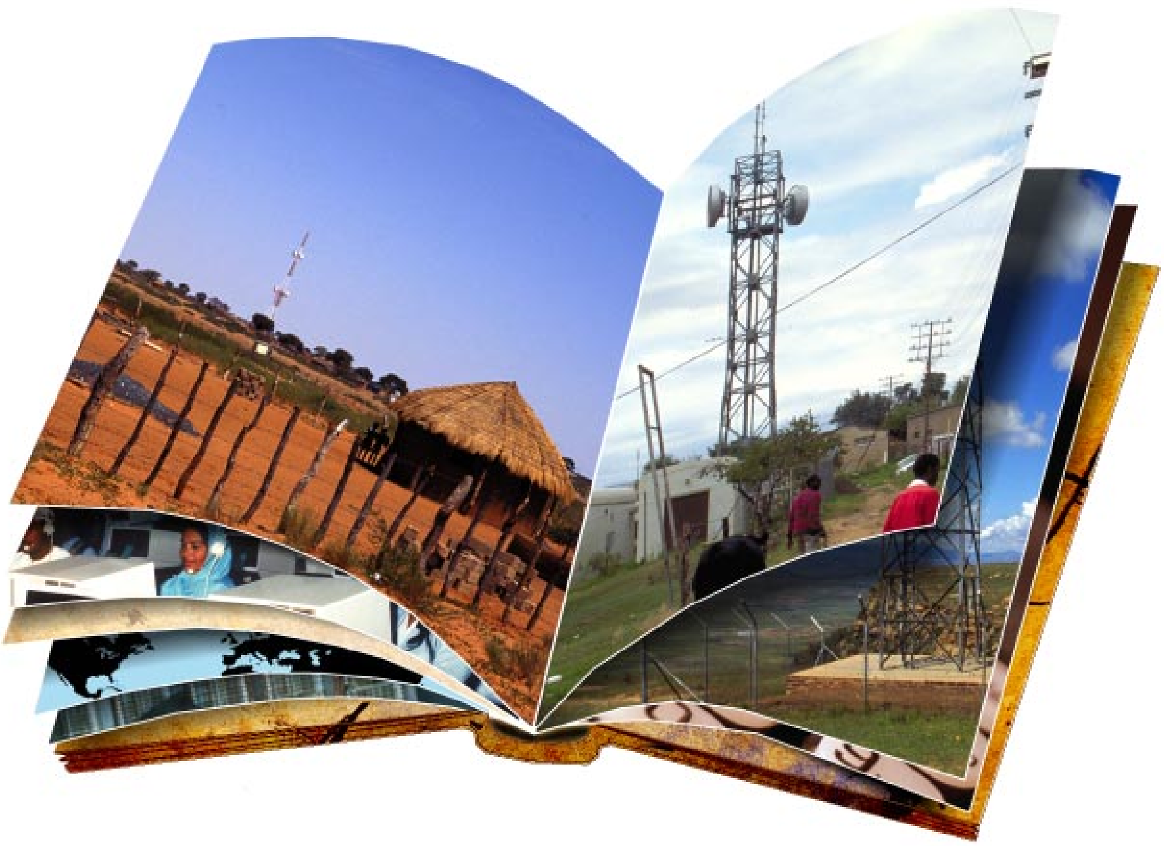
INTERNATIONAL TELECOMMUNICATION UNION

Preparation of handbooks for developing countries: *New developments in rural telecommunications*



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ITU-D Study Groups

First Study Period (1995-1998)
Report on Question 2/2

THE STUDY GROUPS OF THE ITU-D

The ITU-D Study Groups were set up in accordance with Resolutions 2 of WTDC-94 (Buenos Aires, March 1994). For the period 1994-1998 Study Group 1 was entrusted with the study of five Questions in the field of telecommunication development strategies and policies, and Study Group 2 was entrusted with the study of eight Questions on more technical matters. The actual work began in 1995 and resulted in a series of twelve Recommendations, which were approved at WTDC-98 (Valletta, March 1998).

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PUBLICATIONS OF ITU-D STUDY GROUPS

Study Period 1995-1998

Study Group 1

Report on Question 1/1	Role of telecommunications in economic, social and cultural development
Report on Question 2/1	Telecommunication policies and their repercussions at the level of institutional, regulatory and operational aspects of services
Report on Question 3/1	Impact of the introduction and utilization of new technologies on the commercial and regulatory environment of telecommunications
Report on Question 4/1	Policies and ways for financing telecommunication infrastructures in developing countries
Report on Question 5/1	Industrialization and transfer of technology

Study Group 2

Report on Question 1/2	Special concerns of developing countries in relation to the work of the Radiocommunication and Telecommunication Standardization Sectors
Report on Question 2/2	Preparation of handbooks for developing countries
Handbook on	*New developments in rural telecommunications*
Handbook on	*New technologies and new services*
Handbook on	*Economic, organizational and regulatory aspects of national spectrum management*
Report on Question 3/2	Planning, management, operation and maintenance of telecommunication networks
Report on Question 4/2	Communications for rural and remote areas
Report on Question 5/2	Human resources development and management
Report on Question 6/2	Impact of telecommunications in health-care and other social services
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Preparation of handbooks for developing countries

New developments in rural telecommunications

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FOREWORD

I am pleased to present the latest in the series of handbooks on rural telecommunications published by ITU. Earlier handbooks on this subject were produced by CCITT (now ITU-T) GAS 7, which is now disbanded. The present Handbook has been prepared by BDT as a contribution to ITU-D Study Group 2, Question 2/2 of the last cycle. It draws heavily on contributions to this Question and on a number of article papers and handbooks on the subject published by the ITU (see References).

Teledensity in rural areas in developing countries is generally very low and many rural communities are still lacking access even to basic telecommunications. It is now widely recognized that telecommunications is a growth engine, and that also the majority of the populations of developing countries, who live in rural areas, must be given a chance to benefit and to participate actively in the emerging global information society. Universal access, which requires large investments in the development of rural telecommunications, is considered a matter of high priority by the ITU membership.

Many manufacturers therefore now see rural areas as one of the most important future markets for telecommunication equipment, and new technologies suited to the conditions of rural and isolated areas are being developed all the time. Therefore, any handbook on this subject quickly becomes obsolete in terms of choice of technology. However, the basic principles remain valid and it is hoped that the users of this Handbook will benefit from the general guidance it provides and will be encouraged to keep abreast of technological developments.

Hamadoun I. Touré

Director
Telecommunication Development Bureau

ACRONYMS

ADM	Add-drop multiplexer
AMPS	Advanced mobile phone system
AN	Access node
ANSI	American National Standards Institute
AOM&P	Administration, operation, maintenance and provisioning
AON	Active optical network
ATM	Asynchronous transfer mode
BAAP	Buenos Aires Action Plan
BDT	Telecommunication Development Bureau
BML	Business management level
BOT	Build, operate and transfer
BSC	Base station controller
BTO	Build, transfer and operate
BTS	Base transceiver station
CAI	Common air interface
CDMA	Code division multiple access
CP	Concentration point
CPE	Customer premises equipment
CT	Cordless telecommunications
CT2	Cordless telephone second generation
D-AMPS	Digital advanced mobile phone system
DAMA	Demand assigned multiple access
DC	Digital concentrator
DECT	Digital enhanced cordless telecommunications
DP	Distribution point
ETSI	European Telecommunication Standards Institute
FDD	Frequency division duplex
FDMA	Frequency division multiple access
FITL	Fibre in the loop
FSS	Fixed-satellite service
FTTC	Fibre to the curb
FTTCa	Fibre to the cabinet

FTTH	Fibre to the home
FWA	Fixed wireless access
GAS	Special Autonomous Group
GDP	Gross domestic product
GEO	Geostationary orbit
GMPCS	Global mobile personal communications by satellite
GNP	Gross national product
GOS	Grade of service
GSM	Global system for mobile communication
HDI	Human development index
IC	Information and communication
IFC	Installed first cost
IMT-2000	International Mobile Telecommunications-2000
IRR	Internal rate of return
ISDN	Integrated services digital network
IT	Information technology
ITU	International Telecommunication Union
ITU-D	International Telecommunication Union – Development Sector
ITU-R	International Telecommunication Union – Radiocommunication Sector
ITU-T	International Telecommunication Union – Telecommunication Standardization Sector
LAN	Local area network
LDAU	Local digital access unit
LDC	Least developed country
LE	Local exchange
LEO	Low-Earth orbit
LTU	Line termination unit
MCT	Multipurpose community telecentre
MDF	Main distribution frame
MEO	Middle-Earth orbit
ML	Main line
MSC	Mobile switching centre
N-AMPS	Narrow-band advanced mobile phone system
NEML	Network element management level
NML	Network management level

NMT	Nordic mobile telephone
NPV	Net present value
NT	Network termination
NTT	Nippon Telephone and Telegraph Corporation
NTU	Network termination unit
OSI	Open systems interconnection
PACS	Personal access communications system
PBX	Private branch exchange
PCO	Public call office
PCS	Personal communication service
PDH	(Plesiochronous digital hierarchy)
PHS	Personal handy phone system
PLANITU	Computer-aided network planning
PLDT	Philippine Long Distance Telephone Company
PLMN	Public land mobile network
PMP	Point-to-multipoint
POI	Point of interconnection
PON	Passive optical network
POTS	Plain old telephone system
PPP	Purchasing power parity
PSDN	Public switched data network
PSTN	Public switched telephone network
PTO	Public telecommunications operator
PWAC	Present worth of annual charges
RDAU	Remote digital access unit
SAN	Satellite access node
SDH	Synchronous digital hierarchy
SML	Service management level
STS	Stratospheric telecommunications service
TACS	Total access communication system
TDD	Time division duplex
TDMA	Time division multiple access
TMN	Telecommunication management network
TOT	Telephone Organization of Thailand
TS	Time slot

UHF	Ultra high frequency
UNDP	United Nations Development Programme
VAN	Value-added network
VHF	Very high frequency
VPN	Virtual private network
VSAT	Very small aperture terminal
WTDR	World Telecommunication Development Report
WTO	World Trade Organization
xDSL	Asymmetric digital subscriber line (ADSL) High rate digital subscriber line (HDSL) Single-pair high rate digital subscriber line (S-HDSL) Symmetric digital subscriber line (SDSL) Very high speed digital subscriber line (VDSL)

REPORT ON THE QUESTION 2/2

Preparation of handbooks for developing countries

New developments in rural telecommunications

1 Introduction

1.1 Purpose and scope

Volume I (Geneva, 1992) of the Special Autonomous Group 7 (GAS 7) Handbook deals with radio systems in rural areas, while Volume II (Geneva, 1994) deals with switching, ISDN, financing aspects and the use of optical fibres for rural networks [1].

The present Handbook, prepared in close collaboration with BAAP [2] Programme 9 (Integrated Rural Development), is intended to complement and update the GAS 7 Handbooks.

By focusing on existing or emerging technologies capable of providing cost-effective solutions that are appropriate to the needs of rural areas in developing countries, it aims to provide information to assist those countries in their decision-making. Emphasis has been placed on methodologies rather than recommendations, since it is up to each administration and PTO to determine the best solution to meet the telecommunication needs of the rural populations in its country.

1.2 Organization of the Handbook

This Handbook is divided into five sections. Following this introduction, Section 2 reviews the special characteristics of rural environments and their implications for the development of telecommunication networks in rural, isolated and poorly served areas. It also discusses the benefits derived from telecommunications in terms of economic, social and cultural development. Strategies to develop universal access are suggested, the ultimate goal being that of universal service provision.

Section 3 reviews the planning of networks in rural and remote areas, addressing engineering, financial, fiscal and regulatory aspects. Rural telecommunication development financing options are also discussed, as are the implementation, operation and maintenance of rural telecommunication networks.

Section 4, on network technologies, examines the various technologies which may be used in the implementation of rural telecommunications, with particular emphasis on radio technologies, which, in many cases, provide an efficient and cost-effective means of developing the necessary infrastructure.

Section 5 provides a comprehensive technical and economic comparison of different technologies. A concentration/distribution point between the local exchange and the subscriber may be necessary, to which end wireless or combined wired and wireless technologies may be the most appropriate. A detailed cost comparison is made for three different models. The Chapter concludes with a study of the services that could be offered over the network, and with clear insistence on the fact that there is no universal solution for the development of rural telecommunication infrastructures.

Annex 1 provides an example illustrating the factors that need to be taken into account in the financial analysis of bids.

2 Particularities of rural environments, implications for telecommunications, benefits derived from rural telecommunications

2.1 Definition of a rural area

Traditionally, the term rural is applied to the countryside or anything related to it. Rural is often used in opposition to urban. However, this is not the case here. For the purpose of this Handbook, the expression “rural and remote” (or just “rural”) refers to rural, isolated and poorly served areas, where various factors interact to make the establishment of telecommunication services difficult.

A rural area [3] may consist of scattered settlements, villages or small towns, and may be located several hundreds of kilometres away from an urban or city centre. However, in some cases a suburban area may also be considered as rural.

A rural area exhibits one or more of the following characteristics:

– scarcity or absence of public facilities like reliable electricity supply, water, access roads and regular transport;

– scarcity of technical personnel;

– difficult topographical conditions, e.g. lakes, rivers, hills, mountains or deserts, which render the construction of telecommunication networks very costly;

– severe climatic conditions that make critical demands on the equipment;

– low level of economic activity mainly based on agriculture, fishing, handicrafts, etc.;

– low *per capita* income;

– underdeveloped social infrastructures (health, education, etc.);

– low population density;

– very high calling rates per exchange line, reflecting the scarcity of telephone service and the fact that large numbers of people rely on a single exchange line.

These characteristics make it difficult to provide public telecommunication services of acceptable quality by traditional means at affordable prices, while also achieving commercial viability for the service provider.

The last characteristic in the list has an ambivalent effect. To take it into account, rural telecommunication networks must be dimensioned accordingly, with more switching capacity and a greater number of trunk transmission circuits than would be needed in urban areas. If this is done, the high traffic and revenues per access line help enhance the financial and economical results achievable by the rural network. Otherwise, the network will be chronically congested, providing poor service and wasting much of the network capacity on failed call attempts.

Penetration rates in rural areas of many developing countries are very low. Substantial delays are common in providing service to willing customers, and in many countries even a lot of quite large villages do not have a single public telephone. In the low-income countries (as defined by the World Bank) there were, in 1996, an average of only 8.9 residential main lines per 100 households and 0.56 public payphones per 1 000 inhabitants (compared to 102.7 and 5.17, respectively, for high-income countries) – ITU World Telecommunication Development Report 1998 [4].

A major cause of the limited penetration rates being achieved in these low-income economies is that, because of the particular characteristics outlined above, terrestrial rural telecommunication systems (especially those being implemented under a policy of universal service provision) require relatively large capital investments. In twelve recent projects funded by the World Bank, access lines being added in rural areas of developing countries were, on average, three times more expensive than those being added in metropolitan areas.

