain contact with the relevant local and national authorities responsible for these developments which inevitably create new demands or shift existing demands.

Demand can also be stimulated by an improvement to the existing telephone service, such as the opening of an automatic exchange, the provision of STD, opening of new trunk routes, etc.

As already mentioned, traffic forecasts are necessary for the dimensioning and optimisation of the junction network, which can involve the opening of new exchanges during the planning period. Changes in the urban structure can obviously influence the subscriber distribution and therefore the traffic patterns.

c) Coordination of activities

In order to reduce costs, extension planning should be arranged so that its implementation coincides as far as possible with other work. This applies to other telecommunication operations as well as to the work of public utilities (water, gas, electricity, road construction, public works in general).

Significant economies can be realised by undertaking joint projects for underground plant, for example telecommunication and power cable laying. Needless to say, reinstatement costs can be avoided if ducts and buried cables are laid before new roads and footways are surfaced.

d) Choice of cable system

Before extension planning is started the records of the existing cable networks must be examined and updated. From the development plan, the foreseen service areas can be determined and an idea of the extent of the primary cables obtained. In most cases, these primary, or main, cables will be in ducts - either existing or new. For the secondary, or distribution, network the choice has to be made between ducted, directly buried or overhead systems. The choice is usually made on an economic comparison basis, for example a comparison of the present worth of annual charges (PWAC) for each system as described in References [1] and [2], but other factors, both technical and environmental, also have to be taken into account. Generally speaking, overhead systems are not to be recommended in areas of high subscriber density - for both technical and aesthetic reasons - and are therefore usually confined to relatively remote suburban areas. Even in these areas local planning regulations could prohibit overhead lines so that underground distribution has to be provided.

As already mentioned, with digital local exchanges the service area can be extended by the use of remote subscriber units (RSU), or remote line units (RLU), to connect remote groups of subscribers. The choice in this case is between extending multi-pair main cables or providing optical fibre or PCM cable to the remote unit from which short subscriber lines are extended. Radio-relay links can also be considered for this application. There is almost invariably an economic (and always a technical) advantage in using the remote unit solution.

e) Planning of duct routes

The provision of duct systems enables the cable networks to be extended or modified without disturbance to the surfaces under which they are laid. The provision period for the cables laid in ducts, in particular the primary, or main, cables, can therefore be quite short - typically about five years as already mentioned - compared to that for directly buried, or overhead, distribution cables for which the provision period has to be much longer, typically 15-20 years. However, the initial cost of a duct system is very high and, in unfavourable ground, the maintenance costs can be significant. Thus the provision period for the duct system itself has, for obvious reasons, to be long - in most cases well over 25 years. It is equally obvious that extending an existing duct system is a difficult and expensive operation so that the planning has to take into account the risk that parallel or alternative routes could not be practicable. In this case, the maximum anticipated requirements for capacity have to be installed at the initial stage. This applies in any case to the exchange entry of the duct systems.

In addition to the main subscriber cables, allowance should be made for possible junction, trunk and other cables which could be accommodated in the same ducts. In the case of junction and trunk cables, these are now almost invariably optical fibre systems for which special arrangements may be required. For example, the condition and structure of an existing duct system can inhibit the installation of optical fibre cables. Details of the precautions to be taken, and the installation methods, are given in Reference [4]. When planning the alignment of a duct system it is advisable to allow for that of future junction cables, i.e. the alignment should if necessary be modified to incorporate the route of inter-exchange circuits.

In view of the long service life of duct systems, it is difficult to project the requirements for pairs as the subscriber forecasts are, at best, only reasonably accurate over about 15 years. Empirical methods for the projection of the subscriber density are used, a typical example being shown in the following table, which is reproduced from Reference [1]. It is emphasised that the factors given are approximate but can nevertheless serve as guidelines in the absence of accurate forecasts.

Duct systems should, in principle, be planned to be laid under footways and not under carriageways to avoid both inconvenience to traffic and the construction of excessively strong manholes, etc. which have to withstand heavy traffic loads. It should be emphasised here that there is still a strong case for the provision of well planned duct systems in the urban and metropolitan areas of developing countries - in spite of advances in radio access etc. In the future optical fibre cables are likely to dominate the primary network, and eventually the distribution to the subscribers.

Example of anticipated increases of subscriber density in metropolitan exchange areas
(Expressed in average number of subscribers per hectare)

Current stage and type of development	Present density limits	20-year density limits	50-year density limits
I. Embryonic urban development, 'rural and reserved living' land zoning predominates II. Young industrial suburbs. May feature large tracts of land zoned for 'special purposes'. III. Partially established suburbs featuring large undeveloped tracts. Low residential penetration IV. Established heavy industry. Low residential telephone penetration in remainder of area.	0.5 - 2.5	3.7 - 6.0	6.0 - 10.5
I. Advanced stage of initial urban development. May include early industrial development. II. Established areas featuring medium to heavy industry, with adjoining low residential penetration	2.5 - 5.0	6.0 - 10.0	8.0 - 14.0
I. Recently established areas, typical outer-suburban residential density, high residential penetration. II. Partially established areas featuring current development of remainder. Average residential penetration. III. Long established areas, low residential density, medium residential penetration. IV. Long established areas, medium residential density, low residential penetration.	5.0 - 7.5	7.5 - 12.0	10.0 - 17.0
I. Recently established areas, predominantly residential with high penetration. II. Long established areas, medium residential density and penetration, redevelopment commencing.	7.5 - 10.0	11.0 - 16.5	15.0 - 30.0
I. Long established areas, medium residential density and penetration, redevelopment commencing. II. Long established areas including large commercial centres, medium residential density and penetration. III. Long established areas featuring predominance of commerce, low residential penetration, redevelopment commenced. IV. Advanced stage of redevelopment, medium rentals, low owner-occupancy, itinerant population.	10.0 - 12.5	15.0 - 27.0	25.0 - 40.0
I. Predominance of redevelopment, medium rentals and incidence of owner-occupant. II. Redevelopment well advanced, upper-middle rentals and incidence of owner-occupant. III. Long established areas featuring predominance of commerce, high residential density, low residential penetration, redevelopment commenced	12.5 - 15.0	17.5 - 32.0	29.0 - 43.
I. Predominance of residential redevelopment, high rentals, high incidence of owner-occupancy. II. Predominance of residential and commercial redevelopment, medium rentals and owner-occupancy. III. Predominantly commercial. City core	> 15.0	Apply multiplying factor of 1.4 to 2.6	Apply multiplying factor of 1.7 to 3.3

9.2.5 Planning for reliability

Excluding the switching systems, and some of the transmission terminal equipment used in the junction networks, practically all the equipment and plant used on local networks is in some way exposed to damage by the elements as well as by human and other intervention. In addition, most of the plant is invisible, as it is installed underground, so that damage is not immediately apparent. Unlike common equipment such as switching and transmission systems, the subscriber network consists of thousands of individual circuits each of which is subject to faults but is not individually supervised. Thus it is hardly surprising that faults in the local component of the telecommunication network comprise a substantial proportion of the total.

Certain precautions can be taken at the planning stage to minimise the effects of the inevitable faults which can occur. These are briefly reviewed in the following sections.

a) Choice and specification of equipment and material

Probably the most obvious precaution is to install suitable equipment and high quality material in the first place to reduce the fault rate. Guidance on outside plant technology and material is given in Reference [3] while optical fibre cable construction, installation, jointing and protection are considered in Reference [4].

b) Construction practice

Even the best equipment and material cannot be expected to perform correctly if it is poorly installed using inadequate construction practice. This aspect is covered in general terms in References [1] and [3]. Certain administrations publish comprehensive engineering instructions and other documentation which is often available on request and can provide valuable assistance for administrations which need to produce this type of documentation.

c) Protection measures

Damage to external plant is caused principally by:

- entry of moisture into cables and other plant;
- corrosion;
- insect, rodent, animal, etc. attack;
- lightning strikes;
- civil works (excavators, etc.).

The precautions to be taken against the first three of the above causes are comprehensively treated in Reference [3] while protection against lightning discharges, etc. is considered in Reference [5].

As far as damage due to civil works is concerned, the routes for directly buried and ducted cables should be as secure as possible and be provided with adequate markers, including a marker tape above the trench or duct. Directly buried cables are obviously more prone to damage due to civil works and some additional protection can be provided by placing concrete slabs above the trench.

Protection against the entry of moisture into cables can be provided either by pressurising the entire cable system or by using exclusively jelly-filled cables. Pressurisation is virtually mandatory in the case of lead-covered, paper-insulated cables but, with more modern technology, the alternative solution using jelly-filled, plastic insulated cables is now available. Given the high initial cost, and continuing running costs, of pressurisation systems, the option of using jelly-filled cables is particularly attractive for the administrations of developing countries - in which the relatively complicated pressurisation equipment could present its own maintenance problems.

d) Junction networks

As mentioned in § 9.2.2 above, the reliability of the junction network can be improved by adopting a ring structure which, in addition to providing redundancy, gives the possibility of alternative routing (in the “reverse” direction of the ring). A further advantage of this structure is the provision of short subscriber lines and a possible elimination of the primary network. Needless to say a ducted optical fibre cable junction network provides the maximum reliability, flexibility being improved by the introduction of SDH systems.

e) Provision of O&M centre

The quality of service, as perceived by the subscribers, will be improved by an efficient fault clearance record. For large urban and metropolitan networks this can only be achieved by the provision of adequate supervisory facilities at one or more operation and maintenance (O&M) centres, preferably including automated line testing. Provision for these facilities should be made at the planning stage. It is important, for the smooth running of local network O&M centres, that full documentation of the external plant is available. This is considered in the next section.

9.2.6 Documentation for external plant

The importance of comprehensive and accurate documentation of local networks cannot be over-emphasised. Updated documentation is absolutely essential for successful development and extension planning as well as its more obvious use for the operation and maintenance of the local network.

The types of documentation, including records, required are as follows:

a) Site plans

Site plans should always be based on accurate topographic maps of the areas concerned and are used for:

- planning of the network;
- definition of the most economical and secure routes;
- coordination of work with other public utilities;
- preparing subscriber density maps;
- detailing the civil works required for local network projects (duct routes, jointing chambers, overhead lines, buried cable routes);
- locating plant for maintenance and repair;
- general indication of network structure;
- facilitating negotiations for land purchase.

Different scales for the site plans are required according to the application, the scales varying between 1:25000, for uses such as indicating structure and exchange boundaries, etc., and 1:200 for coordination of work, negotiations with land owners, etc.

An example of a simple site plan is shown in Figure 9.2. On an actual plan a key explaining the symbols would be included.

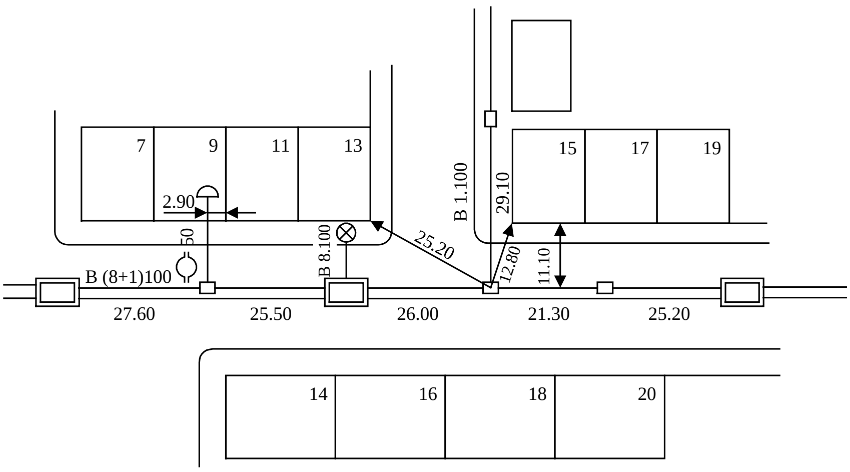

Figure 9.2 : Example of site plan

b) Schematic plans

These are intended to indicate the electrical arrangement and technical characteristics of the external plant, including:

- the types of cable (giving also the overall size, length and conductor diameters);
- details of CCPs and DPs;
- details of cable jointing positions;
- particulars of jointing chambers;
- size of ducts and their occupancy;
- distances CP-CCP, CCP-exchange.

Schematic plans are not drawn to scale but their content must follow the arrangement shown in the site plans for ease of interpretation. For example, the corresponding schematic to the site plan above is as shown in Figure 9.3 below.

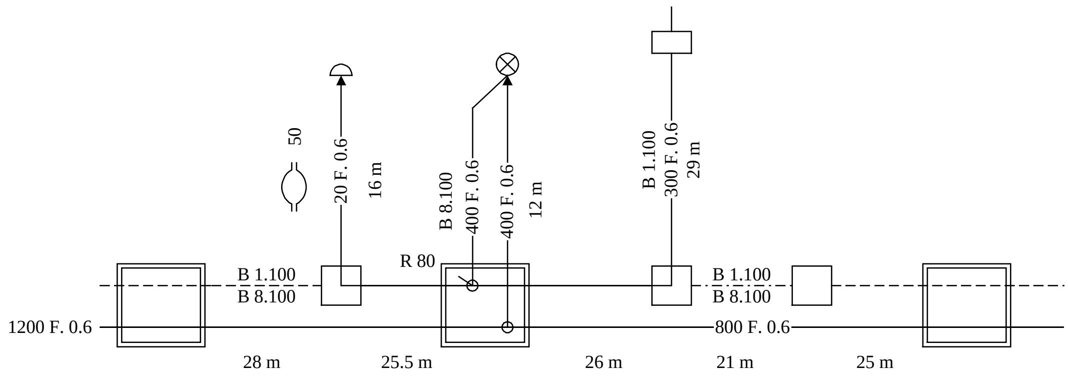

Figure 9.3 : Example of schematic plan

Schematic plans must be continuously updated for use in extension planning and, together with the corresponding site plans are also used in the specifications for cable projects. To avoid an over-crowding of symbols, lettering, etc. separate overlays can be prepared.

c) Registers of subscriber lines

These registers are essential for the purposes of:

- assigning pairs to new subscribers;
- checking the occupancy of cables and CCPs;
- tracing the route of a subscriber's line for fault clearance purposes;
- network rearrangement when required;
- providing network growth statistics.

The registers should include the following information:

- the subscribers' numbers;
- the main cables;
- the CCPs (occupancy, etc.);
- details of link cables between CCPs;
- details of distribution (secondary) cables;
- details of DPs and street addresses;
- details of subscribers' installations.

This information should preferably be computerised so that it can be used, for example, to interact with automated line testing systems (as well as to be immediately available).

d) Cable register

This is effectively an inventory of the cables installed in the network. The details of each cable in use are entered either on a card or, preferably, as computer data and should include (for each cable):

- the cable reference number (also on schematic plan);
- its location on the network;
- number of pairs and conductor diameter;
- type of armouring and sheath;
- type of insulation;
- length;
- name of supplier;
- year of provision.

e) Plans of duct systems

These are similar to the schematic plans and contain information on:

- the number and sizes of the ducts;
- the length of each section;
- the type of duct;
- location and details of jointing chambers;
- the duct occupancy;
- the date of installation.

This information can also be entered in a register system.

f) Cable fault statistics

These are obviously useful to reveal weak points in the network construction and choice of material and to enable corrective action to be taken in the future. All faults must be carefully recorded and the causes classified as follows:

- mechanical damage;
- faulty laying;
- faulty manufacture;
- fault due to corrosion;
- fault due to lightning or power surge;
- other or unknown.

A further classification of the above should be made to indicate whether the defect is in the cable itself, a joint in the cable or an interconnecting point.

g) Inventory of subscriber stations

This can either be combined with c) above (subscribers' installations) or be prepared separately. It serves as a record for charging purposes if the equipment is the property of the administration or as a record of the type approval if the equipment belongs to the subscriber.

h) Subscribers fault records

These are essential for the maintenance organisation and include the subscriber's name, address and number together with the line routing, date of connection and changes in service. Each fault is recorded with the date of occurrence and repair and the means used.

Computer assisted design (CAD) is now recognised to be an effective tool for the implementation and expansion planning of local networks, among its advantages being a drastic reduction in the mountain of paperwork involved using conventional methods. All the documentation listed above, including the maps and diagrams, can be digitised and used, together with computerised demand/traffic forecasts for a comprehensive study of the local network design and development. In addition it can obviously be used for the day-to-day routine operation and maintenance tasks, the advantage in this case being ease of retrieval.

9.2.7 Some future scenarios

Several developments are likely to be realised in the local networks of the more or less near future. These concern both the feeder and distribution segments and are considered below.

a) SDH in the junction network

The synchronous digital hierarchy (SDH), designed principally to provide a more flexible transmission structure and at the same time to exploit the enormous potential bandwidth of optical fibres, will gradually replace the conventional plesiochronous hierarchy at all network levels - including the local networks for which it is particularly suitable when deployed in ring structures. SDH is considered in more detail in § 9.4 as well as in the now numerous CCITT Recommendations on this subject which are listed in the same paragraph. As far as the junction network is concerned, the structure will be radically changed with the use of SDH add/drop multiplexers (ADM) in either a terminal or add/drop configuration. ADMs provide direct access to low order tributaries without demultiplexing and re-multiplexing the entire high-speed line signal. The lower order tributaries can consist of conventional (plesiochronous hierarchy) digital signals as well as SDH signals. Deployed in a so-called self-healing ring (SHR), significant savings in both equipment and cable can be made - as shown in the example of Figure 9.4. The same protection as in arrangement B is provided with only four network elements, the add/drop multiplexers, as shown in C.