This discussion of the distinctive challenges of providing telecommunication services in rural areas of developing countries in an economically efficient manner should not be taken to mean that this cannot be done on a commercial basis, or always requires subsidy. Often, investment in telecommunications in developing countries can be funded by normal commercial means. In general, in developing countries, where demand normally outstrips supply, a well managed telecommunication entity operating with an efficient pricing policy can recover, from tariffs, the full cost of providing the service. It is usually assumed that, to achieve this, telecommunication services in rural areas require significant cross-subsidy from long-distance services or services in metropolitan areas. Even this, however, need not necessarily be the case. If network design uses technologies that can aggregate calls over a wide area (e.g. a variety of terrestrial or satellite-based “wireless” architectures) in order to minimize the adverse effects of small scale on unit costs, telecommunication services for rural regions can often generate significant commercial returns on the investment required.

2.2 Universal access and universal service

2.2.1 Definitions

In the context of this Handbook, “universal access” is defined as access to telecommunication services at an acceptable distance from people’s homes. What constitutes an “acceptable” distance will depend on available means of transport (by foot, bicycle or vehicle) and how people value their time.

By definition, “universal service” would mean at least one telephone line for every household. This target has only been attained by a handful of countries and is far beyond what could realistically be achieved in developing countries in the foreseeable future.

2.2.2 Provision of universal access

NOTE – A comprehensive discussion on universal access provision, can be found in the World Telecommunication Development Report, 1998, ITU.

Access to telecommunication facilities and services should be provided at a convenient central location in each community. The portfolio of services offered should meet the needs of the community. Both the types and quantity of services offered will increase as demand grows and as new applications and opportunities emerge.

Such access can be provided initially by means of public call offices (PCO), capable of evolving at a later stage into multipurpose community telecentres. Some telecommunication administrations, such as Bangladesh, Chile, India, Indonesia, Kenya, Peru, Senegal and Yemen, have given priority to the provision of public telephones in rural areas. Some, such as for example India, Indonesia and Senegal, have undertaken innovative policies to encourage private entrepreneurs to set up and operate PCOs. This has mobilized significant investments for the expansion of payphones, and improved availability and reliability.

Studies of PCO [5] use in rural areas of developing countries indicate that a well managed policy of PCO development provides commercial returns on the investment required to install the offices, as well as considerable benefit to users, substantially exceeding the price of their telephone calls (“consumer surplus”).

Payphones can support not only the universal service goals of countries with currently limited access line networks, but can give remote businesses their only link into the public network, thus enhancing opportunities and productivity for entrepreneurs and also creating jobs.

The concept of multipurpose community telecentres (MCTs) [6] – a shared information and communication (IC) service facility – is today widely recognized as a means of improving access to IC services in rural and remote areas (as well as in deprived urban areas). Community telecentres are also called community teleservice centres, community information centres, electronic cottages, or – in a more basic version – “telekiosks”. They provide information technology (IT) and telecommunication facilities, user support and training for the majority of the population of a rural community who cannot afford such facilities on an individual basis and/or do not have the skills to use such tools.

In addition to public telephone, fax and voicemail services, fully-fledged MCTs would provide access to data networks (e.g. Internet) for e-mail, file transfer, access to electronic libraries and databases, government and community information systems, market and price information, environment watch, etc., as well as facilities and equipment for teletraining and TeleMedicine. Being equipped with computers, printers, photocopiers, etc., MCTs could also offer (shared) office facilities, equipment and training for local production (and reception) of community radio and TV broadcasting programmes.

Furthermore, other community services such as the postal service, banking and power and water supply could be located in the MCT, which could thus become a centre for telecommunity development and affairs, as well as for social and cultural activities.

2.2.3 From “universal access” to “universal service”

The telecommunication statistics published by ITU show that there is an imbalance between urban and rural telephone penetration. They also indicate that the lower the *per capita* GDP, the greater the disparity between urban and rural penetration. This is illustrated in Table 1 below.

The difference between urban and rural telephone penetration is mainly due to an income threshold effect.

TABLE 1

Estimated telephone penetration in rural areas of developing countries

Source: ITU, 1998 – World Bank

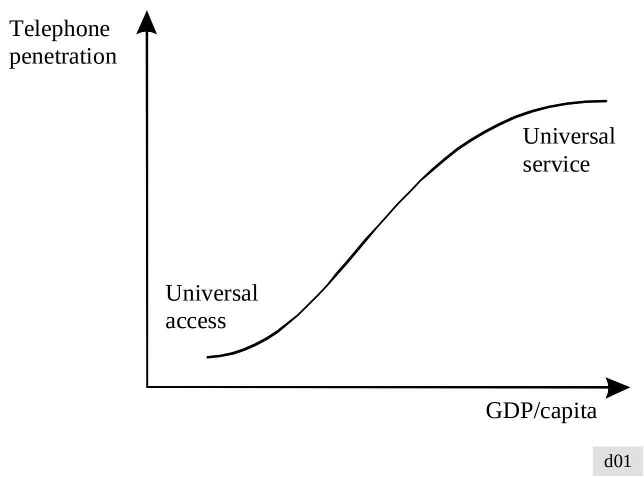
Year 1996	Population (millions)		Telephone penetration (main lines per 100 inhabitants)	
	Total	**Rural (est.)**	**Total**	**Rural (est.)**
Low-income countries	3 258.10	2 350	2.45	0.7
Low-income countries except China, India, Pakistan	947.29	695	0.825	< 0.1
Lower middle-income countries	1 170.62	510	9.71	2.3
Upper middle-income countries	440.36	110	13.36	7.9

Thus, when a large portion of the population is below the income threshold at which they could afford a private telephone line, special strategies are required to provide universal service.

Figure 1 below illustrates the progression from universal access to universal service targets as countries' per capita GDP grows.

FIGURE 1

Universal access to universal service



The key question facing governments and regulatory agencies (and telecommunication operators which have universal access/service obligations) is not whether to invest in the expansion of rural networks, but how. In other words, what particular approach to the expansion of rural networks will be most cost-effective?

2.2.4 Strategies to achieve universal service

Any practical universal service strategy aims both to extend the geographical coverage of the public switched telephone network and provide additional access lines; however, the relative emphasis given to these two aspects of a universal service policy can vary.

One approach lays most emphasis on adding to the local access plant and local switching capacity, so as to rapidly provide more access lines and reduce the waiting list. This might be termed the "direct" approach to universal service objectives. However, there is a case for not seeking the highest possible rate of growth of access lines. The alternative is to boost the expansion of local transmission links and tandem switching, and of the long-distance network. This might be termed the "indirect approach" to universal service: it may connect somewhat fewer new access lines than the direct approach in the short term, but it will do so across a wider geographical area and may also (for reasons explained below) result in more access lines being connected in the longer term.

Either approach may be preferred, depending on the fundamental priorities set by economic and social policies. Policy makers in some countries have defined their universal service goals and telecommunication operators' universal service obligations mainly in terms of the number of access lines to be added in new areas, implying an emphasis on the "direct" approach. One example of this is India, where licensed private fixed-service operators have recently been required to build at least 10% of their new direct exchange lines in rural areas. Policy makers in other countries have defined universal service goals in terms of measures indicating the geographical scope of the network, implying some degree of reliance on the indirect approach. Examples of this kind of policy include the second of Kenya's telecommunication development programmes which commenced in 1979 and which stressed the expansion of service in Kenya's rural areas, with the emphasis on "district focus": installation of new digital switches in nine locations to ensure that all forty-one "district headquarters" in Kenya had automatic telephone service. This goal was achieved in 1988.

Before discussing the various considerations involved, it is worth noting that the emergence of advanced "wireless" network architectures, especially satellite-based, greatly eases the policy dilemma represented by the choice between these two approaches. The same investment in wireless systems can often simultaneously extend the geographical coverage of services over wide areas and add capacity. Indeed, in the case of satellite systems, there is normally no choice to be made between investing in coverage and investing in capacity, since any capacity added to the system is simultaneously available across a very extensive geographical area corresponding to the coverage "footprint" of a satellite or a "constellation" of satellites. These general observations apply to a wide range of modern satellite architectures relevant to the provision of rural service in developing counties, including the use of geostationary-satellite transponders in advanced VSAT DAMA systems, and non-geostationary satellites in global mobile personal communication systems (GMPCS).

2.2.5 Advantages and disadvantages of the "direct" and "indirect" approaches

NOTE – Inward traffic is an additional source of revenue – experience suggests that this revenue is often higher than the revenue generated by outward traffic. Furthermore, it is often ignored when carrying financial analysis of development projects.

As described above, the "direct" approach to universal service is one that assigns high priority to rolling out the local access plant of the public switched telephone network (PSTN) into rural areas and low-income suburban areas. In order to attract residential subscribers in such areas, the price of basic service must be low. If this is achieved by large cross-subsidies, paid for from high charges for long-distance and international calls (largely business subscribers), this may hamper economic growth, much like a tax.

By contrast, the "indirect approach" to universal service inherently increases the supply of long-distance services. Not only do these have a high market value because they are used by entities and persons using telecommunications in high-value activities, but research also shows that these kinds of telecommunication applications have a strong impact on production, and hence increase national income and *per capita* incomes. This helps make it possible, in the longer term, for more households to afford residential basic service at non-subsidized (or only slightly subsidized) prices, which in turn will help make increased supply more commercially feasible.

The contrast between the two approaches described above can be illustrated by reference to a hypothetical compact rural village of the type commonly encountered in many developing countries (in India, for example, there are over 500 000 villages with populations of under 1 000). A strategy following the "direct approach" to universal service might give priority to creating or expanding a local network in the hypothetical village so as to connect a substantial proportion of households. Achieving this might require offering access service and local-call service at heavily subsidized prices. Yet local-call service in itself has relatively limited market value in such a village (face-to-face communication is habitual and easy), while long-distance calls may be extremely valuable, for example in medical emergencies.

In any such village there will be people who need long-distance service frequently, and many others who need to make long-distance calls (or even international calls) occasionally, in order for example to deal with medical emergencies or to keep in touch with distant family members. Also, these are the type of calls on which they will place a high value. Unless the village is absolutely self-sufficient (a very rare situation), it exports and imports products and also possibly services. Much of this "external" trade is managed by resident brokers, merchants and shopkeepers, who could perform their functions more efficiently if they were linked to the markets in which they sell or buy by long-distance telephone service at reasonably low prices. Several studies also show that better communications increase the bargaining power of rural producers in the marketplace, enabling them to obtain greater revenues. Faster and better response to conditions in distant markets would also tend to benefit the producers of the village's "exports" and the consumers of its "imports". Long-distance telecommunications can provide a village with access to medical advice (for example, giving local nurses and other paramedical personnel the opportunity to consult physicians located elsewhere) and educational programmes.

2.3 Economic, social and cultural benefits

In connection with Question 1/1 – Role of telecommunications in economic, social and cultural development, ITU-D Study Group 1 has issued a Final report [7] which gives an exhaustive overview of the benefits derived from telecommunications. A growing body of research has demonstrated the value of telecommunications as an engine for economic growth. Studies have shown that, in most cases, the economic benefits that users gain through the use of telecommunication services considerably exceed the associated costs. Many governments also see efficient telecommunication provision as a catalyst for nation-building and social cohesion. The universal access/service ideal aims at promoting equity, opportunity and participation among the citizens of a country: in particular, telecommunications can make an important contribution towards integrating peripheral populations into national, economic, social and political life.

The effort to establish dependable and efficient telecommunication services is fuelled by recognition of the significant impact such services can have on the pace and direction of the country's future development. An overview of the various benefits derived from investments in the telecommunication sector are given below.

2.3.1 Overview of benefits

2.3.1.1 Multiplier effect

Investments in a sector normally increase economic output by an amount greater than the investment itself – the multiplier effect of investment. The injection of fresh capital acts as a catalyst for business activity in both supplier and user sectors. The communication sector is more important as a supplier of inputs to other sectors than as a user of inputs from them. The impact of telecommunication development projects on the national economy is mainly in the form of increased employment, production and/or productivity.

2.3.1.2 Direct foreign exchange earnings

The installation of additional telephone lines and enhanced telephone services for long-distance international calls are expected to increase international service revenues considerably, and hence increase foreign exchange earnings.

2.3.1.3 Energy savings

Telecommunication services can partly substitute for transportation and can also bring about more efficient use of transport facilities and fuel and, hence, contribute to improving the environment.

2.3.1.4 Improved marketing strategy

Improved telecommunications helps enhance marketing efficiency and competition. Information on the prices, quantities and attributes of products must be available to buyers if a market is to perform its resource allocation function correctly. Use of the telecommunication network is an important element in this process. Telecommunications can also serve to establish more direct contact between primary suppliers and end markets. This shortening of the distribution chain can reduce the cost of distributing goods and services, and possibly allow higher incomes for primary suppliers (specifically, in rural areas) thus helping to alleviate poverty.

2.3.1.5 Enhanced interaction within and between economic sectors

The development of virtually any sector of the economy relies on the adequacy of the country's infrastructure network – roads, bridges, electric power generation with its distribution facilities and telecommunication networks. The key role of telecommunication services is very apparent in areas like agricultural development, industry, commerce, service-oriented industries such as banking and tourism, news and information. In the absence of accessible and reliable telecommunication services, such activities suffer a variety of inefficiencies.

2.3.1.6 Development of international commerce

Businesses are increasingly becoming international in scope. Appropriate investments in the telecommunication sector will facilitate international business activity, thereby contributing to increase export earnings.

2.3.1.7 Support for regional decentralization

Governments have long offered incentives to locate business enterprises in less developed regions. However, the effectiveness of these incentives has been partly negated by the high information and transaction costs and transport costs associated with locating in a remote region. Improved telecommunications can substantially reduce these costs. Therefore, investments in telecommunications can be an effective tool in attracting employment-generating activities to the less developed regions.

2.3.1.8 Improved efficiency of government programmes and services

Public administration relies heavily on coordination between central headquarters, regional centres, local area offices and even individual government officials. An expanded and improved telecommunication network will provide more effective means for the dissemination and exchange of ideas and information and for administration of government programmes. It will also facilitate the extension to low-income rural areas of health, education, government administration and other services, as well as scarce expertise for advice, support and supervision.

2.3.1.9 Potential benefits from growth in the subscriber base

A form of multiplier effect, but from the subscriber’s viewpoint, is that new telecommunication service subscribers not only acquire the potential to gain direct benefits, but also increase the potential benefits of those who are already connected to the telecommunication network. Moreover, the benefits resulting from a call do not stop with the parties involved in the call, but can extend to parties who are contacted subsequently as a result of the original call.

2.3.1.10 Improved infrastructure and environmental services

Data services provide the ability to remotely monitor and control the delivery of electricity, water, transportation, and oil and gas services to rural areas (when existing), and system problems can be quickly identified. Other examples include remote metering for billing and irrigation system control based on weather and soil conditions. They also provide means of environment monitoring and hazard alert services, such as warnings of impending volcanic eruptions, severe storms and floods, tsunamis, and the like. In particular, satellite services generally tend to be disaster resilient and allow for rapid assessments and response when terrestrial communication systems are not available or destroyed.