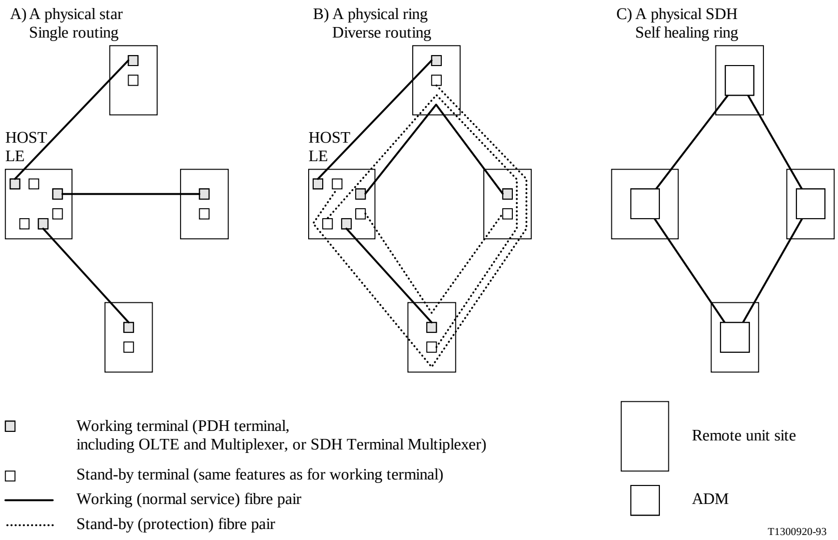

Figure 9.4 : Comparison of junction network configurations

The self-healing ring (SHR) principle, in which failures detected at a low level (e.g. loss of incoming optical signal, excessive BER, etc.) can trigger an automatic network reconfiguration, is included in CCITT Recommendation G.803 which also gives some important information on the functional architecture of SDH networks which can be exploited in network management.

One of the other significant capabilities of an SDH network is its ability to support different services, giving an obvious improvement in flexibility. For example some inputs could be used for the conventional telephony service, others for private networks, specialised data applications, etc. thus allowing the gathering (and conditioning) of traffic between different subscriber categories over the same access network. This requires cross-connect facilities between the ADM and the local switching and a further element of the SDH network is the digital cross-connect (DXC) unit which has a number of SDH ports and can re-arrange the elements of the STM-N[1] input to the STM-N output; for example elements containing telephone traffic are extracted and grouped for transmission to the local exchange, elements dedicated to private networks are extracted and sent to their required destinations etc. The disposition of the above components in a self-healing ring is shown in Figure 9.5, the so-called “dual-hosting” involving two local switches being incorporated for network security. Normally only one local switch is implemented.

1 STM-N = Synchronous Transfer Mode of hierarchical order N

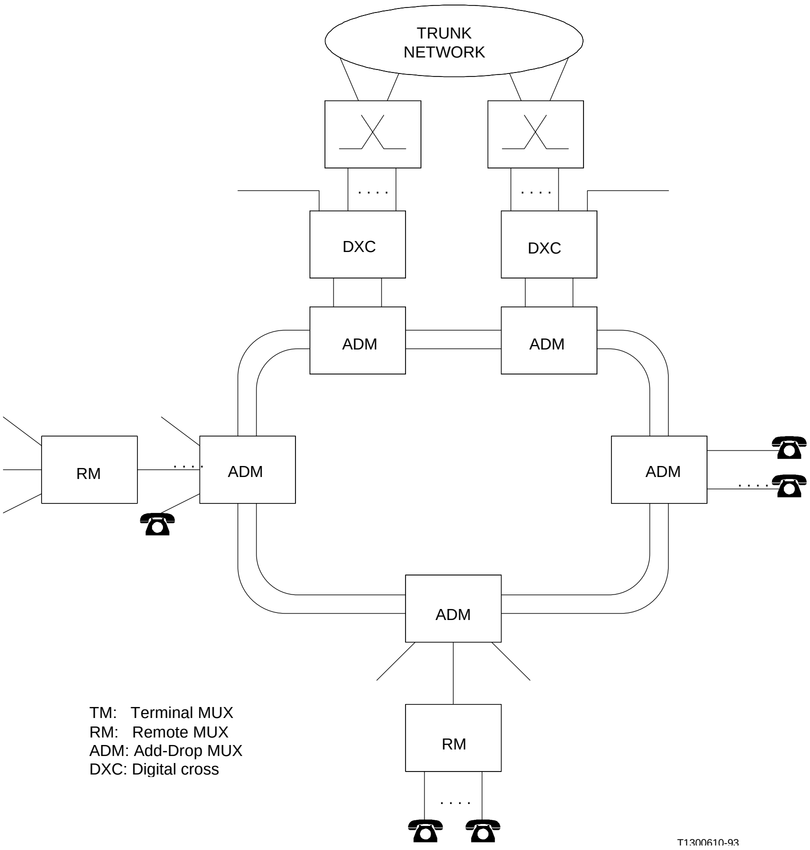

Figure 9.5 : SDH ring network structure

Facilities based on SDH, which offer significant advantages for local network applications, will co-exist for some time with conventional installations before they are progressively replaced. In the future, SDH networks will be required to carry more and more broadband services which require end-to-end control and performance monitoring of a high order.

Although, due to its flexibility, SDH can be relatively easily incorporated into existing networks, this should not be used as an excuse for ad hoc planning. As for all planning, the introduction of SDH should be considered with care - especially as it is likely to be driven by the perceived need for broadband services, which is difficult to forecast. In any case, the choice of primary nodes is crucial and should be carried out in close collaboration with the commercial department or its equivalent. The first implementation stage should be the linking of these nodes in a bus structure, to be expanded later into the classical ring structure(s) discussed earlier.

b) Optical fibre in the distribution network

Existing access networks, with the exception of some lines to major business and other organisations, consist entirely of metallic pairs and provide a predominantly telephony-oriented service. Fundamentally, these pairs are not capable of supporting more than the basic ISDN access of 144 kbit/s - over a limited distance and using special terminations - although certain compression techniques now being evaluated could conceivably prolong their use for some wide-band interactive services such as video on demand, for example.

However, for one reason or another - either a genuine demand or aggressive promotions by the now numerous network operators - the local networks will eventually have to handle wide-band services as well as the conventional telephony service. In preparation for this, active field trials and, in some cases, replacement programmes, are already being undertaken by several Administrations to evaluate the feasibility of introducing optical fibre technology into the access network. The concept of introducing optical fibre systems between the subscriber and the local exchange has become generally known as “fibre in the loop”, or FITL.

Obviously, a traditional star structure, in which each subscriber is served by a separate pair, is impracticable for economic reasons using optical fibres; although the optical fibre itself is relatively inexpensive, the optical and electronic equipment is not and efforts are being directed to developing structures which enable these expensive components (as well as the optical fibres) to be shared among as many subscribers as possible. At present, the so-called "passive optical network", arranged in a tree configuration with passive optical splitters, appears to be the favoured solution to meet the expected requirements of the subscriber access network of the future. The tree configuration is more cost effective (i.e. at shorter distances) than a full star network, at least in the initial stage of development. The general arrangement is shown in Figure 9.6.

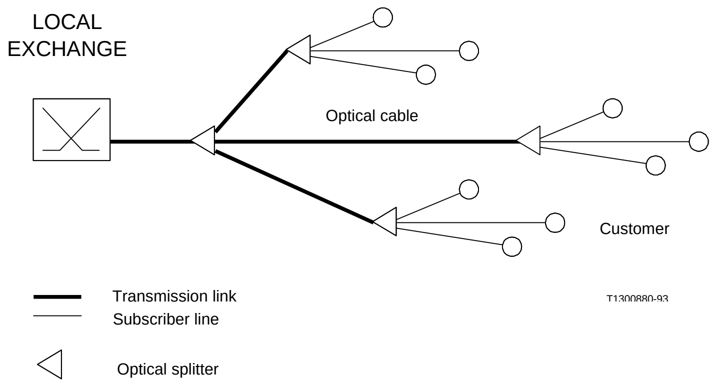

Figure 9.6 : Basic passive optical network (PON)

The provision of a PON could provide the infrastructure to support future wide-band services such as TV signals and B-ISDN, or its equivalent, as well as continuing to supply the conventional telephony service. Obviously, planners should attempt to assess the time-scale for such a development - and the financial implications, although it is to be expected that the cost-sharing principle inherent in the PON should result in a cost per line at least comparable to the conventional metallic system. The infrastructure provided for broadband services could ensure the "future-proof" network required for later, still unknown, developments.

The external network consists essentially of (single mode) fibre and passive optical splitters, the size and location of the latter depending on local conditions, the bit-rate and the optical power budget (which also determines the physical length of the network). As the optical fibre cables are shared, the transmission method has to take this into account so that three multiplexing methods, or a combination of them, could be used. These methods are time division (TDM), frequency division (FDM) and wavelength division (WDM) multiplex and examples of their application are shown in Figures 9.7 and 9.8. In both these applications, the telephony signal at a wavelength of 1300 nm is transmitted in the TDM mode and the broadband signal is combined using WDM into the network.

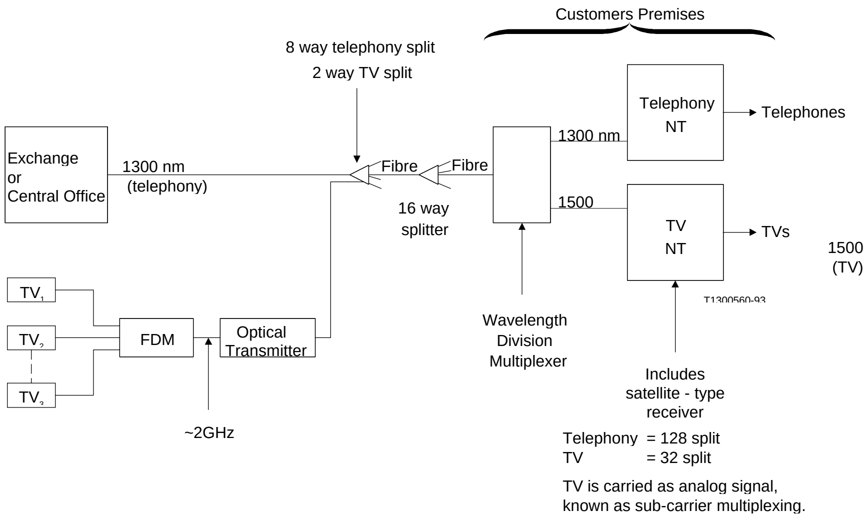

Figure 9.7 : PON for telephony and TV using TDM, FDM and WDM

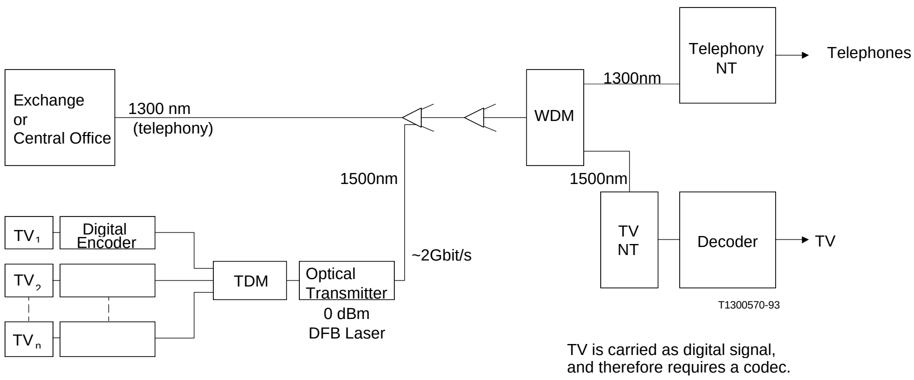

Figure 9.8 : PON for telephony and TV using TDM and WDM

c) Cellular radio in the local network

Cellular radio systems have seen a remarkable growth in the industrialised world in spite of the relatively large differential in the tariffs between the cellular and fixed networks. This differential is due to the fact that the fixed network costs have been amortised for some considerable time so that the tariffs are in general rather low. However, radio-based access in the local network is not only feasible but could become a serious competitor to metallic pairs and optical fibre as it is, at least theoretically, less expensive to implement and certainly can be established in a short time-scale.

The use of cellular type fixed systems, suitable for use in urban, as well as rural, networks is considered in CCIR Recommendation 757 to which reference should be made. One option for incorporating these systems is to design a system which is optimised for and dedicated to entirely fixed use while the other, preferred, option is to utilise existing cellular systems with minimum modifications for fixed applications. This is to cater for the case of the system being capable of accommodating mobile, as well as fixed, subscribers (see also §9.5.4).

A further development is the establishment of radio networks with extremely small cells (picocells, microcells, etc.) enabling extensive frequency repetition, fast handover and low power, but numerous base stations - which in this case are miniaturised terminals linked into the local network optical fibre loops.

d) Multi-access radio systems

Although designed primarily for rural applications, the multi-access, or point-to-multipoint (PMP), system can also be used in the urban environment to relieve the pressure on providing subscriber lines to outlying districts for example.

The general arrangement of a PMP system is shown in Figure 9.9, which includes its more common repeatered configuration often required for rural systems. At, or near, the local exchange is the central station transmitting via an omni-directional antenna to a number of out-stations, each of which uses a directional antenna. The central station transmission is in TDM format on a continuous carrier, while transmission from the out-stations is in TDMA burst format.

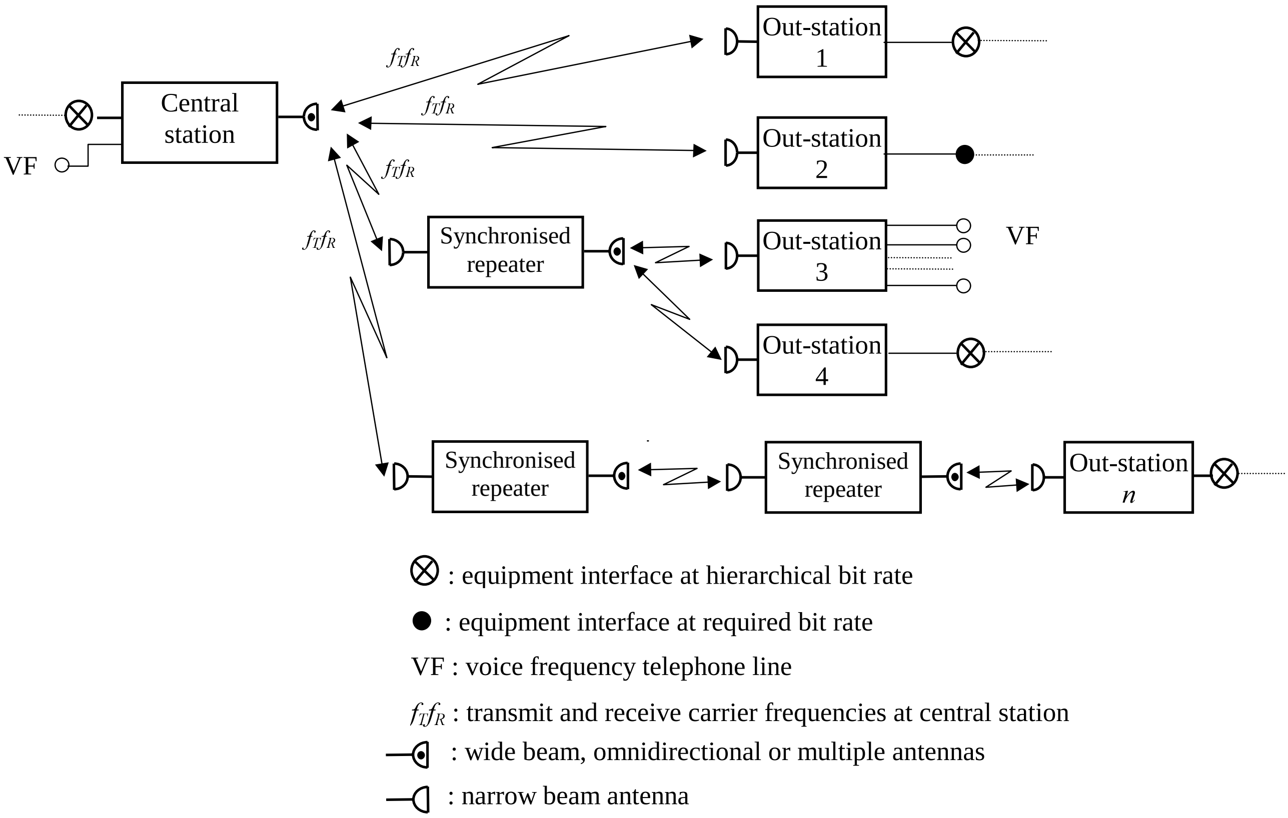

Figure 9.9 : Typical configuration of PMP TDM radio-relay system
(See also CCIR Recommendation 756)

Each out-station can serve either an isolated subscriber or many subscribers, for example over 200, with a variety of telecommunication services. The latest systems can provide 64 kbit/s circuits for both voice and data, and could therefore provide basic ISDN access if required.

9.2.8 References

1) GAS 2. Local network planning. Geneva 1979.
2) GAS 9. Case study on an urban network. Geneva 1984.
3) CCITT. Handbook on outside plant technologies for public networks. Geneva, 1992.
4) CCITT. Construction, installation, jointing and protection of optical fibre cables. Geneva, 1990.
5) CCITT. The protection of telecommunication lines and equipment against lightning discharges. Geneva 1974.

9.3. Switching equipment, types and policy

9.3.1 General aspects

Switching systems applied in the Public Switched Telephone Network (PSTN) can be classified according to their capabilities to perform certain functions in the network such as:

- rural exchange
- local exchange in a single exchange local network
- local exchange in a multi-exchange local network
- tandem exchange in a multi-exchange local network
- trunk exchange
- international exchange
- exchange for special networks or applications such as mobile networks or free-phone services.

In such a network, it happens frequently that certain of these exchange functions are combined in one exchange, for example:

- rural or local exchange in a single exchange local network with trunk exchange,
- local exchange in a multi-exchange local network with tandem exchange,
- trunk exchange and international exchange,
- exceptionally, local, trunk and international exchange.

It is obvious that the combination of the different network-node functions into one exchange depends on the capability of the switching system concerned.

Switching systems can also be classified according to the technology used, the control methods applied and transmission method used in the exchanges, i.e.:

- electromechanical (EM) or electronic systems,
- wired-control or stored-programme-control (SPC) system, where the wired-control systems can be classified into direct control (step-by-step) and register or common control systems,
- digital or analogue switching, where analogue switching can be classified into 2-wire or 4-wire switching.

Last, but not least, the systems can be classified according to their termination connecting and/or circuit switching capacity, thus providing for small, medium and large sized switching systems.

9.3.2 Inventory of the existing switching capacity in the network

As a first step, an inventory has to be made of the different switching systems used in the network, their application, their equipped capacities (terminations and trunks) and their geographical distribution throughout the country. The date of installation and the initial capacity might be indicated, as well as the date and size of the most recent extension. Information about the ultimate capacity should also be included, with possible indications about the limitations (system capacity, accommodation problems).

9.3.3 Review of the existing switching systems in the network

There may be a variety of switching systems in the network, some of which may be a bottleneck in network development, while others are a serious handicap for system operation and maintenance. A third category may be working normally in the present network configuration but incapable of meeting longer-term development objectives, and finally new systems, capable of meeting current and future requirements.

It will be necessary to review the switching systems currently used in the network on the basis of the above-mentioned aspects and prepare a programme for disposal, re-allocation, no further extension, etc. according to the condition and capabilities of the equipment

At the same time infrastructure such as power, equipment accommodation and air-conditioning also have to be considered in this context.

In a first category, there would be the exchanges and systems to be replaced as soon as possible for various reasons, usually age, unreliability, together with the poor functioning of exchanges, in most cases old electro-mechanical exchanges. Problems related to these exchanges are also the lack of spare parts and may be the lack of staff trained for maintenance of these old exchanges.

A second reason would be the incapability or difficulty to adapt these exchanges to the expanding network. For example, old local exchanges in multi-exchange local networks may not be able to meet requirements for routing, numbering and signalling in such networks, and the necessary adaptations will be difficult or impossible to realise.

A second category of exchanges would be those for which a reasonable operation and maintenance can be ensured for the time being but are unable to meet new network and service requirements. Such exchanges and systems could be maintained for the time being; they should not be extended and new exchanges of this type should not be (re)installed. The exchange type could, for example, be more recent electro-mechanical common-control exchanges or semi-electronic register/common-control exchanges.

A third category of exchanges could be those which would meet, to a certain extent, new service requirements, but would not be able to be integrated in future network configurations and meet long-term network and service requirements. Such exchanges could be extended, but new exchanges should not be installed. In this case, the exchange type could, for example, be an analogue SPC-system or early digital systems without modern capabilities such as ISDN and Signalling System No. 7.

Finally, there may be a last and most recent category of exchange types, which would be able to meet all present and future foreseeable and defined requirements, and such a system could be considered for extension and new exchanges. This category would include the current modern digital switching systems.

Based on this philosophy, the switching projects for extension, replacement and new exchanges during the coming years could be elaborated.

9.3.4 Policy for the procurement of new switching equipment

From the considerations in the previous section, it will be clear what type of switching equipment will have to be procured for the extension of the network. If the considerations and examples of this section were to be followed, then only the modern digital switching systems would be considered, and in some cases, for the extension of existing exchanges, other modern outdated systems such as analogue SPC or early generation digital systems without modern capabilities.

Regarding the procurement of new digital switching systems, the issue of having one or more of such systems in the network has to be considered.

For the strategic plan, it is not necessary to define the number and types of digital switching systems to be used in the network, but only to indicate a possible policy for the procurement of this equipment.

The ideal situation would be to have one, well-functioning, digital switching system in the network, with good supplier support and attractive price levels for equipment and services from this supplier. This would be perfect in view of maintenance and operation, spare part provision and equipment compatibility in the network and for the services.

This situation with one supplier and system only would also be the best solution for small networks, where considerations of simplicity in operation and maintenance play an important role.

However, for various reasons, such as security of supply, equipment price level, quality of support of the supplier, it may be desirable to have more than one new digital switching system in the network. In such a case, some factors have to be taken into consideration:

(a) Remote switching units of a certain type have to be connected to a parent digital exchange of the same type;

(b) It is common practice to connect a group of digital exchanges to an operation and maintenance centre, and it is therefore an advantage to have one system type for such a group in order to avoid problems of maintenance, staff training, support and connection for such an O&M-centre.

It is therefore recommended that in case of more digital switching systems in a network, the distribution of those systems over the network is made on the basis of geographical or organisational areas.

If it is decided to introduce a second digital switching system in the network, it is recommended to decide on such a system on the basis of tendering, either open international tendering or from a number of suppliers who are supposed to be interested in such a project and having activities in the country or region.

Tendering has to be based on detailed technical specifications. For information on technical specifications, Reference 1 should be consulted.

The call for tenders should also include a sizeable project and not only one or a few individual exchanges, in order to stimulate the interest by potential tenderers and to obtain attractive price quotations for the project, which may be used for future network extensions as well.

It would be an advantage if such an exchange project could include exchanges of different function and size, from a remote switching unit up to an international exchange and between, in order to obtain good information on price levels on the whole equipment family of the proposed system. Tenderers should in any case submit itemised prices for switching equipment and other sub-systems.

In addition to equipment prices, the tenderers should also provide detailed information and price quotations for additional services to be offered by them such as training, maintenance contracts and remote diagnostic analysis (telemaintenance) by the tenderers.

9.3.5 Future development of switching systems

The current digital switching systems have been developed in the late 1970s and the 1980s, their basic mode of switching is circuit switching of 64kbit/s channels, based on synchronous transmission and adapted to the existing digital hierarchies for digital transmission systems. The systems are also suitable for the so-called narrow-band ISDN with basic and primary access and bit rates up to 2 Mbit/s.

During the past ten years, many developments have taken place, which will have an impact on the requirements for switching in future network configurations, the most important being :

a) the development of very high capacity optical fibre systems;

b) the definition of the Asynchronous Transfer Mode (ATM), a high speed, packet-mode information transfer mechanism, to be used for high capacity systems;

c) requirements to interconnect services requiring very high bit rates, such as LANs and MANs;

d) the definition of Broadband ISDN network functions and interfaces.

It is quite possible that new switching systems will be developed, based on the above mentioned basic requirements, and that the fundamental switching characteristics would be based on ATM cell switching. Such a switch could then also provide other switching modes such as circuit switching.

At this stage it is difficult to forecast how such a switching system will look, different solutions can be envisaged, with their advantages and disadvantages.

In any case, the network operators should be careful and not adopt too many “conventional” digital switching systems in their networks.

9.3.6 References

1. GAS 6 - Handbook on economic and technical aspects of the choice of telephone switching systems, ITU, 1981.

2. GAS 9 - Economic and technical aspects of the transition from analogue to digital telecommunication networks, 1984.

3. GAS 3 - General network planning, 1983.

9.4 Development of the transmission networks

9.4.1 General

The transmission networks, which include the local, national and international facilities, are developed within the overall plan according to:

- the national transmission plan;
- the traffic forecasts;
- the routing plan;
- the digitalisation strategy.

As for the remainder of the network, it is assumed that the transmission component is at the stage at which no further analogue equipment is to be procured, i.e. all new routes specified in the strategic plan will be digital and all existing analogue routes will be progressively re-equipped with digital facilities.

While analogue and digital equipment will continue to co-exist during this phase, the aim has to be to use the minimum quantity of analogue to digital conversion equipment - which becomes obsolete and has to be discarded when the network becomes fully digital. Thus every effort has to be made to ensure, for example, that digital transmission links are available before digital switching is installed and that the use of devices such as transmultiplexers is kept at an absolute minimum during this transition phase which is now short, rather than long-term.

This section provides a review of the transmission systems now available, with some guidelines on their application, as background material for transmission network planning personnel faced with the problem of evaluating possible solutions.

Obviously, the equipment and systems selected to realise these solutions must be as “future-proof” as possible but, at the same time, equipment which does not appear to be field-proven should be avoided. The possible solutions must of course be evaluated from a financial, as well as a technical point of view following the procedures given, for example, in Reference [1].

The transmission systems peculiar to rural networks, principally multi-access radio systems, are not considered in this section; reference should be made to § 9.5.

9.4.2 Transmission media to be considered

As already mentioned, the general assumptions made in this document are that the telecommunication networks to be planned will be entirely digital and that no further analogue equipment will be procured. Analogue equipment which has not completed its useful service life could conceivably be re-deployed but, in many cases, it will be found more economical to withdraw it from service. In extreme cases analogue to digital conversion equipment can be used to prolong the service life of almost new equipment, but this is not to be recommended as a general policy. In view of the above, only digital transmission media will be considered here.

The advantages of digital techniques are now well known and are not repeated here, except to recall the principal of these advantages, which is the so-called synergy-effect, i.e. the combined advantages of using integrated (digital) switching and transmission techniques exceed the sum of the individual advantages (in this case economically as well as technically). The systems which can be used for the development of the network are briefly described below.

a) PCM cable systems

These have been widely used for many years, even in the totally analogue environment, to improve the utilisation of balanced pairs in junction and other networks, up to 30 audio circuits being provided over two pairs. Regenerators are designed to occupy the former loading coil positions, typically at 1800m spacing. PCM cable systems can still be economical when installed on existing balanced pairs but the necessity for power feeding on all but the shortest junctions renders them unreliable by modern standards. They are certainly no longer competitive with optical fibre cables in most applications, especially if new PCM cable pairs have to be installed.

b) Digital radio-relay systems

Digital radio-relay systems are used at all levels of national networks, including metropolitan junction networks. They are rapidly replacing the equivalent analogue (FM/FDM) systems which formed a substantial proportion of national and cross-border transmission facilities.

In view of the large amount of infrastructure in the form of buildings, towers, power supplies, etc., already in place, it is obviously desirable that the replacement digital systems should operate not only at the same repeater spacing but also at the same capacity. This has led to the successful development of digital radio-relay systems using 'conventional' (i.e. below about 8GHz) frequency bands even for high-speed (140 - 155Mbit/s) transmission.

As for all radio-relay systems, the effects of selective fading become severe for the high capacity systems and can limit the use of long repeater spacings for digital applications. In the case of digital systems, the effects of this type of fading, which are due to spectrum distortion, are obviously more serious than for an equivalent capacity analogue system, given the much wider spectrum of, for example, a 140 Mbit/s system. In addition to selective or multi-path, fading, outages can be caused by diffraction fading due to obstruction of the path by surface obstacles under adverse conditions and, for radio-frequencies above about 10 GHz, fading due to precipitation. In certain areas, ground-based ducts can give rise to the so-called “black-out” type of fading.

Diffraction fading can be minimised at the initial planning stage by ensuring that each path is designed to provide adequate clearance under the worst expected effective earth curvature (k-factor) conditions, as described in CCIR Report 338.

Fading due to precipitation can only be mitigated by keeping each path short, which at the same time reduces the effects of multipath fading. Fading due to precipitation is also considered in the above CCIR Report.

“Black-out” fading is relatively rare, except in some tropical and sub-tropical coastal regions, and is extremely difficult to both predict and cure. This type of fading can sometimes be countered by shortening the path, using “high-low” technique or by using space diversity antennas, with one inside and one above the suspected duct.

In the usual case of providing a high capacity digital system using radio-frequencies below about 8 GHz and conventional repeater spacings, the determining factor is the degree of selective or multipath fading present on each section. The effects of this type of fading increase in proportion to the frequency, but increase dramatically with the path length. For this reason, it is normally necessary to limit the path length to 50-60 km for 70/140 Mbit/s systems. (As already indicated, systems using higher frequencies are limited to extremely short path lengths in any case to avoid the effects of precipitation).

It is important for planners to realise that the conventional methods used for estimating outages due to fading on FM/FDM systems are not valid in the case of medium to high capacity digital systems. This is because a BER approaching the outage value can be caused by a selective fade which is much less than the single frequency fade specified by the equipment manufacturers as the “threshold” value (i.e. the so-called “flat” fading margin) and used in FM/FDM systems to predict the performance.

The extent to which the fade margin of a digital system will be eroded by the effect of multi-path fading depends on:

- the properties of the digital radio system itself, i.e. the modulation method, capacity, bandwidth used, etc., and its susceptibility to dispersion effects[2];

- the degree to which frequency selective fading actually occurs on the radio path.

The second of these factors can be estimated from the well known empirical expressions published in CCIR Reports and in the literature. It depends on frequency, path length, angle of arrival, climatic conditions and the terrain over which the path is to operate. The properties of the radio-relay equipment can only be determined by the equipment manufacturer and involve some rather complex calculations and measurements. There is no single, reliable method of predicting outages in high-speed digital radio-relay systems. As implied above, planners must rely heavily on the manufacturers of the equipment they propose to use, as well as on the published literature which includes several methods by means of which the outages can be estimated. These are given in CCIR Report 784-3 and include:

- the concept of net, or effective fade margins;

- the use of equipment “signatures”, a factory, or laboratory, measurement involving a 2-ray model;

- the use of “linear amplitude dispersion” (LAD) statistics.

Reference should be made to the above-mentioned CCIR Report for more details of these methods, but it is recommended that planning staff should ascertain the methods by which manufacturers of the equipment proposed for the network use for establishing the critical parameters of net fading margin, signatures and the degree of LAD.

It is emphasised that experimental investigations are still being undertaken on this subject but, for practical purposes, it is worth recalling that the investigations so far carried out have shown that the use of adaptive equalisation in combination with space-diversity antenna systems is the most effective counter measure against selective fading in digital radio-relay systems. Frequency diversity, both in-band and cross-band, is also an effective counter-measure (as well as providing a protected system). Cross-band diversity, for example 6 and 11 GHz, is particularly effective.

On existing wide-band analogue sections, the presence (and often the degree) of selective fading can be seen in variations of the continuity pilot level. This is a useful indication of the fading to be expected when the system is converted to digital operation. For new digital sections each hop has to be carefully surveyed and stations sited to avoid both excessive length and ground reflections. It is crucial to find profiles for which ground reflections are blocked but which satisfy the normal clearance criteria and path length limitations.

c) Optical fibre cable systems

Optical fibre cables have now effectively replaced coaxial cable systems in the long-distance and inter-continental (submarine cable) networks, as well as the conventional metallic pairs in metropolitan junction networks.

The first systems of this type, installed in the mid-seventies, used step-index, multi-mode fibre with LED transmitters at a wavelength of 850 nm, giving a regenerator spacing of about 10 km and a capacity up to 34 Mbit/s. Present day technology enables a regenerator spacing of 130 km at a capacity of 560 Mbit/s per pair over single-mode fibre using laser diode transmitters, as for example in the TAT-9 (1550 nm) cable installed in 1991.

This enormous capacity, one of the well-known advantages of optical fibre, makes “future-proof” transmission systems possible, i.e. the capacity of a system can be increased as required without replacing the physical carrier which is the most expensive component. The wide regenerator spacings enable 'repeaterless' inter-exchange links to be easily established.

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[2] The amount of dispersion on a path is defined as the peak-to-peak difference in the measured attenuation (dB) across the transmitted spectrum. The dispersiveness of fading on a path is represented by the amount of time a chosen in-band power difference (IBPD) is exceeded (see also CCIR Report 784-3).

Terrestrial optical fibre cable systems currently in service, including junction networks, use single-mode fibres and operate at wavelengths of 1300 nm, or 1550 nm, using laser diode transmitters to give regenerator spacings of about 45 km at 560 Mbit/s. This is now the established technology, using the so-called plesiochronous digital hierarchy which will remain in operation for many years to come. However, due to the lack of flexibility in very high capacity point-to-point links (specifically the difficulty and expense of de-multiplexing at intermediate points), the synchronous digital hierarchy (SDH), using a first-level bit-rate of 155.52 Mbit/s, has evolved and is specified in CCITT Recommendations G.707, G.708 and G.709. In addition to the first-level bit-rate, two higher level rates, formed by byte interleaving of, in this case, 4 and 16 first-level signals, have now been specified:

- level 4: 622.08 Mbit/s;
- level 16 : 2488.32 Mbit/s.

SDH is a concept for transmission, principally over optical fibre cables, and has been developed to exploit the enormous potential capacity of this medium. However, the possibilities of using SDH over radio-relay systems is under investigation. As already mentioned, its principal advantage lies in its flexibility combined with extremely high capacity using simplified synchronous multiplexing with no need to multiplex/demultiplex the entire digital signal if access is required to particular channels. It is likely that many Administrations will up-grade their long-distance networks with SDH technology, and it will also be exploited in the feeder portion of local networks in conjunction with add/drop multiplexers (ADM).

Even more spectacular progress has been made in submarine optical fibre cable technology, for example regenerator spacings of up to 130 km are realised for the 140 Mbit/s feeders of one transatlantic cable which provides a total capacity of 23000 circuits (of 64 kbit/s). In the near future, operation at 5 Gbit/s using optical amplifier technology will be possible.