2.3.1.11 Safety, security and enhanced social well-being

Telecommunications contributes to, and helps maintain, the well-being of individuals, families and communities by facilitating contact between relatives, friends and associates, and by giving rapid access to services needed to preserve life, health and property. Telecommunications can contribute to expanding human settlement areas by providing communication channels reaching even the more remote areas. It also facilitates political, cultural, economic and social integration.

2.3.2 Examples of benefits

2.3.2.1 Gross national product and telecommunications

The contribution of a telephone to GNP is greater the lower the *per capita* GDP. This is illustrated by the following figures (Table 2).

For example, an increase in the telephone penetration in rural sub-Saharan Africa from 0.095 to 0.28 would contribute to an increase in the total GNP of the region of the order of USD 4 to 5 (i.e. an increase of 3% of total GNP).

The contribution of a telephone call to GNP is of the order of USD 4 to 12 for countries with a GNP/capita of USD 100 and between USD 1 and 3 in countries with a GDP/capita of USD 300.

TABLE 2

Contribution of a telephone to GNP/capita

Source: Document 1/183 – Study Group 1, Question 1/1
(last study period 94-98)

GNP/capita USD	Contribution USD
100	11 804
200	5 550
300	3 727
500	2 384

2.3.2.2 Benefit/cost ratio

A number of studies have been undertaken to quantify the benefit that a consumer can derive from access to a telecommunication service.

The following example reported in 1981 by the Indian Communications Ministry is self-explanatory (Table 3):

TABLE 3

Benefit/cost ratio in India

(study carried out on 120 users of a PCO)

With Telecom		Without Telecom				
Average distance of call km (a)	Call cost Rupees (b)	Transportation cost by bus Rupees (c)	Lost-time value[1] Rupees (d)	Total cost of transportation Rupees (e)	Surplus Rupees f = (e-b)	Benefit/cost ratio $g = \frac{f}{b}$
11.24	1.37	4.53	2	6.53	5.16	3.76
34.57	3.54	8.45	4	12.45	8.91	2.52
80.54	4.56	16.19	8	24.19	19.63	4.30
149	5.44	27.69	8	35.69	30.25	5.56

[1] Estimate of the value for the lost time if travel is necessary.

It was shown in 1986 that the following benefit/cost ratios were obtained in the Philippines by enterprises having access to telecommunication facilities (Table 4).

TABLE 4

Benefit/cost ratio for enterprises in the Philippines

Activity	Benefit/cost ratio
Agriculture	44
Health	33
Other	21

2.3.2.3 Human development index and telecommunications [8]

The Human Development Report published by UNDP in 1990 introduced the notion of a composite indicator, containing three equally weighted aspects of a country's human development: longevity (given by life expectancy at birth), knowledge (given by adult literacy and average number of years of schooling) and income (given by real GDP/capita expressed in terms of purchasing power parity – PPP $). This indicator, which is called the human development index (HDI), varies from 0 to 1. Countries with an HDI above 0.8 are considered to display high "human development", while in those with an HDI below 0.5 the human development level is considered to be low. Such an index seems to be a suitable and effective measure of the social, economic and cultural development of a country.

As an example, between 1961 and 1992, the HDI of the countries of sub-Saharan Africa grew from 0.2 to 0.357, as against from 0.255 to 0.653 in East Asia.

There is a correlation between HDI and telephone penetration and it has been shown that the higher the HDI, the greater the increase in telephone penetration. However, the causal relationship between HDI and telecommunication growth needs to be studied in more detail and quantified.

2.3.2.4 Selected examples

– *The benefits of public telephones in Senegal* [5]

A study was undertaken in Senegal in 1986 to quantify user benefits from public telephones. Around 700 users of public telecommunication facilities were asked in interviews to provide information, in order to draw up a user profile with a view to calculating a value for the consumer surplus (the direct benefit derived from using telecommunications as opposed to an alternative form of communication). The data included age, level of education, occupation, the purpose of the call, the travel distance for the purpose of communication and the preferred alternative method of communication in the event that the call attempt had failed. Apart from that, telephone users were also asked some questions to find out how much they would be willing to pay for a better-quality service or to have a public phone available closer to their home.

The Senegal study also took into consideration that it is difficult to put a value on the opportunity cost of time in a rural setting, which is subject to seasonal variation and informality, and where some travel may serve multiple purposes. These aspects were taken into account by disregarding any travel which was multi-purpose and by always choosing the lower of any opportunity cost alternatives. An average cost of a 4.3 minute call was used irrespective of distance, and the average user benefit per call was evaluated as the cost of the best alternative here referred to as "consumer surplus". Because distance is disregarded, the consumer surplus is underestimated for shorter distance calls and overestimated for longer distances, but on average consumer surpluses of between 38% and 134% are obtained or, to put it differently, benefit/cost factors ranging from 1.38 to 2.34.

– *Rural telephones in Vanuatu* [9]

A study was conducted in Vanuatu in 1988 with the objective of optimizing the placement of rural PCO telephones. In spite of a good telecommunication infrastructure for urban areas and big businesses in rural areas, the rural population did not have easy access to telephones. There were only about 60 rural telephones (44 of which were public) serving some 80% of the total population of 130 000. The study was undertaken to determine the extent and optimal spatial layout that would yield the highest benefits to rural users of public telephones for a given cost, by measuring and modelling the losses resulting from the lack of adequate telecommunications.

Data were collected on the round-trip distance travelled (either on foot or by vehicle) to all existing public phones in rural areas. Annual demand for domestic calls per 100 inhabitants was then expressed as a function of the cost incurred by the individual callers, based on the minimum subsistence wage and the cost of paid transportation by vehicle. The cost of travel was estimated to be vatus 30 per km, (vatus 100 = USD 0.75 (February 99)) which was in turn used to calculate the consumer surplus. A spatial model was then developed to determine the benefit of extending the rural network by reducing the distance rural dwellers had to travel to reach a telephone. The country was divided into ninety-six zones, and the model was used to compute the call rate per 100 inhabitants, volume of telephone traffic, distance to the nearest telephone, zone in which the nearest telephone was located, and consumer surplus for each zone and for the entire study area in aggregate.

Expanding the number of telephone locations from forty-four to sixty-four was calculated to yield an incremental benefit of vatus 2.6 million a year (56 000 km of travel saved per year); if 100 zones received a phone, the incremental benefit would be vatus 11.4 million a year (125 000 km saved per year). The average annual benefit achieved per location from the addition of ten locations (increasing the number of telephones from forty-four to fifty-four) was vatus 78 200. Overall, the economic benefits gained from the telephone network increased with the number of locations, but at a decreasing rate; most of the benefit was obtained in the first 100 locations, since as traffic increased, it tended to include more lower-value calls. One serious limitation of the study was that the benefits were not evaluated net of costs, since relevant information was not available on the costs of providing service; it is thus not known whether the recommended strategy was on a cost recovery basis.

Table 5 shows the effect of installing more telephones to reduce the distance to the nearest phone. The result is an increase in calling rates. The incremental benefit of having 200 telephones is 3.7 million vatus/year, and for 500 telephones 7.0 million vatus/year.

TABLE 5

Distance vs number of telephones

Number of telephones	**Distance from the nearest telephone**		
Current situation	3 km	5 km	8 km
With 200 telephones	1 km	3 km	5 km
With 500 telephones	1 km	1 km	3 km

Benefits accrue to each market segment as new rural locations are served by publicly accessible telephones. The annual rural benefits by market segment (millions vatus/year) are summarized in the following Table 6.

TABLE 6

Annual rural benefits

Market segment	**Annual rural benefits (million vatus/year)**		
Number of locations	**200**	**300**	**500**
Domestic	7.4	9.7	11.5
Government services	7.7	8.8	11.0
Business & agriculture	2.9	2.9	2.9
Total	**18.0**	**21.4**	**25.4**

– *Rural telecommunications in Indonesia* [7]

In Indonesia, a combination of purposive and random sampling was used to select 299 respondents in four categories: subscribers who had a telephone in their homes, which in many cases were the sites of their businesses; workers in offices where a telephone was available; telephone borrowers, who had no telephone but were known to borrow other people's telephones fairly regularly; and non-subscribers with no ready access to a telephone. The sample was fairly evenly distributed in terms of sex, age, education and other criteria.

The study found that there was a pressing need among people in rural areas to communicate beyond their immediate environment. Among the sample of non-subscribers, nearly 40% needed to communicate with people outside their work places regularly. The corresponding percentages were much higher among home telephone subscribers (79%), office workers (80%) and telephone borrowers (76%).

Development programmes in rural Indonesia require close communication between offices and organizations. The importance of the telephone for this kind of communication is suggested by the following findings. Of the home telephone subscribers, 76% used the telephone for communicating with offices and organizations, compared with 52% of office workers and 23% of borrowers. Among the non-subscribers, nobody mentioned using the telephone for this kind of communication. On the other hand, 78% of non-subscribers relied on personal visits, compared with 61% of borrowers and 42% of office workers. Only 10% of home telephone subscribers used personal visiting for such purposes.

Regarding alternative means of communication, more than half of the Indonesian respondents took the option of borrowing someone else's telephone, reconfirming the importance of the telephones in their lives. Most respondents felt that the telephone had influenced their lives, more so among the home telephone subscribers (96%) than among office workers (69%) and borrowers (47%). For most respondents, the influence was seen in terms of facilitating various kinds of relationships, rather than merely transmitting information or saving time. It seems that interpersonal relations are of primary importance to work and business in these Indonesian rural communities. As work relations expand in the course of economic development, the telephone becomes an indispensable means of maintaining those relations that are essential to job performance.

– *Rural Telecommunications in Thailand* [7]

In Thailand, four districts were selected, two semi-rural and two rural, all of them within a distance of not more than 900 kilometres of Bangkok. The semi-rural districts were: Phuket with 1 400 telephones and Kamphaeng Phet with telephones. The two rural districts were Pasang with 100 telephones and Choke-chai with no telephones at the time of the study.

Again, a combination of purposive and random sampling was used to select 400 respondents in four categories: subscribers who had a telephone in their homes, which were usually the sites of their businesses; workers in offices where a telephone was available; people who had two telephones, one in their home and one in their office; and non-subscribers with no ready access to a telephone. The sample was fairly representatively distributed in terms of sex, age, education and other criteria.

The findings were similar to that of the Indonesian study: the Thai respondents felt a strong need beyond their immediate environment. Among non-subscribers, 85% needed to communicate with people outside their workplace regularly. This figure was much higher than in Indonesia, perhaps partly because of the inclusion of two semi-rural areas in the Thai sample. In the other Thai groups, the percentages were: 96% among office workers, 93% among home telephone subscribers and 98% among those with two telephones.

The need to communicate with offices and organizations was just as pressing as in Indonesia: 77% non-subscribers, 91% office workers, 89% home telephone subscribers and 95% among those having two telephones.

This study indicates that even in rural areas there is a nascent demand for telecommunication services in countries such as Indonesia and Thailand. Where the telephone is available, be it from private business, government offices or individual homes, the limited facility is fully utilized. Roughly three-quarters of the surveyed calls were long-distance. If more public telephones are installed in rural areas, the findings suggest that they will be used to the fullest extent and will produce revenues, mostly from long-distance calls.

For many of the rural residents surveyed, the lack of telephone services appears to be a major handicap. In the Thai sample, nearly 65% of those who did not have a telephone in their neighbourhood had to travel more than 25 km to get to a telephone. Nearly 10% had to travel more than 40 km. More than 90% of the calls involved were long-distance.

The rural long-distance telephone project in Thailand has been undertaken by the Telephone Organization of Thailand (TOT), under the universal service obligations, to provide rural telecommunications through both public and private connections. The project is also designed to meet broader socio-economic objectives, by providing high consumer surplus and stimulating economic activities.

In 1996, MIDAS Agronomics Company Limited conducted a study of the socio-economic impact of rural telecommunications. Information was collected from three groups of people such as telephone users, public call office operators and members of the public (village leaders, farmers, poor people, business people, teachers and students). The study was conducted in nine provinces to meet the criteria of geographical distribution, incidence of poverty and remoteness of the area. Within each province, three villages were selected for the study, one with a recently installed telephone, one with a longer history of telephone usage, and one without a telephone.

The study found that the public telephones installed under the project provided substantial benefits to the people in rural areas. Poorer members of the community were able to hear about the availability of jobs and keep in contact with family members living in distant places. Telephones contributed to better informed decisions about migration. Farmers and traders were able to check on prices and increase their incomes. Telephones assisted public and private agencies in delivering services to rural people, including the benefits of rapid reporting of accidents and other emergencies. The economic value of saving in travel and other communication costs meant that benefits were worth at least twice the amount spent on a telephone call. In turn, the findings of the study helped in taking informed decisions on further expansion of the rural telecommunication network.

– *Rural telecommunications in Colombia* [10]

The Canadian International Development Agency (CIDA) conducted a field visit in 1997 to the Pacific Coast of Colombia, west of the city of Cali, where two point-to-multipoint microwave radio (PMP) systems were brought into service in 1994. The purpose of the visit was to review the in-service experience and also to assess how the objectives in terms of economic, social and cultural development had been met.

The two PMP systems serve eighteen small communities with a total population of approximately 25 000. Access to some of these communities is possible only by sea. The economic base is mainly agriculture and fishing, with three of the communities also being tourist resorts. A total of 31 lines have been installed. Telecommunication services are provided through the Indirect Attendant Service (*servicio de atención indirecta*) operated as agencies of Telecom Colombia. Monthly average revenues for one system totalled 8 500 000 pesos in mid-1997, although there were wide variations in the revenue per line in service, the revenue relative to the population of the communities served, and the monthly revenues themselves.

A usage survey based on 68 structured interviews – 51 with customers and 17 with operators – revealed the following percentage breakdown of calls:

Economic Development (markets, agriculture, transportation, fisheries, tourism)	39%
Social Development (health, government, education, environment)	37%
Personal (family and friends)	24%

Some of the comments made by customers indicate that the availability of telecommunications, in areas where there is no appropriate means of transportation (access only by sea, for instance), has led to improved health care, better administrative services within the community, increased business activity and improved security. It is worth noting that customers are asking for more lines to be made available.

– *Other examples* [11]

In Bangladesh, where 90% of the population lives in rural areas, and almost all rural residents are engaged in agriculture, which accounts for 50% of the country’s GDP, only 10% of telephones are located in rural areas. The county’s topography leads to flooding during the monsoon season, rendering road and railway communication impossible. As a national policy, telecommunications is being extended to rural areas, and 449 of 466 rural sub-districts now have telecommunication facilities. The intention is to develop the rural sub-districts as centres of rural economic activity and primary growth centres, so as to discourage migration to the cities.

The scale and scope of extending telecommunications to these rural areas is beyond the resources of the Government, and so private operators have been invited to participate. Results so far have been promising. Bangladesh has found that rural telecommunications can be a significant source of revenue. The example is given of average revenues of USD 190 per day, per telephone, with usage averaging 100 callers per day.