Using distributed feedback (DFB) laser diode transmitters and high-sensitivity avalanche photo-diode (ADP) receivers over silica core fibre, many so-called “repeaterless” undersea links of up to 200 km have been realised at bit rates of 140 Mbit/s per fibre pair. These have obvious applications as mainland to island, island to island and coastal links. The latter is an interesting method for providing route diversity in countries with long coast-lines.

A further, and obvious, advantage of optical fibre is its immunity to electrical and electro-magnetic interference, a property which enables it to be laid in what would normally be considered as “hostile” environments. These include electric railway routes and high-voltage transmission lines, which are already being used in some countries as secure routes for optical fibre cables. (Ducted and buried cable routes are not considered to be “secure” in the sense that they are vulnerable to damage in the course of civil works).

The high capacity and future-proof characteristics of optical fibre cable makes it an obvious first choice for national transmission networks, but it has to be remembered that the installation costs of long terrestrial routes can be extremely high and can sometimes be prohibitive, for example over mountainous terrain.

d) Satellite systems

In addition to providing an important part of the international network, satellite systems using either INTELSAT or regional transponders in a geostationary orbit, form, in many large countries, an integral part of the national networks. This, in fact, is the classical role of a satellite system - point to multi-point transmission - the national systems having been implemented to overcome the well known difficulties of providing conventional transmission to scattered communities over long distances and often hostile terrain. There is, as yet, little competition to this national application but it will eventually be provided by the so-called personal communications mobile satellite service (PC-MSS) as far as telephony is concerned. The PC-MSS will consist of multiple satellites in low orbit (about 750 km) which can provide almost universal access via small hand-held terminals and could therefore be a serious competitor to conventional cellular radio as well as to domestic satellite systems. The latter, however, could still be required for the distribution of television and sound broadcast programmes although, here again, competition is already present in the form of direct satellite broadcasting (DSB).

Satellite systems are also used in national networks for specialised applications such as data networks, for example.

As far as international links are concerned, higher capacity and quality are now offered by optical fibre submarine cable systems but the satellite links remain as a complementary transmission facility.

9.4.3 Application notes

Some possible applications, and implementation notes, for the systems described above are given in the following sections.

a) PCM cable systems

As already mentioned, these are only economical when existing, de-loaded balanced pairs can be used. In the interest of reliability, power feeding and the use of intermediate regenerators is not to be recommended , so that the application is limited to short sections and there is little scope for the use of these systems in the long-distance network. They can of course be used in parts of the metropolitan junction networks, provided that existing pairs in good condition are available.

b) Digital radio-relay systems

These remain the only viable option for use over difficult terrain where the implementation of an optical fibre cable route would be prohibitively expensive. In the case of the long-distance network, the radio-relay equipment should operate in one of the recommended frequency bands below 8 GHz to provide reasonably long repeater sections for transmission rates up to 140 Mbit/s, or up to 155 Mbit/s in the case of future SDH links.

Although optical fibre cable systems are likely to provide the principal long-distance transmission medium in the future, radio-relay is still essential as an alternative routing medium - even over normal terrain, as optical fibre cables can be vulnerable to damage due to civil works, for example. Thus, they form a vital element in the transmission network security plan. When shorter hops are practicable, for example in certain regional or district applications, the higher frequency bands (up to about 20 GHz) can be used. The hops must of course be short enough to avoid the effects of precipitation fading (see CCIR Report 338). An obvious application for this type of radio-relay is to link cellular radio base stations to their mobile exchanges.

Radio-relay equipment is more often than not installed in remote locations with difficult access and, for this reason, attention has to be given to its reliability. Modern equipment in itself is inherently more reliable than in the past - the system unreliability, almost invariably, is due to primary power supply failures and lack of adequate supervisory information.

In this respect, it is worth recalling a common, and probably principal, cause of outages on radio-relay systems, the failure of the standby generator to start when required. To counter the effects of this type of failure, excessively large storage batteries are often provided to give sufficient autonomy for a maintenance team to arrive. All too often, the maintenance personnel do not arrive in time and the station is shut down. The fundamental cause of the failure to start is usually found to be an inadequately charged starter battery or faulty starter relay, etc. Rather than waste money on large storage batteries, attention should be given to the provision of reliable starter mechanisms, with the state of charge of the starter battery indicated at the supervisory centre. Normally, a remotely initiated test start procedure can be established as part of the routine maintenance programme. In view of the notorious unreliability of conventional power supplies (i.e. duplicated motor generators), the use of alternative energy sources is now widespread. For telecommunication purposes, the preferred alternative source is solar (photovoltaic), power which, when correctly dimensioned, has been found to be ideal for remote repeater applications. Its obvious advantage is the almost complete lack of maintenance required during its service life - there are no moving parts. With increased production and improved technology, the initial costs are now reducing and this type of power supply is more than competitive with conventional systems for low power applications up to about 350 W. In terms of annual charges, those for solar power consist only of the recovery of the capital expenditure (including replacement batteries every 7 years) in contrast to the high fuel and maintenance charges for conventional systems. If the cost of outages is included, the annual charges for conventional systems can become excessive.

Medium and high capacity radio-relay repeaters are, in effect, arranged in the form of back-to-back terminals as regeneration of the digital signal is required. This means that the power consumption of a typical station (1+ 1 radio channels) can be relatively high, certainly significantly more than an analogue IF repeater station. This consumption, typically in the order of 850 W, is beyond the strictly economic limit for solar power mentioned above and the high initial cost (but low subsequent cost) has to be considered in relation to the reliability which can be achieved when compared with the low reliability of conventional power. When the cost of outages is included in the annual charges, the comparison could well favour the initially expensive solar power installations.

In principle, if solar power is found to be completely impractical, every effort should be made to provide a reliable public power supply and the use of continuously running motor-generators in a duplicated configuration should be avoided. If, as is often desirable, radio-relay repeaters are co-sited with TV and FM broadcast transmitters they must be provided with their own, independent solar power supplies and not be supplied from that of the broadcasting equipment, which has a higher fault liability.

Needless to say, the digital radio-relay equipment to be used should be specified for the lowest possible power consumption and the regenerator section design should always envisage the use of large (high gain) antenna systems with low power transmitters.

c) Optical fibre cable systems

These are now almost an automatic first choice for application at all network levels. Long-distance systems can be realised without intermediate regenerators and therefore no power feeding, due to the long spacings now available - up to 50 km for 565 Mbit/s systems, for example. Using optical amplifiers these spacings can be extended to well over 100 km for an STM-1 link at 155 nm. In reasonably dense networks, the links can therefore be established between existing telecommunication facilities where power is available. In metropolitan junction networks, there is of course no question of power feeding and economies can often be realised by using less powerful transmitters over the recommended single-mode fibre pairs.

As already explained, the future high-capacity backbone routes of national networks, as well as international undersea routes will be realised over optical fibre pairs using SDH technique, for which a transmission rate of 2.5 Gbit/s is already envisaged. In the case of undersea links, a transmission rate of 5 Gbit/s is foreseen for the next generation of systems, using optical amplifiers.

In common with all directly buried cable routes, those using optical fibre are also prone to damage as a result of civil works. In the case of the optical fibre cable, the consequences of a break are far more severe (due both to the large number of circuits and the relative difficulty of repair). Provision for alternative routing, over either another fibre route or a radio-relay route, has therefore to be made at the time of commissioning the original route (see §8.7.2).

At the cost of some collaboration with other public utilities and organisations, more secure routes for optical fibre cables can be realised. These are along railway routes and along high-voltage power lines. Rather less secure, but much less expensive and more secure than directly buried cable, are routes along the low voltage pole lines found in most rural areas and often already used for overhead telecommunication cables. Dielectric optical fibre cables which are strong enough for quite long spans are available for this purpose. In certain countries, notably in southern Africa, well maintained open-wire pole routes are available for this purpose.

Finally, in countries with long coast-lines, the so-called “festoon” of repeaterless undersea optical fibre cables can provide a secure alternative route for the terrestrial network. As already mentioned, this type of optical fibre cable system enables links up to 200 km to be established, without intermediate regenerators.

d) Satellite systems

Domestic satellite systems using INTELSAT, regional or national transponders have been established in several countries as integral parts of their national networks. In general, these countries are large with remote and scattered populations which are virtually impossible to reach by means of conventional transmission systems. In the case of remote island communities, the cost of an alternative submerged cable system cannot be justified and the satellite system provides an economic solution for this normally low-traffic application.

Satellite systems have formed an essential part of the international network since 1965, progress in the technique having resulted in an enormous increase in capacity over the years as well as significant improvements in utilisation efficiency. This capacity, however, is not now competitive with that offered by submarine optical fibre cable systems which, as already mentioned, also have more flexibility than in the past. At least in Europe and North America, international satellite systems are now used in a complementary, rather than primary, rôle over low and medium capacity, multi-destination routes for the telephony service. For obvious reasons, satellite systems are ideal for television programme distribution and will continue to be used for this application, both over the international network and for direct broadcasting: the three major international satellite organisations, INTELSAT, INMARSAT and EUTELSAT, in addition to providing their traditional services, also provide an impressive range of additional services but are nevertheless facing increasing and intense competition from privately owned systems. This competition is appearing in areas with currently low telephone penetration rates, especially in Asia, where the short implementation period of a satellite system offers the possibility of improving the telephone penetration in a relatively short time. However, most of these privately owned systems carry traffic which is biased in favour of television transmission with typically 60% of the capacity used for this with 40% for telephony and other services (for example ASIASAT 1, which is jointly owned by Cable & Wireless, Hutchison Hong Kong and CITIC China). Direct access to the subscribers is offered by the private satellite organisations, unlike the international organisations to which the national administrations are usually the only signatories - and who therefore control the access.

All the above systems use satellites operating in the so-called geostationary orbit, the circuit characteristics of which include a significant delay which is noticeable on a two-way telephony connection for example. At present, several organisations (including INMARSAT) are considering the implementation of a network of low orbit satellites - typically 66 at an altitude of 780 km - providing almost universal access using small handheld terminals. The use of low orbit and multiple satellites facilitates the integration of this type of system into the national switched and mobile networks - once the economic, regulatory and political problems are solved. An obvious application is to provide service to isolated and rural areas, as for the current domestic satellite systems, but the principal application envisaged is a global mobile radio service operating in a similar manner to that of the present cellular radio. In this case, the “cells” are represented by different orbiting satellites.

9.4.4 Note on SDH

As indicated in § 9.4.2, the synchronous digital hierarchy (SDH) was developed in response to the need for a system which overcame the limitations of the current structures, i.e. the plesiochronous digital hierarchy (PDH), and at the same time was able to exploit the unique advantages of optical fibre as a transmission medium. In fact the initiative to develop this system was taken in the United States with the introduction of the synchronous optical network - or SONET. SDH is the CCITT version of SONET and is defined in Recommendations G.707, G.708 and G.709.

In spite of its advantages, it is not likely that SDH would have been so widely accepted if its adoption had meant that existing PDH equipment became immediately redundant. From the outset, provision was made for existing PDH signals, of both the European and North American hierarchies, to be carried without problems over SDH networks. Thus operators' investments in PDH equipment are protected, and SDH can be progressively introduced.

Fundamentally, the SDH is a hierarchical set of digital transport structures standardised for the transport of suitably adapted payloads over physical transmission media. The new multiplexing method and frame structure result in a basic rate of 155,520 kbit/s for the first level “synchronous transport module” (STM-1) which consists of payload and section overhead (SOH) fields organised in a block frame structure with a repetition period of 125 mS. The information is conditioned for serial transmission at a rate which is synchronised to the network.

The basic frame structure for STM-1 is shown in Figure 9.10, the higher order (STM-N) signals being framed by byte interleaving of several STM-1 frames.

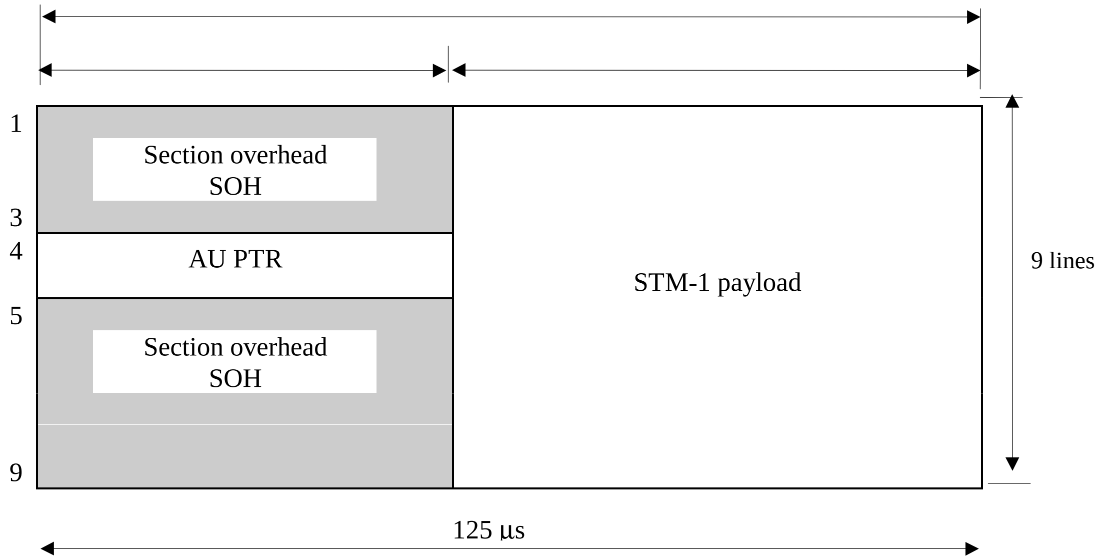


Figure 9.10: STM-1 Frame Structure

The three main areas of the STM-1 frame are shown:

- the section overhead (SOH), which is divided into a number of bytes for various system and network operation functions;

- administrative unit (AU) pointers, which indicate the alignment of payload within the STM frame, the pointers facilitating a simple identification of the individual channels within a payload;

- the information payload itself.

In order to accommodate the signals generated by equipment from the various PDH levels the Recommendations dealing with SDH define methods of sub-dividing the payload area of the STM-1 frame so that different combinations of input tributaries can be carried. A number of information structures, known as “containers”, each corresponding to an existing PDH bit-rate signal (except 8 Mbit/s) is defined. The containers are designated C-1, C-2,..., C-n and have associated control information known as “path overhead” (POH). A “virtual container”, (VC) is framed by the combination of the container and its corresponding path overhead and is the information structure used to support path layer connections in the SDH.

The generalised multiplexing structure for a STM-N signal is shown in Figure 9.11, the remaining elements being defined as follows (see also CCITT Recommendation G.708):

- the tributary unit (TU) consists of a virtual container plus a tributary unit pointer, the pointer indicating the phase alignment of the VC-n with respect to the POH of the next highest level VCs in which it resides;

- the tributary unit group (TUG-2, TUG-3) consists of a homogeneous assembly of TU-1s or a single TU-2, or an assembly of TU-2s and a single TU-3 respectively;

- the administrative unit (AU-n, n = 3,4) consists of a VC-n plus an AU pointer, the pointer indicating the phase alignment of the VC-n with respect to the STM-1 frame;

- an administrative unit group (AUG) is a homogeneous assembly of AUs which may consist of three AU-3s or one AU-4, the STM-N payload supporting N administrative unit groups.

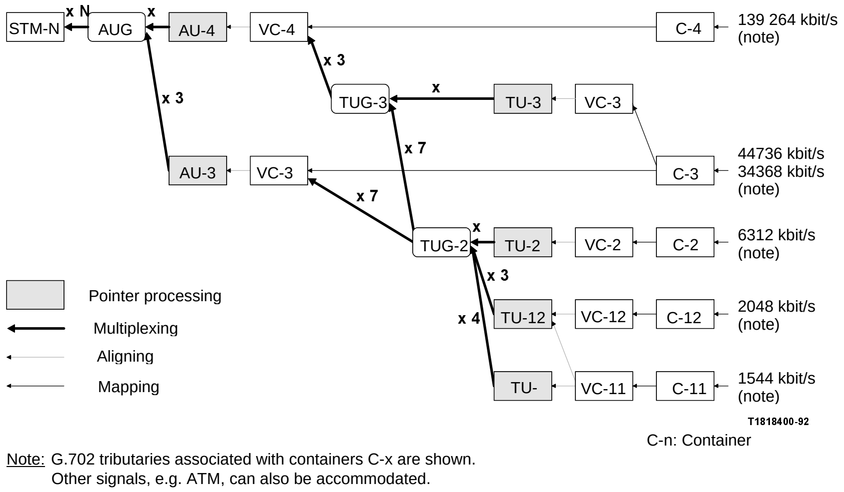


Figure 9.11: SDH multiplexing structure

The above structure, and comprehensive details of the SDH principles, equipment and network, are considered in the CCITT and ITU-T Recommendations on this subject. A summary of the main features is as follows:

- Synchronous multiplexing provides a flexible frame structure which enables the direct adding/dropping of lower order tributaries from high-speed line signals, facilitates the evolution towards higher bit-rates and allows the use of add/drop multiplexers and digital cross-connect systems.

- A single synchronous multiplexer can carry out the functions of an entire PDH series of multiplex equipments for the insertion and extraction of individual 2Mbit/s tributaries for example thus leading to significant reductions in the quantities of equipment used;

- Enhanced operation, administration and maintenance (OAM) capabilities facilitate the development of effectively managed transmission networks, the basic frame structure including functions for their operation and maintenance.

- Standardised optical interfaces for most applications are available enabling compatibility between equipment of different manufacturers at each end of a link. The STM-T electrical interface is also standardised to enable the interconnection of equipment in the same location. The simultaneous availability of SDH and PDH interfaces enables a gradual conversion to SDH to be easily carried out. Its complete compatibility with PDH networks is one of the principal qualities of SDH and allows, for example, the transparent transport of PDH frames in SDH islands during the transition phase.

As far as world-wide standardisation is concerned, SDH promotes the convergence of European, Japanese and North American digital hierarchies.

Although SDH was developed specifically for optical fibre technology, radio-relay systems can be adapted to some extent as transmission media, in particular for the basic STM-1 level, and certain sub-levels which are not subject to ITU-T Recommendations. CCIR / ITU-R Recommendations 750 and 751 consider the use of radio-relay systems in SDH networks.

The following CCITT / ITU-T Recommendations concerning SDH principles, equipment and networks should be consulted:

G.703	Physical/Electrical characteristics of hierarchical digital interfaces
G.707	Synchronous digital hierarchy bit rates
G.708	Network node interface for the SDH
G.709	Synchronous multiplexing structure
G.774	SDH management: Information model for the network element view
G.780	Vocabulary of terms for SDH networks and equipment
G.781	Structure of Recommendations on multiplexing equipment for the SDH
G.782	Types and general characteristics of SDH multiplexing equipment
G.783	Characteristics of SDH multiplexing equipment functional blocks
G.784	SDH management
G.803	The control of jitter and wander within digital networks which are based on the SDH
G.831	Management capabilities of transport networks based on the SDH
G.957	Optical interfaces for equipment and systems relating to the SDH
G.958	Digital line systems based on the SDH for use on optical fibre cables

SDH can be applied at all network levels; currently projects are being implemented, for completion between 1994 and 1997, for submerged optical fibre cable links operating at STM-16 (2.5 Gbit/s per pair) as well as STM-1 levels and providing trans-ocean ring configurations. The application of SDH in the local network has already been considered in § 9.2.

9.4.5 References

1) GAS-3. Methods for evaluating new digital interexchange transmission systems as a guide to national network planning. Geneva 1988

2) CCIR. Handbook on satellite communications (fixed satellite service) Geneva 1988

9.5 Rural networks

9.5.1 Definition of rural area

Traditionally, the term “rural” is used to describe the countryside or sparsely populated, often isolated areas. For telecommunication planning purposes the term “rural area” usually means a zone in which it is both difficult and expensive to provide normal service to the subscribers and, once the service is established, it is not likely to be profitable. Thus, it is usual for the service in rural areas to be either neglected or heavily subsidised depending on the financial resources available to, and in many cases the political pressure placed upon, the operating organisation.

In addition to low population density, rural areas usually exhibit one or more of the following characteristics:

- scarcity, or absence, of public services such as reliable electrical power supplies, water, access roads and transport;
- difficult topographical conditions, which inhibit the implementation of conventional systems;
- adverse climatic conditions, which impose severe reliability requirements on the equipment and infrastructure;
- economic activity limited to, in the worst case, subsistence level agriculture, fishing, etc. or, at best, low level cottage industries.

It is necessary to distinguish two basic types of population distribution applicable to rural areas. In both cases the population density is low but, in the first case to be considered, the population is relatively concentrated in small towns or villages which themselves may be widely separated. Thus the subscriber distribution networks are usually conventional and the only planning problem is the connection of these networks to the nearest local exchange or RSU.

In the second case, the low density population is also widely scattered so that conventional subscriber networks are obviously not practicable and the specialised transmission and distribution systems described later have to be used.

There is one exception to this general definition. In some regions, notably parts of the Asia Pacific region, there are significant 'rural' (i.e. under-developed and non-industrialised) areas which have a high population density together with an extremely low, or non-existent, telephone density. This case is considered in § 9.5.5.

9.5.2 Objectives for rural network development

Clearly, the long-term general objective of all administrations must be to extend the facilities offered to metropolitan and urban subscribers to the rural areas. Due to the wide variety of area types, it is essential to carry out a more or less comprehensive survey of all the rural and similar areas to establish both the individual objectives and the means by which they can be implemented.

Part of this survey is included in the normal course of preparing the long-term development plan for the network as a whole - in particular the demographic and economic data for the preparation of subscriber demand and traffic forecasts. For this, it is essential to have access to the latest census figures which, in addition to providing population distribution data, also provide information on the penetration of various public services in each area as well as a breakdown of occupations, incomes and economic activities.

The survey should enable a classification of all the communities in the rural areas to be made, in terms of population density, type of population distribution, availability of electrical power, distance to nearest access of the national network, type of terrain over which access is to be made, potential for social and economic development, etc. From the classification a priority programme for development can be prepared for incorporation in the national network strategic and other plans.

The immediate objective, depending on the current development of the area, could be the provision of a public telephone facility in an area of defined extent and population, for example one facility per 500 population in an area 10 km^2. In this case the immediate objective is based on population density and the distance to the nearest telephone (3.5 km max.). Future objectives should of course be determined by the forecast demand, for which a realistic assessment of the growth potential is required. In the case of rural areas this growth cannot be assumed to follow the national trend. For example, the traditional migration from rural to urban areas results in a low growth rate, while unexpected development due to industrial or tourist activity could reverse this trend.

9.5.3 General structure of rural networks

Rural networks, in spite of their special features of low subscriber density, remote location, etc., should be considered as integral parts of the national network so that their structure and development must be based on the same long-term objectives which are envisaged for the network as a whole. This means following the same automation and digitalisation programmes etc. so that, eventually, the rural subscribers are provided with the same choice of facilities as are offered to the metropolitan and urban subscribers.

The basic configuration of a rural network and its connection to the national network are shown in Figure 9.12, from which it is seen that this type of network is simply a special case of the conventional local network - the differences being in the methods available for the "transfer" function between the distribution point and the local exchange, or RSU, and in many cases the method of distribution to the subscribers. In some cases, for example in rural towns or villages having a concentrated subscriber distribution and a switching facility close to hand, there is little difference between a rural and a suburban system as conventional means of transfer and distribution can be used.

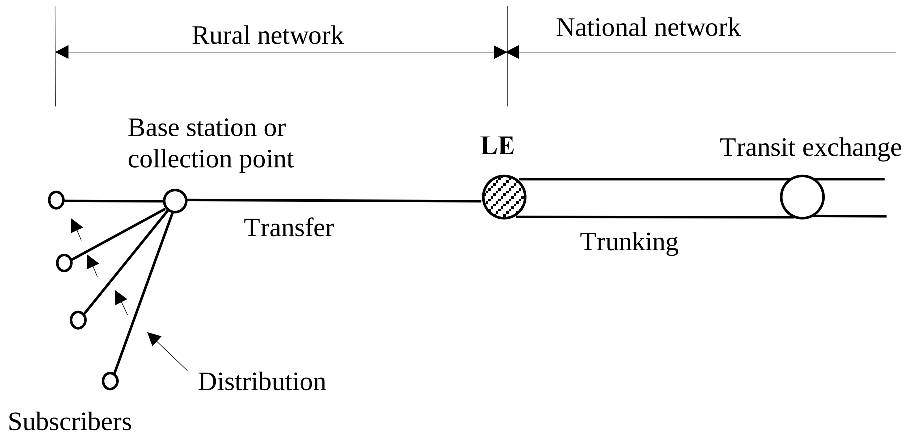


Figure 9.12: General structure of rural network

The above is the traditional telephony service configuration eventually capable of expansion to narrow-band ISDN - type capacity. As explained later, other methods of providing rural telephony will result in different configurations.

9.5.4 Rural telecommunication equipment and systems

It is obvious from the brief description of the rural network characteristics above that the revenue per individual subscriber line cannot be expected to be high while, at the same time, the cost of providing the lines is considerably more than is the case in urban areas. Except by raising the tariffs, there is little to be done concerning the line revenues - which depend on the utilisation. In the case of the line costs efforts have to be made to share the costs to the maximum extent possible by the use of common equipment such as multiplexers, the use of RSUs, etc. With this philosophy, although the initial cost will be high, the resulting marginal costs for adding capacity later will be minimised.

a) Conventional systems

The use of “conventional” systems, i.e. those used on the national network, should be examined. In many cases, these can be used successfully in the rural environment. Among these systems are:

- low capacity digital radio-relay;
- PCM cable systems (for very short links);
- digital subscriber loop carrier systems;
- remote subscriber multiplex;
- optical fibre (suspended) cable systems;
- single channel subscriber radio terminals;
- subscriber carrier cable systems.

These systems are basically similar, except for their application in the rural environment, to those used in the remainder of the network and no problems of integration arise. Operation and maintenance functions can be centralised at the nearest, or in fact any, primary or secondary exchange and identical facilities to those of the urban subscribers can be offered.

The application of some of these conventional systems is shown in Figure 9.13.

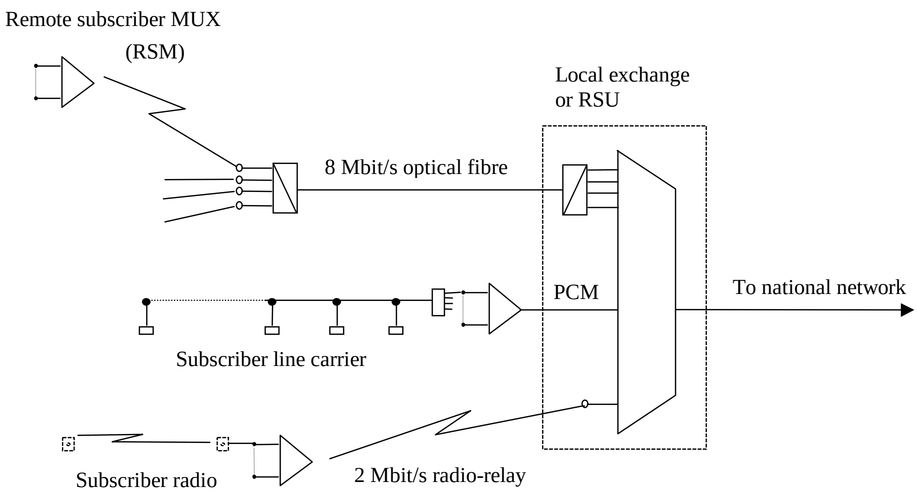


Figure 9.13: Application of conventional systems

It should be noted that optical fibre cable is now a valid choice for rural applications. Dielectric cable which can be suspended over, for example, long spans between power line poles is now available. No regenerators, and therefore no power feeding, are required for considerable distances using single-mode fibre at the low bit rates normally required for rural links.

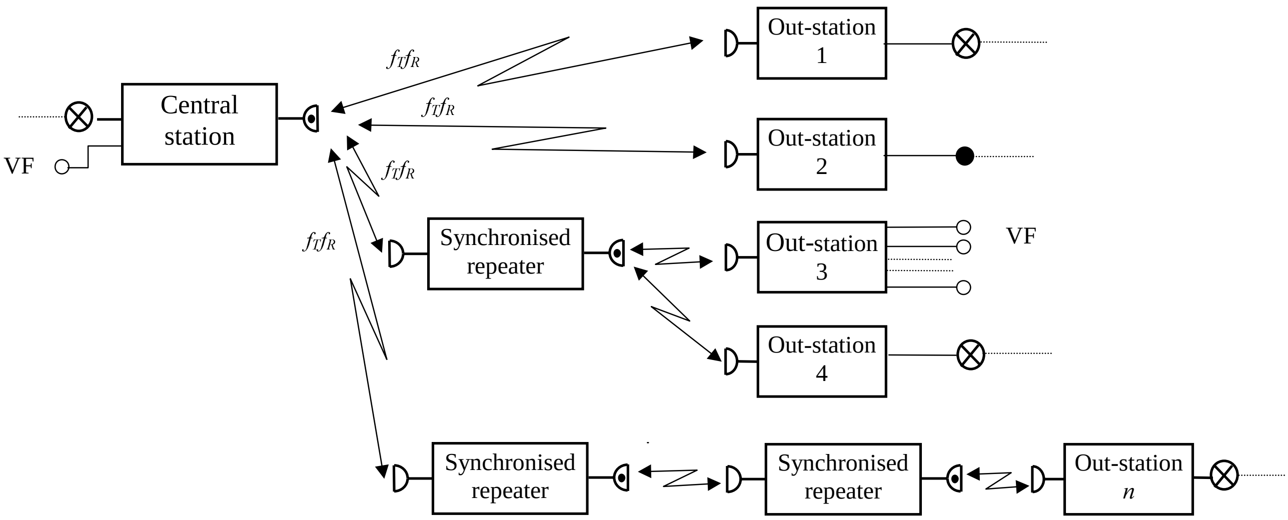
b) Point-to-multipoint radio systems

The specialised systems used to establish rural telecommunications are invariably based on some form of radio technology, the most common of which (at present) is the point-to-multi-point (P-MP) radio system using either frequency division or time division multi-access technique. Obviously, radio access offers clear economic advantages over physical media in difficult terrain with scattered subscriber groups, usually also involving long distances.

P-MP systems allow the common use of channels, either frequency or time-slot allocations, among many subscribers and are therefore radio concentrators. These provide multiple access to subscribers, as already indicated, by the use of multiple frequencies (frequency division multiple access, FDMA) or by the use of multiple time slots (time division multiple access, TDMA). Digital concentrators, which are recommended as discussed later, obviously use TDMA technique. For any type of concentrator, a certain grade of service has to be accepted, this depending on the number of available circuits, the number of subscribers and the originating traffic.

FDMA systems use a central station equipped with a number of radio channels assigned to a greater number of subscribers, each of which is equipped with a single channel radio terminal having access on a demand basis to any of the central radio channels. They are most appropriate for networks having widely scattered single subscribers and can obviously be easily expanded as the number of this type of subscriber increases. They are not suitable for applications in which there are scattered groups of subscribers, for which TDMA systems are used.

A TDMA system consists of a single transmitter/receiver unit at the central station, the transmitted signal consisting of n time-slots, multiplexed in time, and each slot capable of providing a telephone channel. Any subscriber station has access to any of the time slots which are allocated on a time basis by the central station. A typical TDMA configuration is shown in Figure 9.14, the P-MP system being transparent to the rest of the network. A conventional interface allows the central station to be placed at some distance from the interconnection point, to which it is connected by a conventional radio-link or optical fibre cable. This allows the best position (from a radio propagation point of view) to be selected for the base station.



⊗ : equipment interface at hierarchical bit rate

● : equipment interface at required bit rate

VF : voice frequency telephone line interface

$f_T f_R$: transmit and receive carrier frequencies at central station

: wide beam, omnidirectional or multiple antennas

: narrow beam antenna

Figure 9.14: TDMA configuration

The present trend in the type of system shown above is typically represented by digital 60-trunk systems which enable up to 512 subscribers to be served at a GOS of 1.0% assuming a traffic per subscriber of 90 mE. These values are well in excess of those normally accepted for rural systems (50 mE/subscriber, 10% GOS) so that the capacity could be doubled by the provision of an intra-call facility. The number of subscribers per outstation in the above arrangement could be up to 256.

Most of the commercially available TDMA systems use radio frequencies between 1.4 and 2.7 GHz and, for extended systems, frequency planning has to be considered. Reference should be made to CCIR Report 380 (Annex I) which gives examples of the use of frequency pairs in cell arrangements to minimise co-channel and adjacent channel interference. It is important to implement a correct frequency plan at the outset to avoid problems at a later stage. Interference can be reduced by ensuring the use of directional antennas, of as high a gain as possible, at the outstations, facing the central station or intermediate repeater.

As for all systems which share common equipment among the subscribers, and which therefore have low marginal costs for extensions, the cost per line of a TDMA system reduces dramatically as the utilisation increases. The difference can be as much as an order of magnitude between 100% and 20% utilisation - which should be borne in mind when making cost comparisons. Nevertheless, the TDMA system is recommended for providing a service in the rural areas due to its flexibility, as well as its economy at reasonable utilisation levels.

In one of the CCITT, GAS-7 publications (Supplement to the handbook on rural telecommunications, Volume II, Geneva 1989) a cost comparison is made between six methods of transmission and distribution in four typical rural situations:

- Model A (dense population type): an area in which the population density is comparatively high in rural terms and the distances between villages are rather short.
- Model B (Mountainous type): an area in which villages are separated by mountains or hills.
- Model C (in-line type): an area in which villages are scattered along a river or road.
- Model D (dispersed type): a zone of low population density which is spread over a wide area.

These are shown in Figure 9.15 and it is assumed that the central point is also the collection point. The methods compared are as follows:

- TDMA radio systems;
- FDMA radio systems;
- single channel radio;
- PCM cable systems (using new cable);
- digital radio-relay system;
- metallic subscriber lines.