Lebanon cites increasing demand for telecommunications in rural areas, heavily focused on the support of commerce and economic development, including the administrative needs of both public and private sectors, project-type enterprises such as offshore platforms, mines, and forestry, electronic transactions for the banking industry, and network control and management of pipelines companies. Also, the development of rural telecommunications is expected to reduce partially urban migration.

In Myanmar the move towards a market-oriented economy made the need for telecommunications more evident. With the economy performing below its potential, improved telecommunications will foster economic growth, boost production, and lead to improved agricultural output and greater transport efficiency.

In Bhutan, 70% of the population lives in the almost totally unserved and topographically difficult rural territory, some areas as far as seven days' walk from the nearest road. The Government has set a target of bringing telecommunications to all villages by the year 2002. Bhutan participates in a pilot project under Programme 9 – Integrated Rural Development (now Programme 3 of the Valletta Action Plan).

The Government of China clearly recognizes the value of rural telecommunications for economic and social development. China has embarked on an ambitious programme to bring modern telecommunications to the vast rural areas where three-quarters of the country's population live. Practical priorities have led to the establishment of a multi-year rural programme which has first addressed the south-eastern coastal region, and will then move west across the country.

Management of the rural telecommunication programme in China is based on uniform principles which address planning, standards, equipment and system selection, construction, and development applications. The programme makes use of an appropriately wide variety of modern telecommunication technology. The growth objectives in terms of teledensity are very aggressive. The Chinese Government's motivation is clearly linked to the significant economic and social development and advantage that will result.

In Yemen also, the Government recognizes that telecommunications is vital for socio-economic development and growth. Three-quarters of Yemen's population live in sparsely populated and topographically difficult rural areas, mainly in very small communities. Nevertheless, the Government of Yemen is determined to bring telecommunications to the rural and remote areas.

In this initiative, Yemen has enjoyed good support from the international community, from the public sector as well as from the private sector. Yemen's rural programme is moving forward well, with several specific projects in progress which are making use of modern telecommunication technology. Network planning studies are ongoing to continue the progress of the rural programme. The final sentence of a contribution from Yemen deserves to be quoted: "In conclusion, telecommunications will remain an indispensable tool in all human activities, and where there's a will, there's a way".

3 Planning of networks in rural and remote areas

3.1 Background

The World Telecommunication Development Conference (WTDC-94, Buenos Aires, 1994), in its Resolution 4 on telecommunication policies and strategies, suggested appropriate policies and principles, a number of which are of specific importance when considering communications for rural and remote areas. This was reinforced by the second World Telecommunication Development Conference (WTDC-98, Valletta, 1998), in particular:

– Recommendations 6, 7 and 8;

– Resolution 11. Further guidelines are given in the report on communication for rural and remote areas [3] prepared in response to Question 4/2 and adopted by Study Group 2. The BAAP Programme 9 – Integrated Rural Development – (now Valletta Action Plan Programme 3 – Universal Access and Rural Development) adopted by WTDC-94 and WTDC-98 respectively also aims at promoting the development of rural telecommunications.

Telecommunication policies must be developed as part of an overall strategy of economic and social development. Market-based economic principles are playing a growing role in the development of the telecommunication sector.

The regulatory and operational functions should be separated. An appropriate regulatory framework will ensure long-term development of the telecommunication sector on a stable basis, while promoting technological innovation, infrastructure modernization, service diversification and quality of service improvement. Appropriate regulation is also essential in promoting the provision of universal access to basic telecommunication services in rural and remote areas.

Telecommunication development policy must encourage the harmonized development of networks and services with a view to reducing national and regional disparities and improving the interoperability of networks worldwide. Policies must ensure that PTOs give special attention to the needs of rural and remote areas. Recognizing the considerable investment required for the development of modern telecommunication infrastructures, particularly in rural and remote areas, it is very important to explore all alternatives for attracting investment from sources of national savings and for encouraging national and international private sector participation. Technological progress should now facilitate a bolder strategy of offering the same services and the same quality of service to urban and rural subscribers alike.

It is well established that improving telecommunication infrastructure in rural and remote areas can substantially enhance quality of life. However, telecommunications is a necessary but not sufficient component for improving the quality of life in such areas. Other infrastructure components are also essential, for example transportation, drinking water, water for irrigation and electrification.

The cornerstone of a successful and sustainable rural telecommunication service is to ensure that delivery of the service is founded on commercial business principles. The PTO's decision-making processes and operations must be based on business economics, which understand and address both costs and revenues, minimizing the former and maximizing the latter. A "universal access" and/or "universal service" obligation for rural and remote areas may very well be necessary; but careful attention to economics and profitability will go far to lighten the burden of this obligation.

Major cost savings can be achieved by implementing a well planned and orderly rural telecommunication programme. A dedicated programme over several years will develop expertise in the personnel of both the PTO and the equipment vendors. Entrepreneurial PCO operators in the villages will find creative new opportunities to provide value to the rural residents they serve.

Since the provision of telecommunications in rural and remote areas is generally more expensive than in urban areas, every effort must be made to take maximum advantage of the development opportunities in the communities served. It is important to provide enough capacity for all service needs, so that the PTO can realize all the opportunistic revenue that arises from serving these needs.

Ideally, a positive business case can be achieved for the rural service, and this will ensure its ongoing viability and sustainability. Minimal regulatory overview will be required, and the continuity of the rural service will be assured.

National rural telecommunication development initiatives should be organized and implemented through a carefully planned, orderly, progressive, multi-year programme, as part of the national telecommunication development master plan, to ensure that such programmes are implemented efficiently and economically.

3.2 Planning of rural telecommunication network projects/programmes [3]

All planning of telecommunication networks is by its nature complex, involving the interaction of many interrelated variables. Such planning is inherently an iterative process, seeking to move progressively closer to an optimal solution. In all network planning, careful attention must be paid to the long-range planning view. Plans must be open-ended and flexible.

Alternative network plans must *always* be comparable in terms of coverage, services provided, service quality and duration, in order to provide an appropriate basis for decision making.

It is essential to use computer-based planning tools such as the ITU tool "PLANITU", to investigate and compare properly the multi-dimensional network alternatives which are now possible. Such tools are becoming more and more "user friendly" and easier to use.

When planning rural telecommunication networks it is important to consider the socio-economic benefits to the rural area that telecommunications will bring, both qualitatively, and also quantitatively to the extent that this can be defined. It is desirable that the financial advantage of the socio-economic benefits should be considered (see also under § 3.4 "Financial analyses" below).

Quality of service objectives must be clearly established. Expected subscriber demand, and the related revenue expectation, is of course an important input to the planning process. Unfortunately, there is generally little knowledge about the demand in unserved rural and remote areas. Expected usage by those who have never had telecommunication service is difficult to forecast under any circumstances. The recorded waiting list is likely to be greatly outnumbered by the latent unexpressed demand. Therefore, it is essential to explore various scenarios to determine the plan's sensitivity to major variations in demand.

3.3 Engineering economic cost studies

These studies are based on flows of funds of all types, throughout the period studied, including capital expenditure, revenue, maintenance costs, operations and overheads, and also salvage (at the end of the useful life of the equipment or system). Financial provision should be made for the appropriate test sets and spares, for staff training and for other expenses, such as marketing, billing and relevant commissions. These various types of flows of funds, over the period studied, must be correctly accounted for in accordance with taxation and depreciation requirements, which tend to vary between countries.

If revenue is constant when comparing different solutions, then "present worth of annual charges" (PWAC) is an appropriate selection criterion; in rural network studies, however, expected revenue is likely to vary between solutions, in timing if not in overall amount, so the correct criterion is "net present value" (NPV). Another helpful criterion is "internal rate of return" (IRR). The network planner's objective is to provide the network solution that maximizes NPV and IRR. To find this solution, several iterations of the proposed plan will certainly have to be carried out. Network planning decisions should not be based on "installed first cost" (IFC), although this cost must be considered, as it has a direct impact on the project/programme funding requirements.

It is also important to carry out sensitivity analysis. It will generally be found that three or four factors have a substantial impact on the outcome of the study and the conclusions reached, and that the other factors are relatively unimportant. The management task, then, is to focus on and monitor these critical factors as the plan is implemented, in order to make adjustments to the plan, as required.

Network solutions which have the flexibility to adjust readily to unexpected variations in demand are preferable. In this regard, radio-based network solutions, with flexible capacity and the possibility of equipment relocation, tend to have an advantage over fixed wire solutions, which include a large and unrecoverable civil works component.

The planner must also consider the national trunk network, and the international intertoll network. If these networks are provided by different organizations, both revenue separation and interconnection arrangements are very important. These parts of the overall national network are key adjuncts of the rural network, since long-distance revenue will be a major factor in the economic analysis. The ability of the trunk networks to carry the long-distance calls is essential if this revenue is to be realized. In developed countries, "one percent non-completion, busy hour, trunk call" is a network performance standard which is usually specified and generally met.

3.4 Financial analyses

Financial analysis is the step that follows, the engineering economic cost studies. Areas for consideration could include changes in tariff levels and/or alternative tariff structures. Revenue settlements should also be considered. At this stage, a quantified understanding of the socio-economic benefits which will result from the proposed rural telecommunication network may be the key factor in influencing the regulatory arrangements.

3.5 Fiscal planning

Fiscal planning must consider not only the previously determined financial values, but also the schedule of flows of funds, the methods by which funds are to be raised (e.g. debt vs. equity vs. internally generated funds), foreign currency requirements, and other financing strategies. Examples of the latter would include BTO and BOT arrangements.

Two specific areas that must be carefully considered, especially by developing countries which import telecommunication equipment, are foreign exchange risk and import tax. Prudent fiscal management requires arrangements that protect the enterprise from risks caused by unexpected changes in foreign exchange rates. Import tax requirements directly increase the cost of imported equipment and systems, and this additional cost will ultimately be reflected in the price of the service. There is a very good fiscal argument to be made to the effect that the levying of importation tax by developing countries on rural telecommunication equipment is unhelpful and counterproductive.

Giving appropriate consideration to all of the above factors, the fiscal planners must ensure that the proposed rural telecommunications project/programme fits appropriately within the overall fiscal plans and expectations of the telecommunication operation.

3.6 Demand forecast

Demand will largely be determined by the cost of service in relation to the disposable income of potential subscribers.

However, the scarcity of capital usually limits the amount of subscriber demand that can be satisfied in rural areas. In this case, the available investment capital will determine project objectives and the number of subscribers who can be served.

In order to estimate the achievable telephone penetration in rural and remote areas, the following factors must be considered:

– population and its geographic spread;

– GDP *per capita* in rural areas (which, in most cases, is lower than the average GDP *per capita* in the country);

– the amount which individuals or households are willing to, or can afford to spend on telecommunication services;

– the revenue per line required by the operator in order to achieve commercial viability.

3.6.1 Universal access/service and investment

ITU statistics indicate that countries spend between 1 and 3% of their GDP in telecommunication services. In most developing countries, it is reasonable to assume that a rural community will be willing to pay at least the same percentage of their overall income for basic telecommunication services. The average income in rural areas can be estimated from the available statistics.

Consider, for instance, a country with a total population of 20 million inhabitants, 70% of them living in rural areas, with a rural land area of 600 000 km^2. The average GDP *per capita* for the whole country is USD 200, 56% being attributed to the rural population. Each rural inhabitant is prepared to spend 1.5% of its income on telecommunication services. The GDP *per capita* in the rural areas can be estimated to be $200 \times 0.56 : 0.7$ = USD 160. Thus, the amount each person will spend on telecommunication services will be USD 2.4 per year. If the average household comprises six people, each household would spend an average of USD 14.4/year.

Capital costs per rural main line are assumed to be USD 2 500, although experience shows that they can exceed USD 10 000 in some regions. However, capital cost per main rural line is decreasing significantly and the objective of less than USD 1 000 is in sight. It is obvious that operators – and investors – need to recover their investment as quickly as possible. Therefore, they expect an internal rate of return in the order of 25 per cent. To meet such an objective, the revenue per line should exceed USD 830 (10-year financing at 8% p.a, straight-line annual depreciation over a 15-year period, administration, operation, and maintenance costs amounting to 15% of capital investment – increasing 5% per year).

To achieve this revenue, each main line installed in the rural areas of such a country would have to serve 830/2.4 = 346 inhabitants. It would therefore be necessary to install about 40 500 main lines representing an investment of USD 101.25 million.

The provision of universal access – one telecommunication access point, with two telephone lines, within a maximum distance of 5 km would require only 18 500 lines, i.e. an investment of USD 46.25 million.

NOTE – A more detailed calculation should be made to take account of the exact rural population distribution with respect to desert areas, forest areas, etc.

The provision of universal service – one telephone line per household, each household having six inhabitants – would require some 2.33 million lines, i.e. an investment of USD 5.75 billion.

NOTE – The investment required to provide universal service is obviously overestimated, as substantial economies of scale can be obtained when considering the number of main lines to install.

Table 7 summarizes the results:

TABLE 7

Number of lines and required investment in rural areas of a hypothetical country

Requirement	Number of lines	Investment (million USD)	Expected revenue (million USD)
Universal access	18 500	46.25	33.6
Based on GDP/capita	40 500	101.25	33.6
Universal service	2 330 000	≤ 5 750	33.6

NOTE – Noting that investment is a one-time expenditure and expected revenue occurs annually, it appears that the first two approaches are potentially profitable, even though revenue from inward traffic has not been considered.

3.6.2 Growth forecasts

Actual growth rates in the rural sector often depend on the availability of investment.

When investment is sufficient to satisfy demand, growth rates should be based on the demand forecast taking into account the historical telephone growth rate, trends and forecasts for economic growth, and demographic changes, for example, due to urbanization or decentralization.

However, growth in the rural network, particularly in its early stages of development, is often limited by the amount of investment available. In this case, the growth forecast will be based on investment policies and forecasts.

Growth should be forecast over a sufficiently long time span so that decisions can be based on a valid economic study period, typically, two to five years.

Annual growth rates could lie between two and twelve per cent, depending on specific conditions. The lowest growth rates generally reflect situations where investment is limited, or market saturation. The highest growth rates generally reflect situations where sufficient investment has become available and suppressed demand is being met.

3.6.3 Example [11]

The Philippine Long Distance Telephone Company (PLDT) estimates telephone demand by municipality. Municipalities are grouped into 1) those served by PLDT and 2) all other municipalities. The latter group includes municipalities served by other telephone companies and those without any service (new areas).

1) Municipalities served by PLDT

a) Requirements for the existing service area are based on surveys of each municipality. Secondary data like population and income are used to estimate growth potential. Inputs from the PLDT local manager for the concerned area are used in arriving at the final figures.

b) Localities within a 1.5 km radius from the population centre but without service, represent the additional population to be served.

c) Main station demand is computed using the following formula:

   – main station demand = population × main station density;

   – the population variable is given by the average population within a 1.5 km radius from the population centre based on data for existing PLDT rural exchanges;

   – the main station density variable is derived from PLDT rural exchanges but is reduced by 10% to recognize the fact that PLDT-served areas are generally more developed.