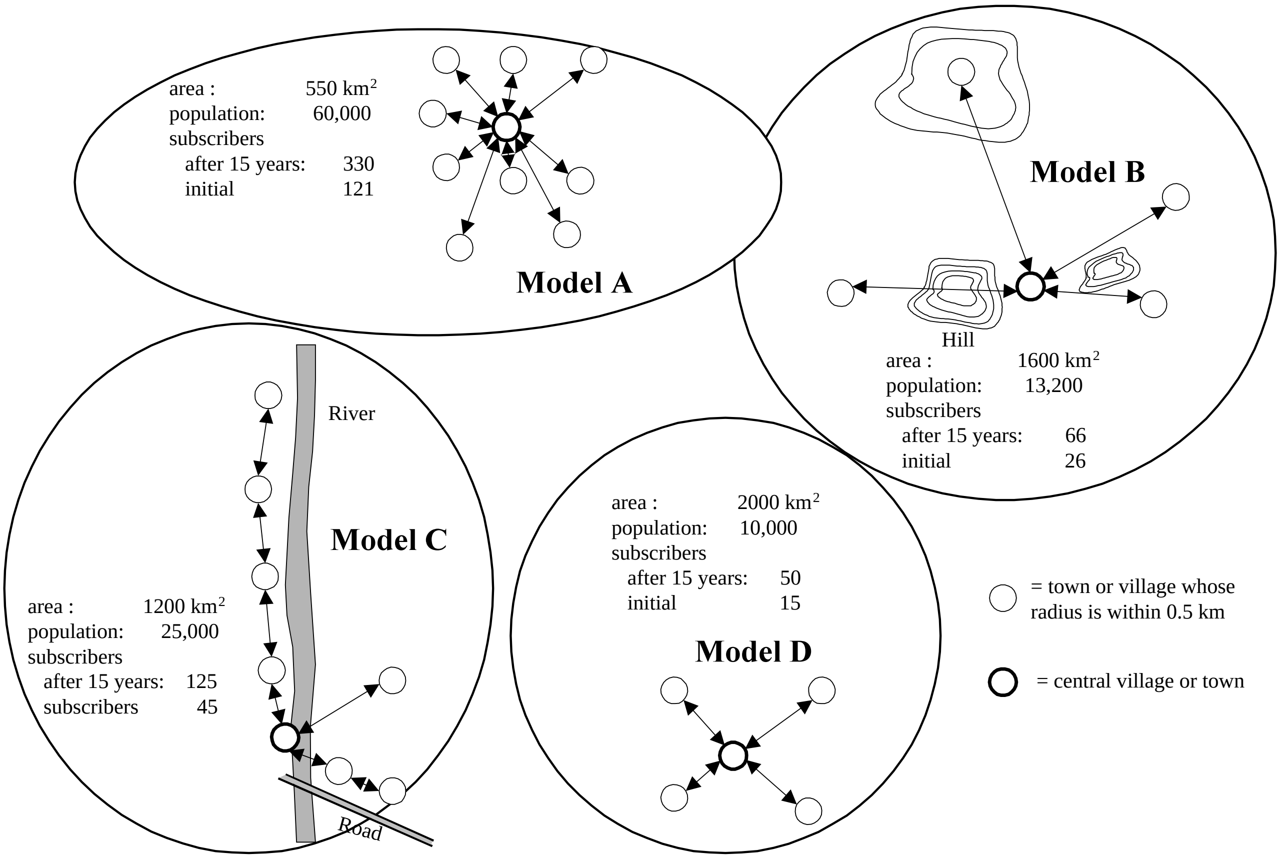


Figure 9.15: Rural area models (four types)

The comparison showed that the TDMA system was the most economical in each case; it was also the most technically superior, as shown in the following table which is reproduced from the GAS-7 manual.

Technical comparison

System: Factor:	PCM cable	Digital microwave system	TDMA radio system	FDMA radio system	Single channel radio	Metallic subscriber line
Possibility of sharing channels between subscriber	No	No	Yes	Yes	No	No
Efficient use of radio spectrum	Not applicable	Fair	Good	Better	Fair	Not applicable
Potential for adding repeaters	Good	Good	Better	Poor	Poor	Poor
Ease of adding subscribers	Good	Good	Better	Fair	Fair	Fair
Ease of adding new remote locations to network	Fair	Fair	Better	Good	Good	Fair
Facility for evolution to ISDN	Better	Better	Good	No	No	Poor
Maintenance considerations (quantity and reliability of hardware, no. of sites)	Good	Good	Good	Fair	Fair	Good

Relative merit lowest to highest is poor, fair, good, better.

It should be noted that fixed cellular radio and possible satellite-based systems are not included in this comparison. These systems are considered in the following paragraphs.

c) Use of cellular type mobile systems

The growth of cellular radio for mobile users has been spectacular over the last decade. Even on a world-wide basis the ratio of mobile subscribers per 100 main lines is almost 4% while in some Scandinavian countries for example the ratio is well over 12%.

It is technically feasible and, in the case of rural development, desirable to adapt cellular radio systems for use as fixed systems and CCIR Recommendation 757 considers this subject in terms of the performance to be expected when these systems form an integral part of national and international connections. Annex I to this Recommendation provides some application notes.

The use of these systems in rural areas is attractive as they are relatively easily established and are obviously less expensive to implement than conventional systems. Two basic approaches are possible:

- to establish a completely new cellular system designed specifically for fixed users;
- to adapt any existing or planned cellular system for fixed, as well as mobile, use.

Both these solutions avoid the principal disadvantage of conventional P-MP systems when applied to widely scattered individual subscribers, which is the fact that these subscribers are, in most cases, intended to be connected by means of physical2-wire lines to their outstation or repeater. In some applications radio access for the subscribers is provided but using DECT techniques - implying the small cell (2 - 3 km diameter) structure and high frequencies (1800 MHz) intended principally for the urban, rather than rural, environment.

For many applications involving the coverage of widely scattered individual subscribers, the first approach mentioned above could prove to be a valid solution. In southern Africa for example many rural areas consist of widely scattered (10 - 20 km spacing) farms with little or no intermediate population. Although these areas could conceivably be covered by a mobile cellular radio network, for example a GSM network, it would be extremely expensive to provide 100% coverage of such a scattered population. It is therefore more practical to establish a fixed cellular network with a large-cell structure using low UHF frequencies and therefore relatively few base stations - located at the nearest local exchange or RSU, or connected by radio relay to these locations. A switching interface unit at the local exchange (i.e. the PSTN access point) effectively carries out a concentrating function by multiplexing the exchange time-slots (1 per rural subscriber) into the time-slots required for the radio base station interfacing (1 per radio channel). Depending on the traffic intensity, concentration factors of up to 10 can be realised on these systems. Processing to enable the rural subscribers to be provided with normal PSTN facilities is carried out at the local exchange switching interface (numbering, charging, etc.). In this application, subscribers could also have limited mobility, i.e. within their cell, as standard analogue cellular radio transceivers would be used.

If the area concerned is already adequately covered by a mobile cellular radio network, the second approach could be used. In this case the fixed terminals obviously have to be adapted to exclude the mobile facilities and include the normal PSTN services and features - in particular the numbering and charging, to facilitate the routing of call. The adapted terminals would therefore consist of a standard telephone set, as used on the national network, connected via a control and interface unit to the type of mobile transceiver used on the particular cellular network. Any unnecessary components are of course removed from the mobile transceiver equipment. This principle can be extended to the provision of multiple terminals, using a concentrator and combiner to a common antenna for access to the cellular network. Such an arrangement could be used to provide the connection of PCOs and 'phone shops' to the PSTN via existing cellular networks.

The adaptation of mobile radio technology to the needs of developing countries, in the urban as well as the rural fields, is considered in CCIR Report 1155 while the Future Public Land Mobile Telecommunication Systems (FPLMTS) which are expected to result from current cellular technology are comprehensively discussed in CCIR Report 1153. A number of developing countries are implementing cellular systems in an effort to solve the rural telecommunication problem and the lack of capacity to expand their urban networks in a reasonable time.

Objectives have been defined in CCIR Report 1153 for FPLMTS among which three features of particular importance for developing countries are identified:

- FPLMTS should be capable of being used for the provision of service to fixed users (rural and urban);
- standardisation of the FPLMTS interfaces, in particular the radio interface, to further reduce the costs and promote the economics of scale;
- flexibility, in terms of, for example, modular systems which can be built up from simple configurations and grow according to requirements.

As mentioned in CCIR Report 1155, further study is required on many aspects of the FPLMTS as adapted for use in fixed networks in the developing countries. These include:

- propagation characteristics;
- interference mechanisms;
- simplification of software and equipment;
- rugged, maintainable equipment;
- use of PABXs, concentrators, etc.;
- use of repeaters for long distance connections;
- performance objectives.

A summary of the requirements of FPLMTS (or other cellular technology) for the fixed service in given in the following table (reproduced from CCIR Report 1155):

Item	Requirement for fixed service
1. Voice encoding - Bit rate - Circuit noise - Voice quality	- FPLMTS should offer performance comparable to that achieved in the fixed network
2. Radio coverage - Repeaters	- FPLMTS architecture should permit the possibility of repeaters, if TDMA is used, repeater design is simplified
3. Design life	15 to 20 years required for permanent fixed service applications.
4. Reliability	MTBF for subscriber stations and base stations should be very high to achieve an acceptable maintenance cost.
5. Environment	Some equipment may be exposed to the outdoor, environment. It will have to withstand rain, snow, dust, sand, corrosion, insects, and a wide temperature and humidity range.
6. Power consumption	As low as possible for solar and other sources.
7. Antennas	Directional at subscriber stations (in some cases base stations) for optimised radio path design using both vertical and horizontal polarisation.

Note - It is important that items 1 and 2 above be taken into account in the basic design of the FPLMTS. Some of the areas where the fixed service application requires special design are listed in items 3 through 7.

d) Use of satellite systems

Satellite systems are well established as an efficient, sometimes the only, means of connecting remote communities into the national network. In addition to the transponders provided by the international satellite organisations INTELSAT, several regional satellites are in operation for this purpose, as well as for normal international communication.

The obvious advantages of satellite systems, which in the case of rural areas provide both the transfer and trunking functions shown in Figure 9.12, include:

- wide area coverage;
- costs which are independent of distance;
- ease of connection to otherwise inaccessible locations;
- ability to provide television service to these locations for re-broadcast.

These systems, all using satellites in the geostationary orbit over one of the Atlantic, Indian or Pacific Ocean regions are effectively, in the case of narrow-band services, thin route point-to-multipoint transmission systems using either multi- or single channel per carrier (SCPC) techniques with various modulation systems. As already mentioned it is relatively easy to provide a television service; in the case of "receive only" (TVRO) using small antenna systems and simple equipment but, for more acceptable picture quality, larger 97 - 8 m) antenna diameters are required for reception from INTELSAT transponders.

Reference should be made to the CCIR Handbook on Satellite Communication (Fixed Satellite Service), Geneva 1988, in particular Supplement N° 3 (1994) which considers VSAT systems, as well as the comprehensive documentation provided by INTELSAT and other satellite operators for fuller information on the application of fixed satellite systems for rural applications.

The satellite systems which are most likely to affect rural (as well as national and international mobile) services in the future are those using multiple satellites in low orbits. The so-called low earth orbit (LEO) satellite concept is intended to provide a worldwide mobile radio network which can enable handheld terminals to be used with minimum changes to the fixed network. Their application to rural systems is likely to be inhibited by the high tariffs expected.

Geostationary satellites are less practical for this purpose (high path losses, transmission delay, etc.) so that inclined orbits providing high elevation paths, of about 50°, at a relatively low altitude (below the Van Allen belts) are chosen.

At least two such systems are now under development, one using 66 satellites at an altitude of 780 km (Iridium consortium) and the other 48 satellites at an altitude of 1 389 km (750 nautical miles, GLOBALSTAR). The INMARSAT organisation is also intending to introduce a similar system at the end of the decade, but using a relatively high orbit with fewer satellites.

It is intended that these systems will be complementary to, and should not compete with, existing terrestrial services. This remains to be seen, as some formidable political and regulatory problems have yet to be overcome. The concept of this type of system is considered in the World Telecommunication Development Report (Geneva, 1994) to which reference should be made.

9.5.5 Case of densely populated rural areas

As mentioned in § 9.5.1, there is an exception to the general concept of a rural area as being sparsely populated, isolated, etc. This is the undeveloped, highly populated rural area typical of some parts of the Asia Pacific region. For economic and other reasons the telephone penetration in these areas is either extremely low or non-existent. For the same reasons the full integration of these areas into the national telecommunication network and the provision of individual telephone / telefax lines is likely to be an extremely long-term process. In the meantime a start can be made to meet the demand for basic telephone service by the provision of public call offices (PCO), initially distributed according to subjective observations of demand if necessary but preferably strategically sited as the result of the comprehensive surveys recommended in § 9.5.2.

One possibility for extended areas would be to establish a virtual network of PCOs in a fixed UHF cellular radio configuration, radio access being obviously more secure (and economical) than the conventional wired access. The network could eventually be expanded to incorporate conventional business and residential subscribers when justified by the demand. Such a network would have to be designed to accommodate the characteristics peculiar to PCOs; these include very high traffic per line, an imbalance in the traffic pattern (much more outgoing than incoming calls) and various charging methods which could be applied.

The single PCO concept can be extended to the so-called 'phone shop', as briefly discussed in § 8.6.4, and the introduction of, for example, telefax or even IT facilities at these communal centres.

It is also interesting to recall that several studies in Africa and Asia have shown that the rural PCO is actually significantly more profitable, in terms of line revenue, than individual business and residential lines. In fact residential lines have been shown to be hardly profitable in low density rural areas. They would therefore, on this basis, be loss making if residential usage were extended (less traffic per line).

9.6 Policy for non-voice and other specialised networks

Traditionally, a distinction has always been made between **voice** and **non-voice networks**. The telephone network is still predominant as far as the number of users is concerned, but a separate network for telex was inaugurated many years ago using exchanges based on telephone switching technology so that, until comparatively recently, two networks, one voice and one non-voice, co-existed. With the advent of data communications, transmission was initially over the telephone network using data modems or over specially leased lines. Separate data networks as we know them today were introduced when the telephone line facilities became inadequate.

The concept of **voice** and **non-voice** networks, is for various reasons now obsolete. It is preferable to focus on:

- The number and location of different kinds of **end users** ("subscriber forecast");
- The various **services** these users need to utilise;
- The **usage** of these services ("traffic forecast").

Services may be of many different kinds. An example of a service that may be quite common in the future is the **LAN interconnect**, i.e. a data bearer service, often using a transmission rate of 2 Mbit/s but sometimes higher speeds. Another interesting class of services is **Multimedia** applications, i.e. both voice and non-voice in the same connection.

9.6.1 Services and applications

Identification of services that may be of interest to the customers of a network is an important step in the demand forecasting process. While some services will be unique for specific networks, other services may well be common to several or all networks. Some services that are already being provided or are actively considered are structured in the following categories:

- Office Communications;
- Teleconferencing;
- Computer-to-Computer Communications;
- Terminal-to-Computer Communications;
- Residential Applications;
- Encrypted Voice Communications.

9.6.2 Office communications

Office communications refers to computer applications and digital communications that intend to increase the efficiency of running an office. Typical applications are:

a) **Electronic Mail**: This is a class of text-oriented message transmission services. The communications may be person-to-person or from one person to many persons. The message text is created at a terminal or computer, stored, sent, routed, and received electronically. Typically, a subscriber would create a message file with an electronic address and submit it to the electronic mail system from a terminal. A communication computer would then send the file to the appropriate computer, at possibly a different location, so the addressed subscriber would receive the message file during a subsequent log-on session.

b) **Communicating Word Processors**: This is text processing with text transfer between processors via communication interfaces. It is different from electronic mail in that it is document-oriented rather than text-oriented.

c) **Integrated Work Stations**: These are personal terminals capable of voice, data, graphics, and video communications, as well as stand-alone processing.

d) **Electronic Filing Systems**: Systems used to file and retrieve documents electronically from a centralised documents data base.

e) **Slow Facsimile**: Transmission of images between facsimile terminals over analogue voice lines.

f) **Fast Facsimile**: CCITT Group 4 digital facsimile of 56 or 64 kbit/s.

9.6.3 Teleconferencing

This can be broadly defined as real-time communications between two or more persons in two or more locations, with the following sub-divisions:

a) **Audio-Graphics Teleconferencing**: Voice transmission augmented by some kind of graphics capability such as facsimile or electronic blackboard.

b) **Freeze-Frame Video Teleconferencing**: Another name is **Slow Scan Video**, which transmits either a fixed visual image every few seconds or else a continuos image with delay, to augment the voice service. Typical transmission rates are 56 or 64 kbit/s.

c) **Full Motion Video Teleconferencing**: Full voice and video capabilities for teleconferencing. The required bit rate is high, but may be reduced by compression techniques.

d) **Videophone Services**: Moving colour pictures added to the voice service. It may be provided in N-ISDN at 64 kbit/s, and with higher quality in B-ISDN at higher speeds.

9.6.4 Computer-to-computer communications

This involves bulk data transfers between computers, with speeds from a few kbit/s up to many Mbit/s. The service is often a very “bursty” one. Batch processing is also an application.

9.6.5 Terminal-to-computer communications

This refers to communications between a human-operated terminal and a computer. The user data flow rate is relatively slow, so the transmission is characterised by short bursts of information with long silent periods in between.

a) **High Speed and Low Speed Data Entry**: This refers to sending data from a keyboard to a remote computer. Interactive processing is not involved. We distinguish between lower-speed and higher-speed terminals.

b) **Remote Job Entry**: Data processing on a central computer with job entry and output retrieval functions at remote terminal or printer locations. Medium or high speed links are required.

c) **Inquiry/Response**: Information is requested from a central data base via a remote terminal. The amount of data processing is limited. Many business applications of **Videotex** would fall into this category.

d) **Timesharing**: Interactive computing where the user edits and moves data files, execute programmes, etc., on line, from a distant location.

e) **Electronic Funds Transfer**: Electronic banking functions, credit card verification etc. It is an inquiry/response type of application with small amounts of information transmitted in both directions.