2) Municipalities served by other telephone companies and municipalities without service

a) Demand is computed using the same formula given above.

b) Regional estimates of main station density are also computed. Residential demand depends on family income, inflation rate and cost of basic necessities. Business demand is assumed to be correlated with gross domestic product (GDP).

c) Demand in barangays (villages) within a 1.5 km radius from the population centre but located outside the village itself is also broken down into residential and business demand.

d) The projection of main station density for residential demand is based on the expected *per capita* GDP growth rate. Business demand growth is expected to be at 3.5% per annum. For barangays within the 1.5 km radius, service will cover 75% in 1987 up to 90% in 2010 for residential and business demand.

3.7 Regulatory aspects

Restructuring and increased liberalization within the telecommunication industry is apparent in virtually every country in the world. This is increasingly clear in the evolving international agreements (WTO) for services.

The 1994 World Telecommunication Development Report explores the breadth and diversity of the issues, the alternatives, the choices that have to be and are being made, and, to the extent possible, the outcomes. The contribution of the service sector to economic wealth is clearly on the rise. At the same time, technological innovation is increasing capacity and lowering costs dramatically, most evidently in the long-haul transmission field, but also in switching, and in operational support and commercial systems. In the local loop (or "access") network, some costs such as right-of-way, power supply and civil works are resistant to reduction, but new technologies offer much improved quality and flexibility.

Tariffs established under monopoly conditions have traditionally subsidized local service from national and especially international long-distance revenue. Business service subsidizes residential service, and urban service subsidizes rural service. When service competition is introduced, the new service providers quite naturally direct their attention to the service areas where price is set well above cost, and shy away from areas where cost equals or exceeds price.

As regards interconnection, the new service providers need to connect their customers' calls through the established PTO's local loop network, certainly at one end of the call, and usually at both. The terms and conditions of this interconnection are central to their business case.

A. Dymond of Teleconsult Ltd., Canada [12], has reviewed policies which can be used to speed up the development of telecommunications in rural and remote areas of developing countries. Table 8 below gives some examples of policies to promote rural telecommunication development.

TABLE 8

Examples of policies [12]

Policy	Country
Placing service obligations to reach certain categories of community on newly privatized monopoly operators	Mexico, Argentina, Venezuela, Peru
Enforcing rural percentages for new competitive entrants, monopoly concessions, reformed or partially privatized operators	India, Indonesia, Malaysia, Botswana
Offering monopoly licences for service areas which are predominantly rural	Czech Republic, Hungary, Bangladesh, Venezuela
Allowing competitive entry or cooperative service providers to serve rural areas	Argentina, Poland
Tying rural obligations to attractive international gateway, cellular or value-added operating licences	Philippines, South Africa
Offering telecommunication development fund finance for areas not covered by main operator obligations	Chile, Peru

The above examples can be classified into two categories:

3.7.1 Category one: Enforced internal cross-subsidization

One example of a country which has established telecommunication service throughout its rural and remote areas through the regulatory implementation of a specifically defined and targeted concession obligation is Mexico [3]. When Telmex, the incumbent operator was privatized in 1990-1991, the privatization concession included very specific terms and conditions for extending telecommunications to communities of specified populations throughout the entire country. At the time, a rural telecommunication policy was already in place, and a rural telecommunication programme was in progress in Mexico. The network planners had considered the technologies which were available and relevant, and the most promising were already being introduced into the Mexican network. The terms of the Telmex concession included the requirement that telecommunications be extended to all communities without service in Mexico, as indicated in Table 9 below:

TABLE 9

Telmex compliance expansion requirement matrix

Population of the community							
	0-500		**500-2 500**		**2 500-5 000**		**>5 000**
Applicants (A)	<100	>100	<100	>100	<100	>100	(B)
By end of 1994	Nil	Nil	(C)	(C)	(C)	(D)	(E)
1995 and beyond	(F)	(D)	(F)	(D)	(F)	(D)	(E)

NOTES

A) Applicants, with three-month deposit paid.

B) No waiting applicant requirement. Automatic exchange service must be provided to all communities with populations over 5 000.

C) Minimum requirement, pay telephone and/or agency: “Access to basic service”.

D) Automatic exchange service must be provided within 18 months of 100th waiting applicant.

E) Automatic exchange service must be provided to all communities with populations over 5 000.

F) Provide service if 75% of costs can be recovered.

At the time of the concession, based on existing census information, it was estimated that this requirement would involve the provision of service to approximately 9 600 additional communities, with the expectation that additional census data before the end of 1994 would both add additional communities to those that required service and change the category of some of those communities already on the list.

The Mexican experience, following the Telmex concession, is an example of a relatively well executed and successful rural telecommunications programme, one that was orderly, and economically implemented, and that met its goals. It was planned and carried out over a four-year period, with clearly defined terms of reference, a specific target performance and a mandated completion date.

3.7.2 Category two: Licensing of exclusively rural operators

In countries like Bangladesh, Czech Republic, Poland or Venezuela, rural operators have been licensed to operate primarily in rural areas. A number of issues have to be considered: profitability, revenue sharing and interconnection.

3.7.3 Interconnection

The following draws on the work of the fourth ITU Regulatory Colloquium/Strategic Policy and Planning Unit [13, 14].

In order to create a competitive environment for telecommunications, new market entrants must be able to interconnect on terms that are “just and reasonable”. These terms include not only pricing, but also many other dimensions which will be briefly discussed below.

It is useful, as a preliminary, to realize that a large proportion of a long-distance entrant's total costs consists of payments made to the incumbent PTO for interconnection services. As an example, over 45% of the total cost incurred by Sprint (one of the long-distance carriers in the United States) in providing an average call, consists of payments for interconnection services to originate and terminate its calls or to carry them for part of the long-distance route of another long-distance carrier (this figure is based on analysis of Sprint's annual reports 1991-1993 by M. Tyler *et al*). Similarly, a few years ago, two Japanese long-distance entrants, DDI and Teleway Japan, were paying about 35% of their price for a typical call to the incumbent PTO, Nippon Telephone and Telegraph Corporation (NTT), for local carriage of a call. All entrants which initially offered only long-distance service (including, in some instances, international service), have faced interconnection costs of similar magnitude.

Interconnection prices which permit entry and sustained operation by competitors are a necessary but not sufficient condition for an economically sound interconnection policy. The level and structure of interconnection pricing also affects the balance of competitive advantage and the specific strategies and behaviour of both the incumbent and the entrant. Terms of interconnection based on appropriate economic criteria, and the resulting development of competitive pressures, can provide incentives for the incumbent to improve its performance and for entrants to seek out the most cost-effective ways to build new networks and develop or re-engineer operational systems and practices. On the other hand, interconnection prices that are too high (or "anticompetitive") will result in a misallocation of resources. The WTO agreement on basic telecommunications provides some guidance in this regard: "Interconnection with a major supplier will be ensured at any technically feasible point in the network ... under non-discriminatory terms, conditions (including technical standards and specifications) and rates and of a quality no less favourable than that provided for its own like services or for like services of non-affiliated service suppliers or for its subsidiaries or affiliates ...". Administrations seeking a broad framework on which to base an interconnection policy would benefit from the broadly-adopted WTO reference paper.

3.7.3.1 Types of interconnection

Seven types of interconnection are considered in this ITU report on interconnection. They are relevant for rural development to the extent that rural services may be supplied by a supplier in competition with the existing PTO. In many cases, competition may be a necessary tool to promote rural telecommunication development and extend the existing network. In other cases, restructuring, alternative planning, or, more likely, an influx of direct national or foreign investment within the existing infrastructure may be enough to foster development.

Using the methodology derived by the ITU interconnection report, seven types of interconnection have been grouped into three classes. The classes and types are as follows:

Class 1

1) *Attachment of Customer Premises Equipment (CPE) to the PSTN*. This subject concerns the regulatory rules dealing with interconnection to the PSTN of customer premises equipment (CPE), such as telephone sets, fax machines, modems, or PBXs. Because evolving technology in many cases provides opportunities to chose between having certain specific functions performed by the CPE or by the PSTN, the distribution between CPE attachment (especially of PBXs) and other forms of interconnection is somewhat less clear than it may initially appear to be.

2) *Interconnection of private ("corporate") networks to the PSTN.* Private networks, usually based wholly or partly on the use of leased lines ("private circuits") provided by one or more PTOs, can exist as entities carrying traffic only between points "on-net", i.e., sites connected by PBXs or by leased lines. However, their economic value is greatly enhanced if calls can originate on the private network and terminate on the PSTN, or originate on the PSTN and terminate on the private network.

3) *Interconnection of value-added networks (VANs) to the PSTN.* Providers of value-added or "enhanced" services (for example electronic mail, on-line information/database access services, or specialized data communications services) operate their own network assets such as computers, applications software, and sometimes specialized switches. They need to interconnect with the PSTN and/or a public switched data network (PSDN) in order to provide their services to most end-users.

From the regulator's standpoint, the three types of class 1 interconnections are similar in two basic respects. Because CPE, private networks and VANs do not compete with the basic network business of incumbent PTOs, they have been liberalized in many countries well before public policy in those countries permitted competitive entry into the core-network telephone business. Private networks and VANs are often subject to little if any regulation, and regulators generally permit incumbent PTOs to charge interconnect buyers as though they were ordinary end-users (they might, however, enjoy discounts generally offered to large-volume end-users).

Class 2

4) *Interconnection of new fixed long-distance networks to the PSTN.* For our purposes, this refers to the "classic" case in which the entrant is wholly or mainly a facilities-based provider of only long-distance and international services, as in the case of MCI and Sprint in the United States, DDI in Japan, Mercury in the United Kingdom, Clear Communications in New Zealand, for example.

5) *Interconnection of new fixed local networks to the PSTN.* Although in most cases competitive entry occurred initially in the long-distance and/or international markets (where it has happened at all) alternative fixed networks are now being established in many countries for local service as well. Some of these operators provide only local service over their own network. In order to provide a commercially viable service, such operators must interconnect to one or more long-distance carriers and to the incumbent PTO's local network in their own local area.

Both types of class 2 interconnection have come about only after a country's public policy has permitted entry of one or more enterprises prepared to compete with the incumbent PTO in the market. This usually (but not necessarily) takes place after class 1 interconnection has been liberalized. Once this profound regulatory change has taken place, further and complex regulatory issues arise concerning interconnection, such as the proper level and structure of interconnect charges, and the best processes for regulating those matters.

The interconnection of the entrant's network to the PSTN operated by the incumbent PTO forms an extended PSTN, essentially a unified physical network owned and operated by multiple independent organizations. Interconnection issues of concern to regulators are mainly related to the interconnection of entrants which build and operate their own transmission networks ("facilities-based carriers"), but in some cases extend to resale carriers (those which operate mainly or wholly by reselling the services of other carriers).

Class 3

6) *Interconnection of cellular and other "wireless" networks to the PSTN.* Because the great majority of traffic carried by cellular networks originates or terminates on the fixed PSTN, interconnection to the incumbent PTO is a necessity. Similarly, "wireless" networks which provide local access service by wireless means must interconnect with the PSTN in order to provide commercially viable service.

7) *Interconnection of satellite systems to the PSTN.* In principle, this is not a separate category. If satellite systems provide mobile services, they might fall into type 6. If they are established for in-house corporate use, they might fall into the private network category. If used as facilities by a fixed-network operator, they could be regarded as belonging to class 2. Nevertheless, in practice, interconnection policies concerning satellite systems are often considered as a separate item on the regulatory agenda. This has been the case, for example, in each of the European countries that has allowed competitive entry in satellite communications.

Both types of class 3 interconnection involve entrants that will enhance significantly the networks of national incumbent PTOs. Aside from the generic regulatory issues that also concern the entrants belonging to classes 1 and 2, class 3 entrants raise special regulatory issues that derive in part from the claims that they make on the radio-frequency spectrum and from the transnational mobility of many of their end-users.

3.7.3.2 The multiple dimensions of interconnection policy

An interconnection policy has several different elements. The dimensions of interconnection policy can be defined by considering two questions: what are the terms of interconnection that are important to an entrant, and which of those terms will the regulator seek to influence or control?

Interconnection terms

a) Price aspects:

   – Level of prices

   – Structure of prices

      • Average/de-average

      • Bundled/unbundled

      • Single-part or multi-part.

b) Non-price aspects:

   – Technical operational terms

      • Interconnection functions performed

      • Bundling vs. unbundling of interconnection functions

      • Geographic structure of interconnection

      • Location of the point of interconnection in the network architecture of the incumbent's PSTN

      • Quality provisions

      • Technical interfaces and standards.

   – Administrative terms

      • Information disclosure

         i) Current situation of incumbent's network

         ii) Future plans for incumbent's network

   – Billing/payment terms

The "general level of interconnect prices" means how much an interconnecting carrier pays to the incumbent PTO for carrying a given volume of traffic or for providing a given amount of capacity. A key issue concerning the level of prices is the extent to which they may include an element of surcharge based on considerations other that the resources used by the incumbent PTO to provide interconnection services, for example, to help defray the incumbent's cost of fulfilling universal access/service obligations.

The structure of interconnect pricing has numerous components. Of these structural considerations, the most important are:

– *Averaging vs. de-averaging:*

  Interconnection charges may be set at the same level for all traffic or may vary, usually in order to reflect specific circumstances which affect the incumbent PTO's cost of providing interconnection services. De-averaged charges may vary to reflect factors such as:

  • the volume of traffic at each point of interconnection (POI);

  • how close an entrant's POI is to the nearest local switch in the incumbent PTO's network (if the distance is great because the entrant has chosen to install few POIs, its traffic must reach the incumbent's nearest local switch via intermediate links in the incumbent's network, i.e. tandem switches or "inter-machine trunks");

  • the geographic area where interconnection is provided (the incumbent PTO's costs may be higher in some areas than in others, for example because of the number and geographic density of telephone subscribers).

– *Bundling vs. unbundling:*

  Does the interconnecting carrier pay a single charge for all the network functions required to originate or terminate a call via the incumbent PTO's network? Or is there a menu with different functions being priced separately, with the option to select certain functions and not others, in cases where this is technically feasible? Unbundling may involve offering the use of different geographic parts of the incumbent's network separately, or different technical functions separately, or both.

– *Single-part vs. multi-part tariffs:*

Interconnection charges may take the simple form of a price per minute of traffic in a single-part tariff. Alternatively, the price may comprise several different components: for example, a per-minute charge, plus a charge based on the interconnection capacity provided by the incumbent PTO. More elaborate kinds of multi-part pricing are also possible. A good economic case can be made for some of them although they can be complex to implement.