9.6.6 Residential applications

Residential users are more price sensitive than business ones, and the driving forces behind the demand are not the same. Therefore, residential applications grow at a slower rate than business ones at first, but the growth may accelerate later, when the costs have come down, and when people feel more familiar with the new services.

a) **Home Information Services**: Videotex-type services via a keyboard and a screen, e.g. the TV-screen.

b) **Residential Computing**: Communicating home computers, portable terminals used for work at home, and other home services requiring computer communications.

c) **Remote Appliances Control**: Control of home appliances through telephone connections.

d) **Security**: Systems designed to detect illegal entray into a residence, and which notify law enforcement agencies if break-in occurs. Fire alarm is another application.

e) **Remote Meter Reading**: Automatic periodic reading of meters for water, electricity etc.

9.6.7 Encrypted voice communications

Traditionally, this is an application used by military and governmental organisations. With the increasing rate of industrial espionage with the help of computers, encryption becomes more and more used also in business enterprises.

9.6.8 Market segmentation

Market segmentation is a necessary first step in the forecast process for telecommunication services. For telephony, segmentation is made only in form of a division into **residential** and **non-residential lines**, for example:

- Residential lines
- Single non-residential lines
- PBX lines
- Coin box lines
- Special service lines

This division is due to the use of in principle only one type of service provided by a circuit switched network, and reflects only two aspects: the different growth rates and the different degree of usage of the service.

For non-voice and multimedia services and also for packetised speech, such a segmentation is not sufficient. The segmentation process should be sensitive to the market, the types of services, and the marketing time frame, as well as to the provider's objectives. Since segmentation aids the process of determining the users' access, transport and feature needs, segments should be broad enough to allow the forecaster flexibility, yet narrow enough to render a clear picture of the market, the users' needs and general market trends.

Users may be categorised into segments with respect to the volume of transport needs, engineering sophistication, existing and future telecommunication applications, income level, annual telecommunication expenditure, number of employees, existing use of computers, etc. An example of such a segmentation is as follows:

- Very large businesses;
- Large businesses;
- Medium businesses;
- Small businesses;
- Residences;
- Government and Military establishments;
- International businesses;
- Universities and technical organisations;
- Other official and community organisations.

9.6.9 Mapping of services to market segments

The next step is to map services on to specific market segments. An example of such a mapping is given in Table 9.1 below:

Application	Very large business	Large business	Medium business	Small business	Residence
Electronic mail	x	x	x	x	x
Communicating word processors	x	x			
Work stations	x	x			
Electronic filing	x	x			
Fast facsimile	x	x			
Slow facsimile			x		
Computer-to-computer	x	x			
Communicating minis		x	x		
Batch		x	x		
Low-speed data entry			x	x	
High-speed data entry	x	x	x		
Remote job entry		x	x	x	x
Inquiry / Response	x	x	x	x	x
Timeshare	x	x	x	x	x
Audio / Graphics teleconferencing	x	x	x		
Freeze frame teleconferencing	x	x			
Full motion teleconferencing	x				
etc.					

Table 9.1 : Example of mapping of services onto market segments

9.6.10 Locations

Very large businesses are not always geographically concentrated in one location. They may be divided among several locations in a city or in the whole country. In that case, there will be a communication need not only between each location and other customers, but also between locations, i.e. within the organisation. This latter communication need will often be of the type **LAN interconnect**. It is essential that the network operator estimates this division into locations as well as possible.

9.6.11 Estimation of the demand for a particular location

Table 9.2 shows an example of how the non-voice traffic from and to a hypothetical location may be specified. Note the fractional values for the number of devices **d**. They result from the fact that not every location may have a particular type of device. For this particular location, **R**, the maximum access capacity required when all devices are active at the same time is 10.44 kbit/s. The average access capacity, $\overline{R}$ **,** required in the busy hour is 4.48 kbit/s, and the total actual user data transmitted in the busy hour, **B**, is 1599.9 kbit/s. If no traffic concentration is provided at such a location, it will need the 10.44 kbit/s of access capacity, and 4.48 kbit/s of average access capacity. If concentration is provided, however, it may be possible to get a good service with one 9.6 kbit/s access line for data.

Service(s)	No. of devices **d**	Transmis-sion rate (Kbit/s) **r**	BH holding time (sec) **h**	BH information (Kb) **b**	**r·d**	$\frac{r \cdot d \cdot h}{3600}$	**d·b**
Electronic mail	0.4	1.200	300	80	0.48	0.04	32.0
Comm. Word Proc.	0.2	9.600	600	432	1.92	0.32	86.4
Integrated work station	0.4	1.200	1800	55	0.48	0.24	22.0
Low speed data entry	0.8	1.200	3000	145	0.96	0.80	116.0
Remote job entry	0.4	9.600	1800	2850	3.84	1.92	1140.0
Inquiry response	1	1.200	3000	180	1.20	1.00	180.0
Timesharing	0.5	1.200	600	15	0.60	0.10	7.5
Electronic funds transfer	0.8	1.200	240	20	0.96	0.06	16.0
Totals	4.5				$R_{ij} = 10.44$ kbit/s	$\overline{R}_{ij} = 4.48$ kbit/s	$B_{ij} = 1599.9$ kbit/s

Table 9.2: Demand analysis for a hypothetical location

Once the service needs are identified, network scenarios should be prepared. The present trend is that dedicated networks are designed, but we must expect many of these networks to be integrated in the future, via N-ISDN or via B-ISDN.

9.7 Introduction of cellular radio systems

The two concepts of mobility, as regards telecommunication users, have been mentioned in Chapter 4 of this document. This section considers only the concept of terminal mobility as offered to subscribers by cellular and other mobile radio systems, but excluding aeronautical and maritime systems.

Over the last decade, the growth of this type of mobile telecommunication, in particular of analogue cellular radio systems, has been such that it is likely to become a serious competitor, or at least a viable alternative, to the fixed service over the next decade.

According to the World Telecommunication Development Report (ITU, Geneva, 1994), the penetration of mobile subscribers in 1992 was according to the following table (reproduced from that report):

Mobile subscribers, per 100 inhabitants and per 100 main lines, 1992

Leading countries	*Mobile subscribers*	*Per 100 inhabitants*	*Leading countries*	*Mobile subscribers*	*Per 100 main lines*
Sweden	656'000	7.56	Thailand	248'720	13.89
Finland	354'200	6.85	Finland	354'200	12.59
Norway	280'000	6.53	Norway	280'000	12.34
Iceland	15'250	5.78	Sweden	656'000	11.08
USA	11'033'000	4.33	Singapore	120'000	10.90
Hong Kong	233'300	4.02	Iceland	15'250	10.89
Denmark	206'450	3.99	Brunei	4'100	10.48
Canada	1'022'800	3.73	United Arab Emirates	48'860	9.04
Switzerland	220'650	3.23	Bahrain	9'680	8.60
Singapore	120'000	2.96	Hong Kong	233'300	8.27
Regions			*Regions*		
Africa	33'200	0.005	Africa	33'200	0.33
Americas	12'600'600	1.69	Americas	12'600'600	6.52
Asia	3'330'600	1.05	Asia	3'330'600	2.73
Europe	5'897'400	1.06	Europe	5'897'400	2.97
Oceania	541'500	1.98	Oceania	541'500	5.40
Ex-USSR	13'600	0.005	Ex-USSR	13'600	0.033
World	**22'416'900**	**0.41**	**World**	**22'416'900**	**3.90**

Based on year end 1992 data or most recent.
ITU/BDT Telecommunication Indicator Database.

In the above table, two indicators are used:

- mobile subscribers per 100 population, which is equivalent to subscriber density in the fixed network;
- mobile subscribers per 100 main lines, which could be taken as an indication of the degree of substitution in the network.

The first indicator identifies networks which are highly developed and are located in countries having a prosperous economy. These countries include the United States and the Scandinavian countries which were the first to use cellular systems on a large scale, Sweden for example, now having the highest mobile penetration on a population basis. The leading countries using the second indicator, somewhat unexpectedly, include Thailand, which is classified as a developing country with a fixed network which is hardly highly developed. This, in fact, is the reason for the high proportion, almost 14% of mobile subscribers; the waiting list is so long that subscribers are willing to pay a substantial premium for a mobile connection, as a means of by-passing the provision of a conventional line. At the current rate of growth, the number of mobile subscribers could exceed the number of fixed network subscribers by the end of the decade. Apart from the Scandinavian countries, which also appear in the list using the second indicator, for obvious reasons, the remaining countries have high-income economies and the subscribers can well afford the mobility.

The substitution aspect, i.e. the use of radio access (cellular systems) as a viable alternative when conventional lines are unobtainable, has already been considered in the sections on local networks (paragraph 9.2) and rural networks (paragraph 9.5). This principle is already being applied in several countries, which are now experiencing a spectacular growth in mobile subscriber and total line penetration- admittedly from a rather low initial rate.

At present, the majority of cellular radio systems in service use analogue technology, the principal types being NMT (Nordic Mobile Telephone), TACS (Total Access Communications System) and AMPS (American Mobile Phone System). These systems were originally developed to meet the needs of road users, the mobile equipment being invariably installed in vehicles, with therefore few restrictions on weight and power consumption. The high transmitter power allowed the use of large cells with good coverage. The huge demand forced the operators to the use of smaller and smaller cells, new frequency bands, etc., to accommodate the resulting hand-held portables which are now a common sight on the streets. The principles of these analogue systems are considered later.

To meet even further demand, digital systems are now being introduced; GSM (formerly the acronym for Groupe Spécial mobile of CEPT, but now the initials of Global System for Mobile Communications), ADC (American Digital Cellular) and a Japanese system. All are designed for international operation and are described in CCIR Report 1156, "Digital Cellular Public Land Mobile Telecommunication Systems" (DCPLMTS).

9.7.1 Analogue cellular radio systems

Before the structure of a typical cellular network is discussed, it is useful to recall the basic requirements of a mobile service. The most fundamental of these requirements is that the service, as far as the subscribers are concerned, should appear to be identical to that of the fixed network with which it is to be integrated. This implies that the mobile service should be completely automatic, i.e. no special procedures should be involved in the setting-up and charging of calls, and it must be possible to set up the calls automatically between any two subscribers of the integrated network, whether fixed or mobile. Finally, the introduction of the mobile system should not result in any significant modification to the existing network. The technical solutions which enable these requirements to the realised are incorporated in the analogue cellular radio systems now in service in most parts of the world. The arrangement of a typical mobile network is shown in Figure 9.16.

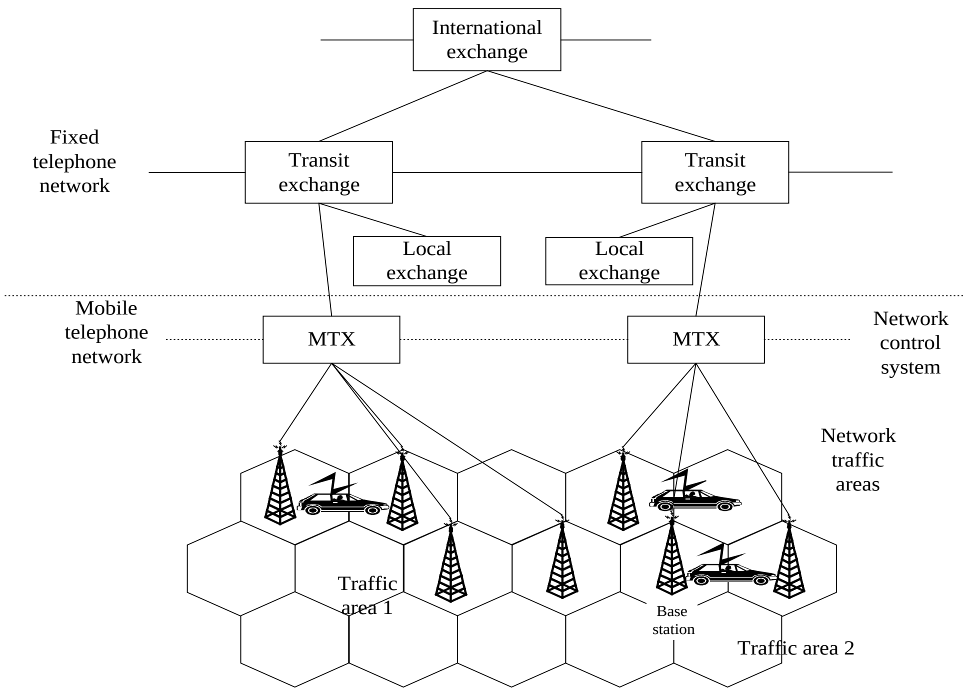


Figure 9.16: Arrangement of typical mobile network

It is seen that the system consists of four basic components:

- mobile telephone exchanges (MTX);
- radio base stations;
- transmission links between MTXs and base stations;
- mobile stations.

The MTX controls all call processing, charging, maintenance and other network management functions, and thus determines the overall performance and the ease, or otherwise, of integrating the system into the national network. The features of the MTX should therefore include all those normally found in modern digital SPC systems together with those specifically required for switching calls in progress (automatic transfer from one cell to the next) and an automatic subscriber tracing facility.

Connections between the MTX and the base stations are by means of conventional digital transmission systems, the capacity of which depends on the number of radio channels equipped at each base station. Each MTX is either co-sited with, or connected to, a transit exchange of the national network and controls a traffic area.

A cellular structure, as indicated by the hexagonal areas shown in Figure 9.16, is used to provide the required radio coverage. At the centre of each cell is a base station equipped with a number of radio channels determined by the required system capacity. A practical limit on the number of radio channels available is imposed by the frequency band and channel spacing used, for example in the earlier 450 MHz, 25 kHz spacing, systems the maximum number of radio channels is 180. Using the 900 MHz band with a similar spacing, 1000 channels are available. In the Nordic analogue system, a spacing of 12.5 kHz is now used to provide almost 2000 channels. The number of cells, and therefore base stations, is obviously determined by the coverage required but, above all, by the terrain. In rural and other thinly populated areas, a large-cell structure can be used, whereas in urban and city areas the cells have to be much smaller - down to less than 500m radius, for example, in some metropolitan areas - and frequency re-use becomes a major problem. The assignment of frequencies, in the range up to about 1000 MHz, to this type of system is considered in CCIR Report 319.

9.7.2 Digital cellular radio systems

As already mentioned, digital mobile systems are now being introduced in response to the demand for increased capacity and an improvement in spectrum utilisation efficiency.

In CCIR Report 1156, these systems are known as Digital Cellular Public Land Mobile Telecommunication Systems (DCPLMTS), three basically similar systems being described in the Report:

- GSM, the Pan-European system;
- ADC, the North American System;
- the system developed in Japan.

Certain features of the DCPLMTS are common to those of the existing analogue systems including the radio frequency band used (800-1000 MHz), the frequency re-use characteristics, outage design objectives, numbering plan, roaming techniques and charging methods.

The advantages, and some disadvantages, resulting from the use of digital techniques are summarised as follows:

a) Digital radio modems

These make more efficient use of the radio spectrum and permit operation at much lower carrier to interference (C/I) ratios than are possible with analogue systems. Thus, the new digital systems can accommodate a wide range of cell sizes according to particular local traffic conditions and enable the implementation of better frequency re-use patterns. Digital modulation also offers better compatibility with ISDN-type networks.

b) Time division multiple access (TDMA)

The use of TDMA results in significant improvements in signalling capability; a mobile station can exchange control signals with its base station without interruption of the speech transmission. The mobile station can also compare the signal level from adjacent cells by momentarily switching to a new time-slot (corresponding to a radio channel). This enables the mobile station to participate in the handover operation, thus improving the service continuity in response to movement or fading conditions. Further spectrum efficiency can be realised by the use of dynamic channel assignment and power control which are made possible by the availability of signal strength information at each end of the link.

With a TDMA system, the cost and bulk of the base stations are reduced as the equipment is common to several radio channels.

A further advantage of TDMA is an improvement in system flexibility; different voice and non-voice services can be assigned a number of time-slots appropriate to the services; for example, with more efficient speech codecs available, increased capacity can be obtained by the assignment of a reduced number of time slots for voice traffic. Further improvements in capacity could be obtained by the introduction of digital speech interpretation (DSI), for example.

c) Digital speech coding

This coding provides for an increase in capacity by means of half-rate codecs when they become available. It also allows effective error detection and correction techniques to be used, thus contributing to improved speech quality and operation at poor C/I ratios.

d) Channel coding and digital signal processing

In cellular systems, spectral efficiency is enhanced by effective digital error control and signal processing techniques. The error control allows operation in hostile radio interference and noise environments while digital signal processing enables adaptive equalisation to be applied to compensate for amplitude dispersion across the radio channel band, as well as enabling the use of diversity, frequency hopping and interleaving techniques to counteract fading.

e) Digital control and data channels

These are the key to the flexibility of digital cellular systems, as well as to the introduction of new services. The digital control channel provides the means for the introduction of network services such as simultaneous voice/data communications and message services, as well as facilitating the introduction of ISDN-type (narrow band) services to the mobile network.

f) Privacy and authentication facilities

These are ensured by the combination of digital encoding of the speech and the digital control channels, the speech being easily protected by means of digital privacy coding algorithms. The control channel enables the correct distribution of the privacy keys and also provides the route for other system facilities, such as the home location register (HLR) and the authentication of the mobile users. The latter ensures the accuracy of the billing information and facilitates the "roaming" of subscribers over a wide geographic area and also between networks.

Some disadvantages, due to the use of the above digital techniques, have to be recognised:

- a significant time delay in the speech path due to the use of TDMA could necessitate attention to echo control when 2-wire connections to the PSTN and other networks are made;
- there could be a requirement for time synchronisation in dispersive radio channels, in particular for wide bandwidths;
- there is a requirement for a higher peak to average power ratio in the transmitters, which has to be taken into account when quoting battery life and estimating radiation effects.