In conclusion, successful and sustainable rural telecommunications can only be achieved within an appropriate policy and regulatory framework. International organizations could provide technical assistance to develop country-specific tariff and interconnection policies which support to the commercial development of telecommunication services in rural and remote areas. Examples of countries where such initiatives have already proven successful include Mexico, described above, and Bangladesh, cited earlier.

Experience indicates that the regulatory regime which most successfully supports the development of rural telecommunications includes the following:

– an independent regulatory authority is in charge of licensing and concession arrangements;
– appropriate tariffs and revenue settlement arrangements are in place;
– concession obligations shall take into account the financial integrity and sustainability of the rural telecommunication service;
– interconnection terms and conditions are addressed and defined;
– effective spectrum management ensures efficient spectrum utilization;
– licensing arrangements are consistent with efficient network structure;

The basis for providing telecommunication services to rural and remote areas should include the following principles:

– service is provided through PCOs and MCTs, and lines to serve business customers;
– rural investment is encouraged, in ways which are broadly consistent with price/cost relationships;
– innovation is encouraged in providing rural service;
– operation of rural PCOs and MCTs franchised by franchising private sector,(local) entrepreneurs is encouraged.

Cost and revenue relationships are key considerations for the regulatory agency, and in particular an understanding of the volume and revenue of incoming traffic, including incoming international traffic. The regulator may require an adequate and appropriate, but not excessive, “local revenue contribution” from all incoming and outgoing traffic, both national and international.

An obligation which makes the provision of service to the rural and remote areas mandatory will often be needed. The financial obligation should be kept as low as practical, consistent with assuring the financial integrity and sustainability of the rural telecommunication service.

An approach which has proven to be successful is the setting of conditions, in the PTO’s licence or concession, requiring accelerated and sustained rural service provision.

3.8 Financing aspects

In many countries, rural telecommunications is still considered a loss-making business. However, recent studies indicate that rural telecommunication service is, in fact, generally profitable.

The provision of telecommunication services in rural and remote areas nevertheless requires a large amount of financial resources (see § 3.2.1 above). The required capital may be obtained from:

– revenue (self-financing);
– private sector investors;
– multilateral development assistance;
– bilateral assistance.

Other forms of financing include:

– internal cross-subsidization;

– skewed interconnect charges or contribution in favour of the rural operators;

– rural development funds.

Both multilateral and bilateral assistance are in short supply, just at the time when more capital is needed by the developing countries for investments in rural telecommunications. Clearly, internal financing, private sector participation and innovative financing schemes are the only possible alternatives.

Successful and sustainable rural telecommunication services must be based on commercial business principles.

The operator must clearly understand and address both costs and revenues, seeking every opportunity for minimizing the former and maximizing the latter. Costs may be driven down by such mechanisms as volume purchasing, competitive procurement, infrastructure sharing, system and equipment design innovation, local manufacturing and use of local human resources. Revenues may be increased by broadening the scope of services carried by a given infrastructure or facility and by efficient marketing.

In addition, the PTO must be permitted, and encouraged, to set and follow its own agenda, without government direction and interference other than a sensitive and "minimalist" regulatory function.

Within ITU-D Study Group 1, a draft interim report has been published on Policies and ways for financing telecommunication infrastructures in developing countries. Together with the proceedings of the six Telecommunications Finance and Trade Colloquia organized by BDT in the various regions of the world and the 1998 Review on Finance and Trade, these documents give a comprehensive overview of the various means available to secure financial resources [15, 16, 17].

It is worth noting that a number of incentives may be granted by the governments to help the PTO and potential investors to establish the required infrastructures at lesser cost. Examples of such incentives are reduced import taxes and duties on equipment, income tax holiday, carryover of deduction of net losses, etc.

One way of reducing the cost of serving rural areas is to encourage the establishment of local cooperatives, which will build, operate and own the local network. This could involve the use of volunteer labour to build telephone plant, with the obvious related cost savings. The cooperative would normally be managed on a volunteer basis.

A key concern in developing a positive business case for rural telecommunications is to ensure that every line generates sufficient long-distance revenue on both outward and inward calling. This is generally achieved for PCOs/MCTs and for institutions and commercial enterprises, which generate significant long-distance calling. If potential residential subscribers are heavy users of long-distance services, then providing residential service to them will help the business case. To ensure that the long-distance revenue from such subscribers is adequate, the "take-or-pay" tariff principle could be used. Under this principle, the subscriber who is provided with a line at his residence will undertake to pay a specified "base amount" of long-distance revenue, even if his long-distance calling volume falls short of that amount.

Franchising the installation and operation of terminal equipment (PCO or MCT) is another way to reduce the PTO's investment and operation costs. Experience in Senegal and India, for example, shows that both the franchisee and the PTO are making substantial profits. The experience in Bangladesh, where Grameen Telecom [18] has obtained a licence to provide telecommunication services in each of the 68 000 villages of the country, is another example of a successful approach. The terminal equipment in each village is purchased by one inhabitant of the village with the help of a microloan. This microloan will be reimbursed by the terminal operator over a period of time using the earnings made from operation of the terminal. It is interesting to note that such an approach also helps in providing employment in remote villages for those operating these terminals.

For the larger investment in the required telecommunication infrastructure, the necessary capital could also be generated through a "revolving rural telecommunication development fund" set up on a national, subregional or regional basis by the operators, who would contribute a few per cent of their revenue to such a fund. The operation of such a revolving fund is described in [17, 19]

3.9 Planning of national rural telecommunication development [3]

3.9.1 Development plans

Planning a telecommunication network for a given area and period of time involves:

- defining the structure of the general network (switching and transmission) and the subscriber access network;
- choosing systems which satisfy environmental constraints, operating objectives, the required functions and customer demand, while giving the best value for money.

Depending on the planning horizon, a distinction is made between the following types of plan:

a) Master plan (long-term planning)

This is a document covering the general development plan over a period of ten to twenty years.

A telecommunication network will not remain optimal for very long if allowed to evolve at the whim of short-term operational management criteria.

That is why it is necessary to draw up a telecommunication master plan, an essential document which will serve as a framework for a coherent policy in terms of equipment, rational technical management and proper control of investment costs.

b) Medium-term plan

A medium term plan, which covers a period of three to five years, deals with the feasibility of projects and their specifications. It is intended to define:

- the target network for the period in question, with an estimate of current and future service needs;
- the major phases of transforming the existing network into the target network.

c) Short-term plan

A short-term plan covers a period of one to three years, and applies to particular project specifications or to project extensions. In other words, it establishes in detail the development of the network and the practical means of implementation.

d) Updating of master plans

Long-term and medium-term plans should be updated periodically to reflect changes in demand and technology.

3.9.2 Fundamental technical plans

The following list of fundamental technical plans is not exhaustive:

- numbering plan;
- routing plan;
- transmission plan;
- digitization plan;
- synchronization plan;
- charging plan;
- signalling plan;
- coverage plan;
- frequency plan; etc.

3.9.3 Network planning

Network planning has to be based on preliminary studies, which entail assembling the following basic data:

1) Demand and traffic forecast

A demand forecast gives a projection of the number of main lines (ML) in the target year (including immediate and future needs of the rural areas concerned). In addition, it should give a breakdown of main lines between PCOs, MCTs, business, administration, residential and service lines and the type of services offered.

Traffic forecast made on the basis of demand forecast, will indicate the traffic volumes and flows. Only when the traffic is known, equipment can be dimensioned accordingly.

The coverage target, in terms of the geographic extension of the network, should reflect economic, technical and operational realities, as well as a definition of universal access/service that is consistent with development needs and the capabilities of the telecommunication operator or operators.

2) Engineering rules governed by the development strategy, taking into account the systems to be introduced and the fundamental technical plans.

3) Data concerning the existing infrastructure which serve as a basis for decisions regarding:

– the replacement of obsolete equipment;

– the extension of the life of equipment which is still serviceable;

– the use or relocation of existing infrastructure (e.g. towers).

Taking into account the above data and information, the network planning further involves the following tasks:

a) choice of exchange sites and transmission nodes;

b) design of switching network structure.

In the past, rural networks have often included large numbers of small local switches. Because of their small scale and remote siting, these switches typically have very high capital costs and maintenance costs per access line. Newer variants of the terrestrial "wired" architecture partially solve this by concentrating traffic from users' access lines in each location via some form of remote unit. The latter may not perform all the switching functions, but instead moves the traffic over efficiently shared transmission circuits to a regional switch. This allows economy of scale which cannot be achieved in an architecture requiring large numbers of small switches.

The newer "wireless" architectures take the same idea a stage further, collecting and concentrating traffic via radio "base stations" (each of which may serve a wide area, where customer densities are low). The traffic from several base stations is routed through a regional switching location which can achieve economics of scale. There are also satellite-based solutions, essentially based on the same concept, except that the "base stations" are in the sky and the geographic areas over which traffic is collected (the satellite "footprints") are much larger. Such architectures are therefore especially suitable for serving regions where there is a very low density of customers (and the fixed cost of a terrestrial base station is too high per customer served), as well as regions with difficult terrain, where the costs of terrestrial plant and/or radio propagation are major problems.

c) design of transmission network structure.

In particular, long-distance transmission links in a rural network represent an important part of the investment, whatever technology is used, e.g. open-wire lines, terrestrial microwave, overhead cables or coaxial cables, optical fibre cables, or even satellite links. Achieving efficient utilization of these links is therefore vital. Possibilities for achieving this include:

– use of digital compression for voice signals;

– using the capability of wireless connection to end-users to collect traffic over a wide area, so that different traffic streams with their "busy hour" occurring at different times are combined on the same transmission medium. The ability to do this is a particular advantage of satellite-based architectures;

– use of common channel signalling (using the ITU-T standards for Signalling System No. 7) to avoid wasting voice circuit time for signalling.

d) planning of civil engineering works (buildings or shelters, access roads, (ducts, jointing chambers, radio sites, towers, etc.);

e) planning of power plant requirements (conventional, solar, etc.);

f) delimitation of areas (local and cross-connection);

g) evaluation in terms of pair/km of primary cables and/or radio-relay transmission equipment linking exchanges and base stations for the access network;

h) evaluation of outward secondary pairs and/or access radio equipment (base stations and subscriber terminals) for the access network;

i) investment cost estimates for the planning period, which are used:

– to estimate the financing required to implement the development plan;

– to estimate overall profitability of investments;

– to allow adequate and timely mobilization of funds.

Land acquisitions for buildings and towers, rights of way for wire networks (poles of cables), power lines and access roads shall be included in the investment estimates.

These tasks will lead to corrections, re-evaluations and periodic updates throughout the life of the development plan. The complexity and repetitive nature of calculations lend themselves to the use of software tools both for planning and for updating purposes.

Depending on the type of planning, specific tools can be used, for instance for:

– general network structure (switching and transmission); and

– local subscriber access network structure (cable and/or radio).

3.9.4 Planning in rural areas

The rural network should be considered as an extension of the national public network. Network planning in rural areas must therefore address both the structure of the trunk network, which carries rural area traffic, and the access network for rural subscribers.

As indicated above, planning software tools are used to prepare the general network structure, including the exchange covering the rural area.

Specific planning tools designed for the “radio” parts of the local network, including, for example, coverage calculations, frequency requirements and frequency planning, are also available.

Such software enables simulations, varying the input parameters, which assist in selecting the optimal network structure and the most appropriate technologies.

3.9.5 Complementary studies

Complementary studies should be undertaken to cover economic feasibility, project planning and human resources requirements for rural networks.

The economic feasibility study helps to select the optimal and most economical solution, taking into account investment costs, income and operating costs. It also allows a readjustment of plan objectives according to budgeted financial resources and operating costs. The final result, which is subject to periodic re-evaluation, can then be used to revise development plans.

The human resources and training requirements needed to operate the network should also be determined, as this will also affect the cost of the project.

In conclusion in any network planning, total demand must be taken into account, including the immediate and future needs of rural areas. For short-term or medium-term projects, detailed specifications are needed to prepare calls for tender to ensure that these meet operating requirements and performance objectives. (Some specifications are provided by network planning, e.g. amount of traffic per exchange, number of circuits, routing plans, required transmission capacity, etc.)

3.10 System design considerations

3.10.1 Criteria for technology selection

In addition to the above, the following criteria should guide the selection process:

a) New equipment will be digital down to and including the local exchange. Below the exchange level (i.e. the subscriber access network or local loop) digital is preferred but analogue is acceptable based on economic grounds. The intent is to maximize network economy while remaining consistent with the state of the art. Community exchanges may be any technology that provides the required service at lowest costs now and in the future.

b) Locally manufactured equipment and components should be given preference, when justified.

c) Equipment and systems built to ITU recommended standards are to be preferred to proprietary or closed standards.

d) Although a range of capabilities will be needed, the number of different equipment types in use should be kept as low as possible in order to maximize economies of scale and minimize operational costs such as spares and training.

e) Modular equipment or systems which have maximum flexibility for expansion and ease of redeployment will be preferred.

f) Field-proven equipment with reliability data, based on in-service statistics, will be preferred for any large-scale deployments. In all cases, warranties should be specified.

g) Equipment with low power consumption and with optional integrated standby power subsystems will be an advantage.

Ideally, a small group of candidate technologies would be selected on the basis of the above considerations and used in the system design process. From this, equipment orders in significant volume could be competitively tendered. To date, the following technologies have been selected and applied in significant volumes by government and private sector implementing agencies:

– multiple access subscriber radio systems;

– fixed and mobile cellular communication systems;

– single-/two-channel radio systems;

– low-capacity digital switching exchanges;

– small Earth stations/VSATs.

The system design process should be comprehensive and consider existing and future service requirements as well as integration with the PSTN and, if required, other networks. Procurement, infrastructure sharing, service integration and quality of service should be taken into account in optimum (least-cost life cycle) system design. Every cost item must be carefully considered, for example:

a) The high cost of self-supporting towers will significantly raise the per-line cost at remote sites serving one or a few lines and is therefore difficult to justify except at sites with an exchange.

b) More repeaters at sites with easy access may be easier to maintain than a few repeaters at sites with more difficult access. However, more repeaters will require more capital and more maintenance.

3.10.2 Environment constraints

The environment influences system design and equipment selection. Therefore the following information should be compiled:

– average monthly temperature highs, lows, and extremes;

– highest relative humidity and temperature combination;

– highest wind speed (steady and gusts) and prevailing direction;

– frequency of electrical storms (lightning);

– precipitation rates (rain, hail, snow);

– dust, insects, fungus;

– corrosive atmospheres or pollutants;

– insolation data (for solar power);

– seismic activity;

– soil characteristics (for civil works and for earthing).

Yearly distribution statistics should be collected for each location, if available. Minimum and maximum values should be those normally encountered, since it is generally impractical to design to extreme, but rarely encountered, conditions.

3.10.3 Implementation

To keep the project on track throughout the implementation phase involves:

– monitoring progress and tracking the completion of milestones;

– inspecting the construction of civil works and equipment installation; and

– reviewing for deficiencies and acceptance testing the completed works.

Computer-based tools for project planning and monitoring are available and should be used, when possible.

3.11 Network management

Network management functions are those related to the configuration, control, monitoring and recording of the utilization and functioning of network resources, in order to provide telecommunication services at acceptable quality and cost.

ITU-T has defined a functional architecture and a physical architecture for the management function, the Telecommunication Management Network (TMN). The generic model is defined in ITU-T Recommendation M.3100. Details related to the SDH information model are given in ITU-T Recommendations G.774, G.774.01, G.774.02, G.774.03 and G.774.04.

Since telecommunication service offerings and traffic handling capacity of switching nodes and transmission systems are constantly increasing, network management (including operational, maintenance and administration aspects) is becoming more and more important. It involves the supervision of several network elements, in order to know their status and usage, to control and to optimize service performance.

The Telecommunication Management Network (TMN) Recommendations present the general architectural requirements to support the management requirements for planning, provision, installation, maintenance, operation, and administration of telecommunication networks and services. Within the context of TMN, management refers to a set of capabilities to allow for the exchange and processing of management information to assist operators in conducting their businesses efficiently. OSI systems management (Recommendation X.700) services and protocols represent a subset of the management capabilities that can be provided by TMN. These concepts are applicable to rural networks, provided the required adaptations and simplifications are made.

The management application functions are contained within the operation system functions of the TMN. They are located in four layers, as follows :

a) At the *network element management level* (NEML) are located functions related to the management of network elements in a region. These are most likely to focus on maintenance but could well include some configuration capability or even detailed statistics.

b) At the *network management level* (NML) are located functions addressing the management of the particular network as a whole. Complete visibility of the whole network will be typical and a vendor-independent view will need to be maintained. Configuration of the network as a whole would be performed at this level, as would performance analysis and statistics.

c) At the *service management level* (SML) are located all functions which manage a particular service. The service may be implemented across several networks, each network supporting many services. It is at this level that customer-related functions are to be found, including subscription records, access rights, maintenance of usage records and accounts as well as functions related to the establishment and maintenance of facilities provided by the service itself, over and above the network facilities.

d) At the *business management level* (BML) are located all the functions necessary for the implementation of policies and strategies within the organization which owns and operates the services (and possibly the network). Influenced by still high levels of control such as legislation or macro-economic factors, these might include tariffing policies, quality maintenance strategies giving guidance on service operation when equipment or network performance is degraded, and so on. It seems that the majority of these functions are unlikely to be automated in the near future, although some tools involving trend analysis, economic modelling, demand modelling or quality impact prediction could be envisaged.

The main management functions of the TMN concern:

– faults: alarm supervision, fault location and performance of tests;
– accounting and statistics: all functions allowing the accounting of network utilization;
– performance: traffic and network management (traffic observations, reconfiguration control) and observations for quality of service optimization;
– configuration: management of configuration parameters, installation, controls and states;
– security: system and network protection against non-authorized resources and data or equipment malfunction.

In all networks, resource management will be facilitated with homogeneous equipment, for both switching and transmission. Maintenance will be simplified and less costly with a smaller number of boards to be tested, repaired or replaced. Management of materials, documentation, training, and so on, will also be greatly simplified if equipment is standardized throughout the company.

Equipment should be able to undergo enhancement or modifications while it is in operation. Evolution should be compatible with previous modifications and with existing services, software, documentation, etc. Most of these modifications, for instance microprocessor software loading when new services are going to be offered, may be performed remotely.

New technologies simplify operation and maintenance with on-line tests, automatic fault detection and localization. This is particularly important in remote areas.

The implementation of SDH transmission equipment improves network availability and reliability. Mechanisms acting at different levels provide information on network operation in order to prevent system failures due to saturation or network resource overloading.

Several ITU-T Recommendations in the G, M and Q-series address aspects of network maintenance, management and operation.

3.12 AOM&P (administration, operation, maintenance and provisioning)

AOM&P for telecommunication service includes:

– marketing of services;
– billing and charging subscribers, including collection of money in coin boxes;
– control of subscriber status (temporary/permanent disconnections);
– preparation of, and adherence to, an annual administration, operation and maintenance budget (personnel and material);
– training of personnel for operation;
– installation works of subscriber stations at new customers’ premises;
– follow-up of customers’ claims;
– user training or instruction;
– administrative maintenance.

Existing rural telephone systems shall be changed as required in order to meet increased demand or demand for new services. The following should be done to maintain the required GOS (grade of service):

– increase number of channels;
– modification of system parameters;
– monitoring of traffic data;
– analysis and utilization of failure statistics;

– inventory control of spares;

– contract and execution of repair by the manufacturer of equipment and units which cannot be repaired in a maintenance centre;

– training of personnel for maintenance;

– preventive maintenance;

– corrective maintenance.

4 Network technologies

The access network is the part of the telecommunication network that connects subscribers to the local exchange. It consists of a number of switching and transmission elements, which, traditionally, have been arranged in a star, tree or bus configuration. Among all the various design topologies, one has to be chosen based on the geographical distribution of existing or planned remote sites, the services to be offered, expected traffic, environmental hazards and security. With the introduction of SDH in the network, a technologically suitable topology is the “ring” configuration. In such a configuration, all switching concentrators and local and remote subscriber units can be connected to the parent exchange through a self-healing transmission ring.

Whatever network topology is chosen, however, the access network to the subscribers can be implemented with a variety of systems using copper, optical fibre, radio, microwave or satellite transmission, or a combination thereof.

In the past, access networks in rural areas were usually implemented with copper wires, sometimes in combination with point-to-point low-capacity radio or point-to-multipoint microwave radio. Today, new technologies make for:

– reduced operation and maintenance costs;

– improved maintenance and operation (e.g. centralized fault localization, service modification, etc.);

– easy and rapid implementation of new services;

– larger bandwidth/higher capacity.

The aim of this chapter is to review these new technologies, considering also their ability to carry new services such as Internet, multimedia, video-on-demand, TeleMedicine, tele-education, etc., which require a larger bandwidth. Even though potential individual subscribers in rural areas of developing countries may not, at present, be able to afford such services, they have to be taken into account when planning new networks or upgrading existing ones. For instance, fully-fledged multipurpose community telecentres (MCT) require a larger bandwidth than public payphones (PCO), since MCTs aim to provide new services as well as user support and training for the majority of the population of a village (or group of villages).

In order to avoid high start-up costs, the access network needs to be scaleable so that the network operator, by adding “broadband plug-in” units, can rapidly respond to new demand at minimum cost.

4.1 Switching systems, concentrators and local and remote units [1]

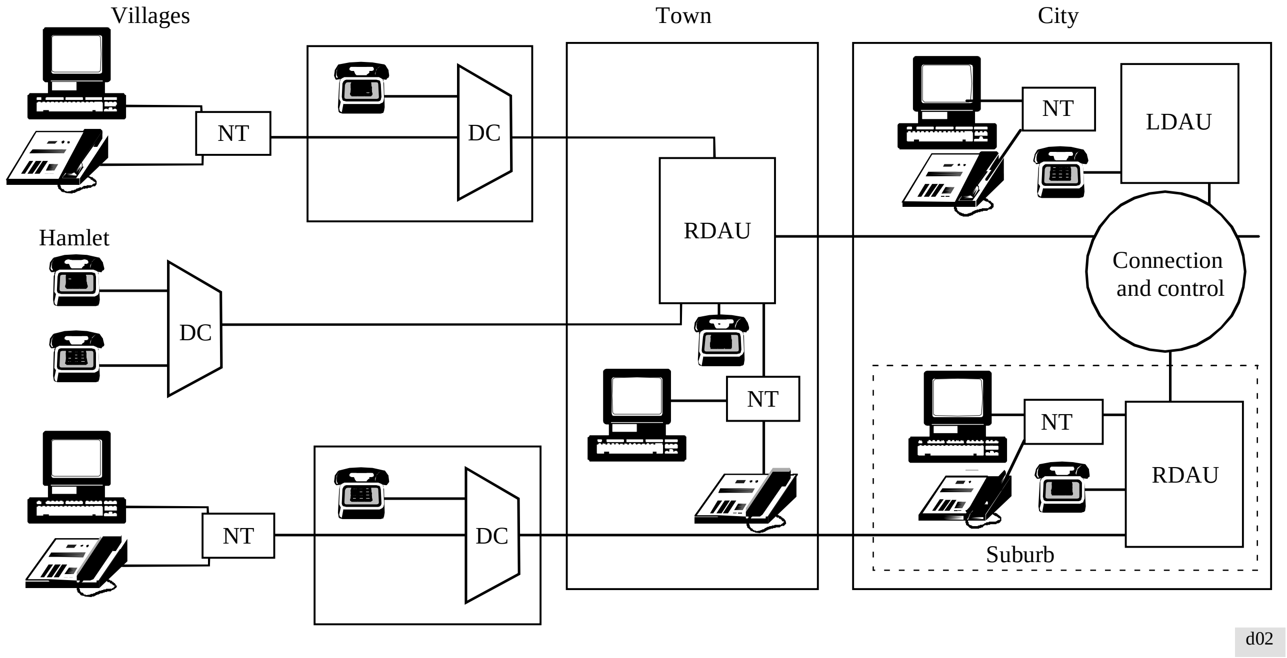
The GAS 7 Handbook gives the example of local network organization (see Figure 2).

4.1.1 Switching

Several suppliers are offering switching systems with a decentralized architecture, where a host exchange provides acentral control unit for functions such as routing and charging. The subscriber connection function is performed by specialized units which may be co-located with the exchange – local digital access unit (LDAU) – or remote from it – remote digital access unit (RDAU). Such an architecture enables an optimum distribution of functions between the different modules and processors. Hardware and software modularity makes the systems adaptable to a range of different network topologies and facilitates expansion of the telecommunication network to meet future needs in terms of number of subscribers, number of locations and narrowband or broadband services.

FIGURE 2

An example of local network organization



RDAU = remote digital access unit
LDAU = local digital access unit
DC = digital concentrator
NT = network termination

The capacity of such switching systems ranges from 2 000 to over 100 000 subscribers. RDAUs and LDAUs, which have a capacity of a few thousand subscribers (typically 5 000), can be split over several locations, which allows for the connection of small clusters of subscribers spread over a large area. In such cases, the subscribers are connected to digital concentrators (DC) with a capacity of a few tens of subscribers and are connected to the RDAUs through 2 Mbit/s links.

RDAUs and DCs are able to perform switching functions for the traffic within their service area, whereas communications to other service areas are processed by the host exchange. Thus, a failure on the path between an RDAU/DC and the exchange does not interrupt local communications and service in the service area of the RDAU/DC.

DCs provide a cost-effective solution where analogue and ISDN interfaces are fully interchangeable, enabling the configuration in any mix as required. They can be managed transparently from the host exchange, eliminating the need for a local management system. Available as indoor or outdoor versions (in the latter case, dust and weather-proof shelters are used), they can be provided with integrated power-conversion and distribution frames, making them ideal for deployment in rural areas.

The various units of a switching system with decentralized architecture interface with the backbone transmission network at 2 Mbit/s, 34 Mbit/s, 51 Mbit/s, 140 Mbit/s or 155 Mbit/s level (622 Mbit/s in the case of very large switching exchanges).

On the access network side, the interface is two-wire or of the V5 type, as recommended by ITU-T.

Some equipment suppliers have already introduced on the market switching systems capable of providing broadband services through the switched network, such as videoconferencing, multimedia and on-demand LAN interconnection. The modular architecture of such switches will also permit new switching technologies, such as ATM, to be integrated on the same platform.

4.1.2 Small stand-alone rural switching systems

Small digital stand-alone rural exchanges are specially tailored for small subscriber cluster applications and offer a cost-effective and flexible solution to rural network implementation. They allow autonomous routing and charging, have their own local management software which can be accessed from a remote site, and offer the same services as large switching systems with a decentralized architecture. Stand-alone exchanges usually have a capacity of between 100 and 1 000 subscribers and also allow the connection of remote RDAUs.

4.2 Multiplexers

To reach remote users, concentrators and subscriber multiplexers have been widely used. Subscriber 2 Mbit/s multiplexers, either symmetrical or asymmetrical, can connect up to 30 subscribers to the exchange. Voice is transmitted on preassigned time-slots, while signalling information is carried on time slot (TS) 16. However, such equipment is manufacturer-specification dependent.

The standard signalling protocols V5.1 and V5.2 allow network operators not to be locked into proprietary switch interfaces.

NOTE – V5.1 protocol is dedicated to managing POTS and ISDN for a maximum of 30 subscribers on a 2 Mbit/s link, whereas the V5.2 protocol is able to manage concentration and allows time slots to be shared among subscribers on a per-call basis, thus resulting in cost savings. Latest version of ITU-T Recommendations G.964 and G.965 describe these protocols in detail.

The new transport technology based on the synchronous digital hierarchy (SDH) coupled with the above-mentioned protocols has led some suppliers to develop a new concept of interconnection based on access node technology [20].

4.3 Interconnection

In the past, outside plant was mainly implemented by means of copper pairs connecting subscribers to the local exchange. Nowadays, the access network can be implemented using a number of technologies, be it wireline (copper or optical fibre) or wireless, or a combination of both. The backbone telecommunication network relies more and more on SDH transport, allowing for narrowband, wideband and broadband services to be offered by the network to meet differing customer requirements.

Figure 3 shows how the network might evolve in a local exchange area using the SDH ring architecture.

Different types of access node already exist or are being developed. Their main characteristics are as follows:

1) *First type*

   The access node equipment can be connected to an STM-I ring with add/drop capacity up to 21 × 2 Mbit/s. It supports the V5.1 (see Note) protocol and handles POTS, ISDN (basic and primary rates) and leases lines.