The basic arrangement of a digital cellular radio system is shown in Figure 9.17, giving the major functional components. The GSM arrangement is identical to this and is described in CCIR Report 1156. Specifications for the GSM system are given in the documents of the European Telecommunications Standards Institute, (ETSI) Paris.

In Figure 9.17, the interfaces between the mobile switching centres and the national fixed networks are all according to CCITT Recommendations, as is the numbering plan.

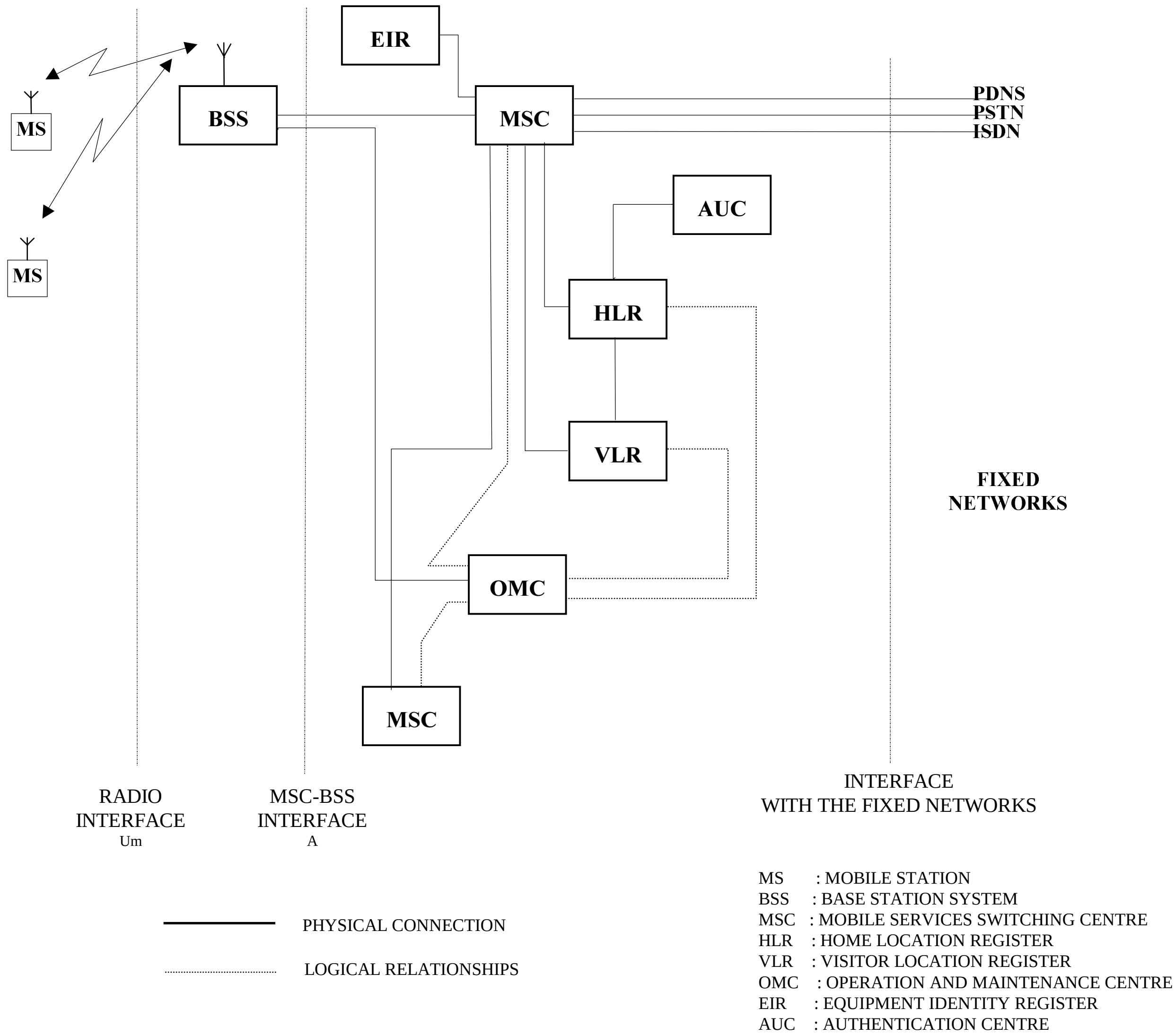


Figure 9.17: Basic arrangement of digital cellular radio system

9.7.3 Future systems

Future mobile systems are based on the concept of the personal communication network (PCN) in which it is theoretically possible for all subscribers to be equipped with a small hand-held terminal capable of being connected to any other subscriber, irrespective of location. The Universal Mobile Telecommunication System (UMTS) project being studied by RACE (Research and Development in Advanced Communications in Europe) is an example. This aims to define a common interface standard to support both “cordless” and cellular operation from a single handset. The target is to offer global mobility.

PCN, as launched in the United Kingdom (in a further effort to stimulate competition), envisages the use of small hand-held terminals, micro-cell arrangement, new and simplified handover algorithms and the use of the 1.8 - 2.3 GHz frequency band. It is to be based, in general, on GSM principles and technology.

The CCIR considers the Future Public Land Mobile Telecommunication Systems (FPLMTS)[3] in its comprehensive Report No. 1153 and in Recommendation 687 to which reference should be made These documents include 19 primary objectives and 10 secondary objectives which include provision for unique user identification (Personal Telecommunication Number, PTN) and interworking with mobile satellite systems when required. The arrangements for the terrestrial and satellite components proposed for the FPLMTS are shown in Figures 9.18 and 9.19, respectively.

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[3] The proposed new name for these systems is “International Mobile Telecommunications - 2000” (IMT-2000), to reflect the fact that the studies are intended to develop systems which could be in service in the year 2000 - and will operate in a frequency band near 2000 MHz.

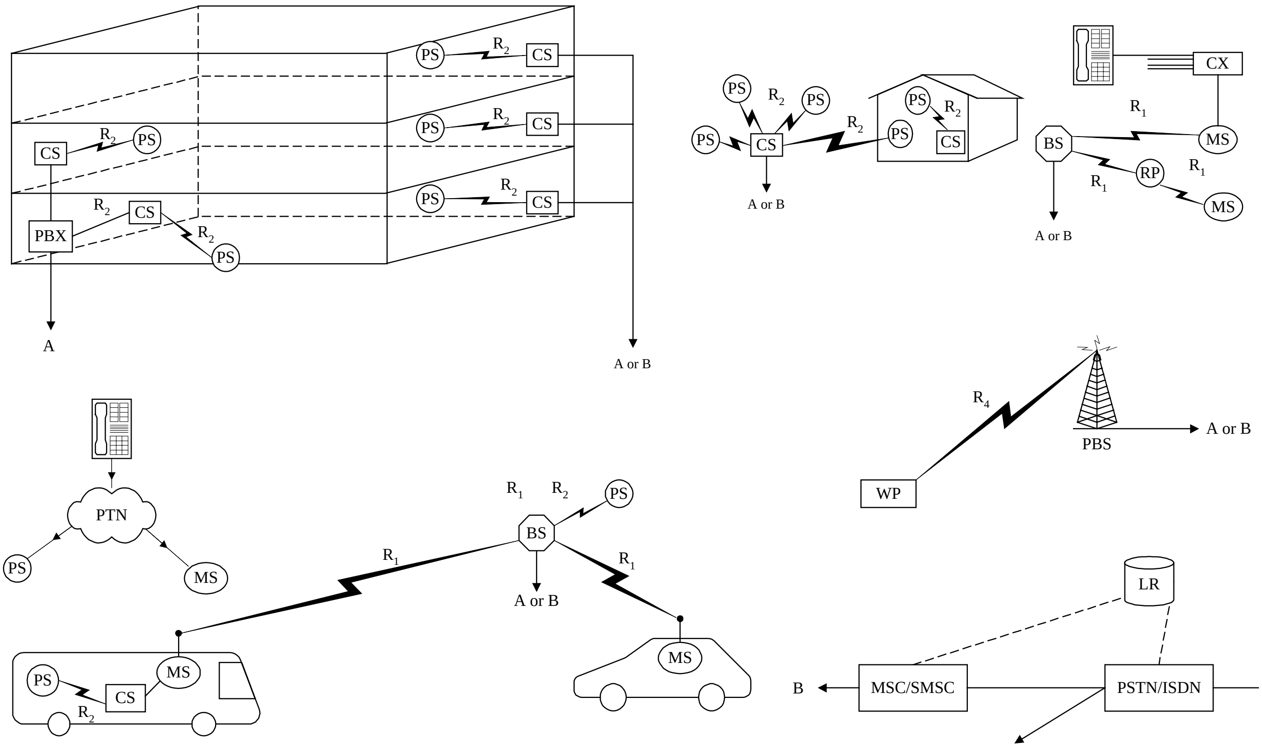

Figure 9.18: Scenario for personal communications with FPLMTS (terrestrial component)

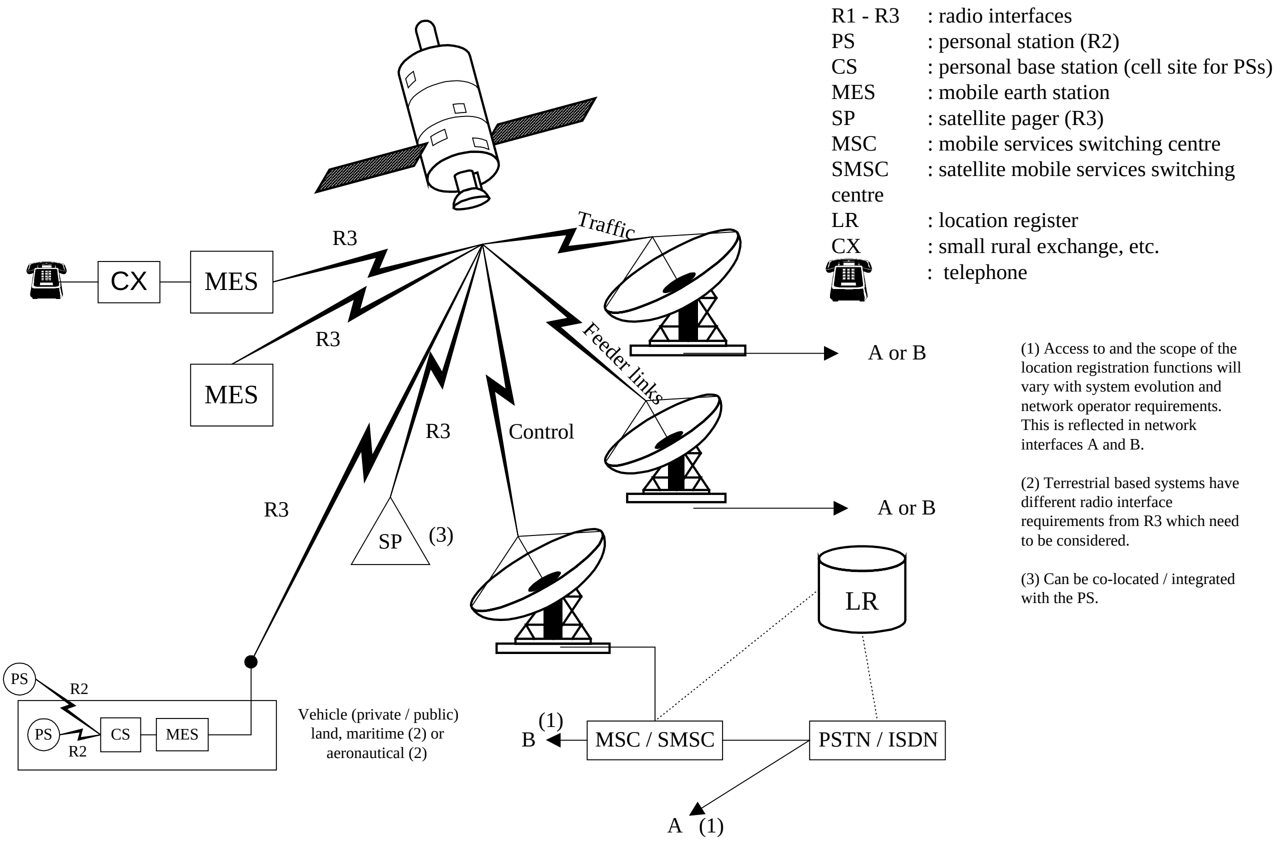

Figure 9.19: Scenario for personal communications with FPLMTS (satellite component)

There remains the low earth orbit (LEO) satellite system briefly considered in Section 9.5. This type of system is intended to be complementary to the existing terrestrial systems, in that it could be used as a gap-filling measure to provide service to remote areas not at present covered or to areas where a terrestrial cellular system would not be practicable (or profitable). Obviously, world-wide roaming facilities could, in theory, be offered once the many formidable technical, economic and political obstacles could be overcome. In the case of developing countries there is an obvious danger that the satellite system could by-pass the national networks. If a country does not have a national mobile network in place, it could be in the invidious position of having one provided for it by an external agency. Obviously, with little regulatory control, the revenues would be much less than those which could be derived from a nationally provided service.

9.7.4 Other mobile systems

In addition to cellular systems interconnected with the PSTN, private, closed networks known variously as private mobile radio, trunked radio systems and multi-channel despatch systems are in use in many countries. Most of these systems are not connected to the PSTN and are operated by police, transport companies, taxi companies, etc. i.e. closed groups of users. Recent developments will result in digital versions of the systems becoming available shortly. These will use TDMA technique. ETSI is preparing the technical standard known as TETRA (Trans European Trunked Radio).

The traffic characteristics and design of these systems are considered in CCIR Report 741 to which reference should be made.

9.7.5 Implementation policy

As the mobile subscriber density increases and the network is extended, more and more base stations are required with the cells becoming smaller in the densely populated areas. Although the cost of base stations can be reduced by transferring a certain amount of the “intelligence” to the handsets, there is still a significant expenditure required for the sites and infrastructure. It is therefore essential that the initial base stations are located with some accuracy and that the subsequent expansion is carried out in a logical manner to take account of frequency repetition patterns, for example. The coverage of a mobile system is determined not only by the number of cells but above all by the terrain over which the base stations are operated. Thus, it is at least desirable, if not essential, that the base station locations and their coverage areas are determined by propagation surveys. This is a time consuming operation, but is preferable to the expense of modifying antenna systems and heights, and possibly the entire network configuration at a later date.

Outside built-up areas, the traditional planning methods using standard attenuation curves and allowing conservative protection ratios could, in some cases, prove sufficient to provide an idea of the antenna heights, transmitter power, etc., required for the base stations. However, in urban areas these methods are of little use due to the effects of the terrain, in particular high buildings. In this case, only propagation measurements are likely to yield reliable results.

This work is often outside the capability and immediate financial resources of many national Administrations, and it is now common practice to contract it out to the system suppliers, who may in fact be the eventual network operators, by means of a concession or other agreement with the Administration. In most countries in which cellular networks have been introduced a competitive environment has been established at the initial stage with more than one private company being licensed to supply and operate the systems. Considering the specialised expertise and the not inconsiderable financial outlay involved, this would appear to be the preferred method of introducing cellular radio networks in developing countries. Needless to say, to ensure its efficient planning and implementation, as well as to obtain the most advantageous financial terms for the Administration, it is essential to engage independent consultants to supervise all stages of the operation.

Reliable demand forecasts are notoriously difficult to make, especially for mobile subscribers; for example, the forecasts made for the original Nordic network were exceeded long before the end of the planning period for which they were to be valid. Nevertheless, a demand forecast has to be made for mobile as well as for fixed networks for obvious reasons. In the usual case for which no past data are available, the only method available is the market survey which, for the typical private enterprise supplier(s) is best carried out by him in collaboration with the Administration.

The resulting traffic forecasts must take into account the effects on the traffic patterns of the national and international networks to which the mobile subscribers are connected.

Obviously, if there is no existing cellular network a digital system should be implemented with specifications according to the GSM (or similar) standard. Provision should be made for the connection of fixed subscribers to the mobile network according to CCIR Recommendation 757. The market survey on which the demand forecast is based should include questions on this subject.

As far as switching and fixed transmission equipment are concerned, it is clearly desirable that they conform with the existing equipment on the fixed network as regards type, manufacturer and technical specifications. It is particularly essential that the digital switching equipment to be incorporated in the future integrated network has provision to handle GSM, as well as any other new services envisaged.

9.8 Note on maritime radiocommunication services

A guide for the preparation of master plans for maritime radiocommunications was published by the ITU in 1991 and is available to all Administrations. In addition, the subject has been discussed at numerous seminars and regional conferences.

It is recognised that, in most developing countries, there is a need to improve these services in order to stimulate shipping activities and improve trade. In particular, improvements are needed in the services for safety, ship operations, port operations and public correspondence for passengers and crews. Assistance is needed by most developing countries to implement the Global Maritime Distress and Safety System (GMDSS) within the time schedule (ending in February 1999) established by the International Convention for the Safety of Life at Sea (SOLAS).

The development of maritime radiocommunication services, including the above aspects, is now the subject of Programme 4 of the Buenos Aires Action Plan as a result of which it is expected that, after 5 years, each concerned country will :

- have a master plan outlining immediate remedial actions which can be taken, in addition to short, medium and long-term plans for the development of maritime radiocommunication services, including the implementation of GMDSS, either submitted for financing or under implementation;

- have staff trained in the preparation of the master plan and capable of supervising its implementation.

In some countries the plans will have been implemented by this time.