2) *Second type*

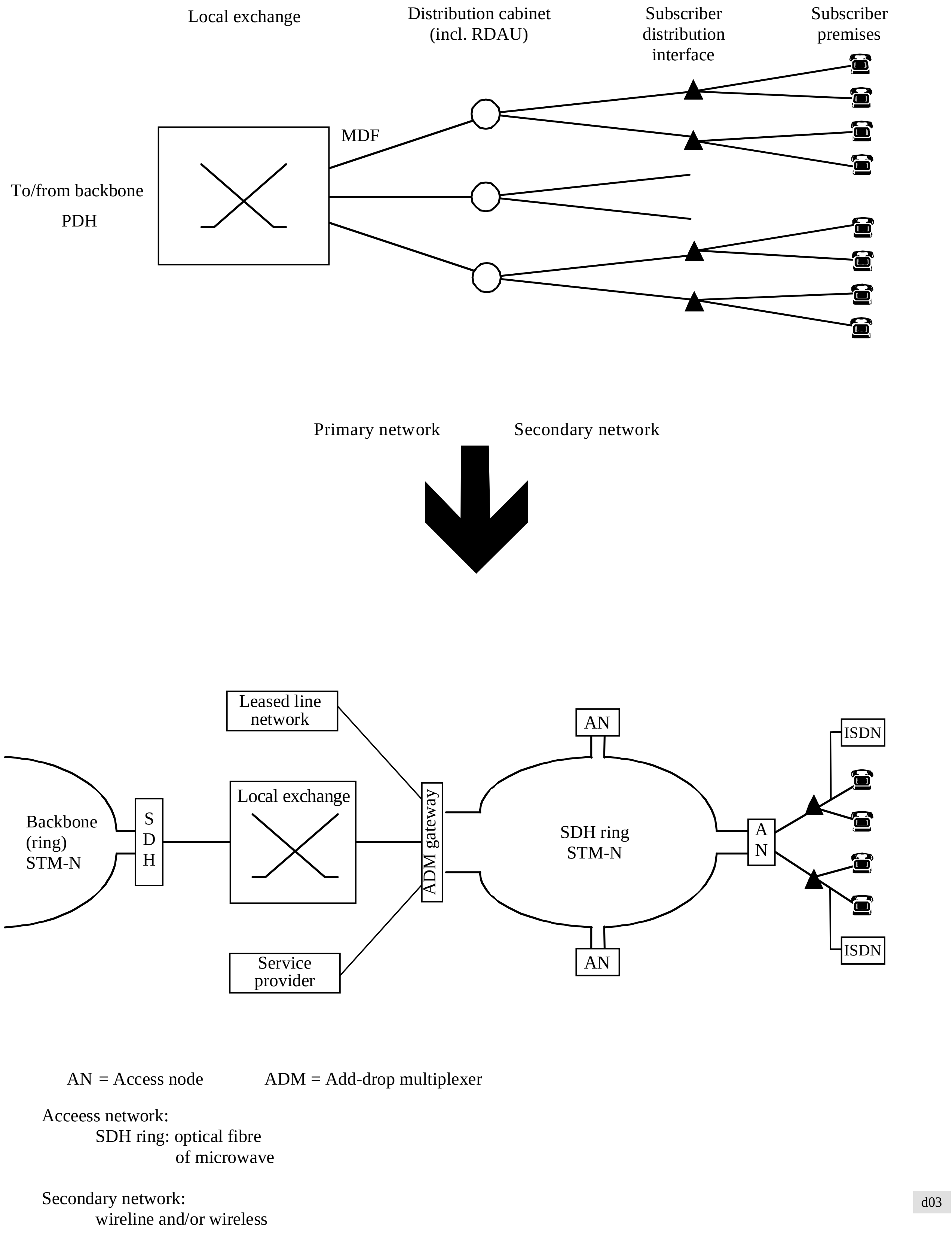
   The access node equipment can be connected to an STM-N ring and supports the V5.2 (see Note) protocol. With 51 Mbit/s both downstream and upstream, available at all the line cards, such access node equipment can handle not only POTS, ISDN and leased lines, but also Internet or other broadband services. Furthermore, an interface card allows multiplexing/demultiplexing of a number of 2 Mbit/s streams which can be transmitted to a specific user group.

   NOTE – V5.1 protocol is dedicated to managing POTS and ISDN for a maximum of 30 subscribers on a 2 Mbit/s link, whereas the V5.2 protocol is able to manage concentration and allows time slots to be shared among subscribers on a per-call basis, thus resulting in cost savings. Latest version of ITU-T Recommendations G.964 and G.965 describe these protocols in detail.

The access node concept represents a very flexible way in which to serve urban, suburban and rural areas in a cost-effective and very reliable manner, thanks to the fact that the ring structure in the primary distribution network is self-healing, using either optical fibre or microwave radio, depending on the environment.

FIGURE 3

Evolution of the network in a local exchange area (source GAS 7)



4.4 Access network technologies

The access network has, until recently, been one of the most costly parts of the overall telecommunication network. Advances in technology now allow for more efficient provision of telecommunication services in rural areas and offer more cost-effective means to serve remote subscribers. The following paragraphs review the different transmission media based on wireline, wireless and satellite (GEO, LEO, MEO) systems.

4.4.1 Non-radio systems [20, 21, 22, 23, 24]

4.4.1.1 Copper based systems

NOTE – It should be noted that this includes all systems based on metallic wires.

Until recently, copper pairs were used in the access network to provide basic analogue telephony in the 300-3 400 Hz bandwidth or ISDN basic rate service to subscribers. In some applications, multiservice multiplexers in the subscriber's premises are used to provide, in addition to POTS, data interfaces (from 1 200 bit/s to n × 64 kbit/s) over special pairs.

1) *PCM 4 pair gain system*

The 144 kbit/s transceivers primarily designed for ISDN have enabled the production of digital pair gain systems such as PCM4.

PCM4 is used to carry four telephone channels over a single twisted pair, and therefore represents an attractive solution to congestion problems. Consisting of two terminations, one in the exchange and one remote, close to the subscribers, the system is easily implemented without additional infrastructure and uses a U interface similar to that of the ISDN basic access between the two terminations. The frame consists of two 64 kbit/s channels and one overhead. Each 64 kbit/s channel carries two telephone signals encoded in adaptive differential PCM. The line code is a 2B1Q quaternary code and enables the signal to be transmitted over reasonably long distances: 4 km over a 0.4 mm pair or 11 km over a 0.8 mm pair.

2) *Primary rate subscriber line carrier systems*

Primary rate subscriber line carrier systems extend regular telephone service and special services from a switching centre to residential and business communities. In the form of standard primary rate digital links on subscriber lines they can provide 24 (1 544 kbit/s digital hierarchy) or 30 (2 048 kbit/s digital hierarchy) channels at 64 kbit/s each. These channels can carry a variety of services, such as Plain Old Telephone Service (POTS), coin, data, ISDN or other special services. Combined with a concentrator function some systems can support up to 544 lines of various mixes of service.

3) *xDSL digital subscriber line systems*

Considering the widespread existence of copper plant and the new services' need for higher bandwidth, new digital subscriber line (XDSL) systems have been and are being designed to transmit data at a relatively high bit rate over copper pairs and some are already in commercial operation or undergoing field trials.

ITU-T has developed (1998) corresponding new standards, designated as the G.990-series of Recommendations, which specify several techniques to provide Mbit/s network access on existing telephone subscriber lines simultaneously with the regular voice communication. Main applications are high-speed Internet access, video and other on-line data communications such as electronic commerce, home office, distance learning and telemedicine.

A summary of the different xDSL technologies is shown in Table 10, in which the data rates and typical ranges give a broad indication of the capabilities of each system.

TABLE 10

xDSL technologies

DSL	Typical range (0.4 mm diameter cable)	Data rates
HDSL	3.5 km	2 Mbit/s
S-HDSL	2.15 km	2 Mbit/s
SDSL	between 5.5 km and 1.5 km	between 144 kbit/s and 2 Mbit/s
ADSL	3.5 km	up to 6 Mbit/s downstream and 640 kbit/s upstream
SL-ADSL	4.2 km (target)	up to 1.5 Mbit/s downstream and 512 kbit/s upstream
VDSL	0.3 km	up to 52 Mbit/s downstream and 6.4 Mbit/s upstream for asymm. VDSL up to 34 Mbit/s, each direction, for symm. VDSL

4) *High speed digital subscriber line (HDSL)*

High speed digital subscriber line (HDSL) technology permits the transmission of bi-directional streams of up to 2 Mbit/s over one, two or three unscreened unconditioned twisted pairs. As a Layer 1 application-independent bit transport mechanism, it enables application-specific interfaces to be easily added. HDSL has a typical range of 3.5 km. It has been standardized by ITU-T (Recommendation G.991.1).

The HDSL system is made up of two units, one on the subscriber side (NTU) and one on the exchange side (LTU). The two units are connected by one, two or three copper pairs and transmit 2 320 kbit/s, 1 168 kbit/s or 784 kbit/s over each pair (Figure 4).

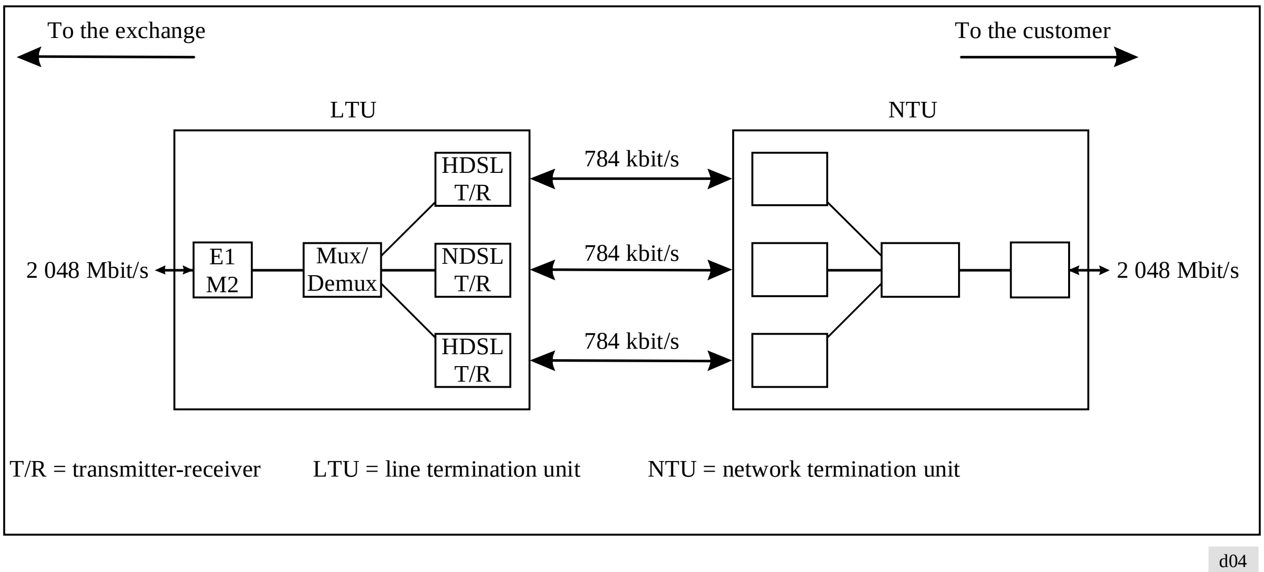
The application of HDSL falls into two main categories:

– upgrading of the existing copper plant to carry more than one telephone channel;

– provision of new services, such as low-speed video or high-speed data transmission.

FIGURE 4

HDSL configuration



NOTE – When 2 pairs only are used, bit rate is 1 168 kbit/s.

5) *Single-pair HDSL (S-HDSL) and symmetric digital subscriber line (SDSL)*

Full rate S-HDSL systems are being developed and will cover distances of up to 2.15 km. In addition an SDSL is being defined that will adjust to the transmission quality of the subscriber access line. This enables the operator to deliver higher bandwidth using existing copper plant. A corresponding standard is under development in ITU-T (1998).

6) *Asymmetric digital subscriber line (ADSL)*

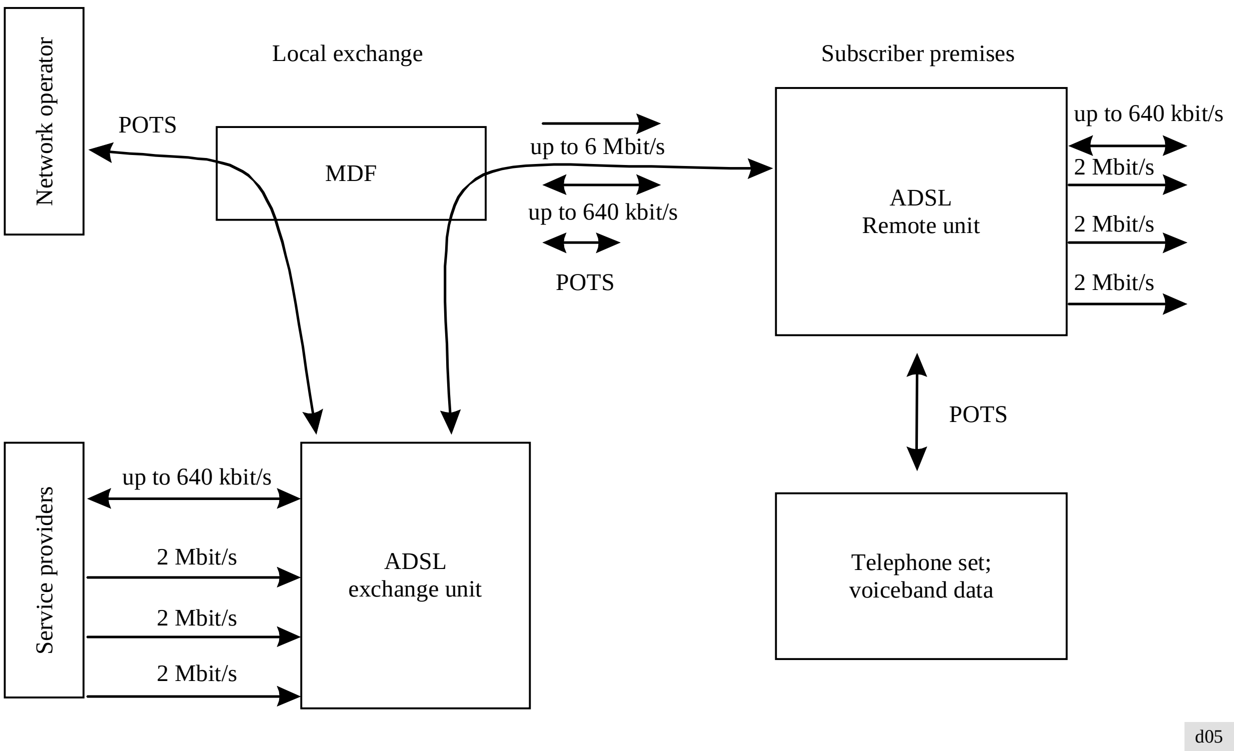
The ADSL has been developed in response to the growing demand for new services requiring a larger bandwidth in one direction of transmission than in the other. Such services include video-on-demand, TeleMedicine (e.g. transmission of x-ray pictures in one direction), tele-education, Internet, etc.

In addition, a POTS channel can always be associated with the ADSL signals without affecting system performance (Figure 5).

ITU-T has developed a draft new Recommendation G.992.1, specifying ADSL transceivers with access bit rates of up to 640 kbit/s in the upstream (subscriber to network) and up to 6 Mbit/s in the downstream (network to subscriber) direction, depending on the subscriber line length. The draft standard is scheduled for approval in June 1999. Meanwhile, ADSL systems are currently (1998) undergoing field trials in several countries and have started commercial service in others.

FIGURE 5

ADSL architecture



7) *Splitterless asymmetric digital subscriber line (SL-ADSL)*

This is a simpler, splitterless asymmetric system which can be installed by the user. Depending on the subscriber line length, the system provides upstream access up to 512 kbit/s and enables the subscriber to download data and video at speeds of up to 1.5 Mbit/s. The system's design eliminates the need for a piece of equipment called "splitter" at the subscriber's premises. The corresponding ITU-T standard is Recommendation G.992.2, scheduled for approval in June 1999. New G.992.2 compliant transceivers will simply plug into the back of a PC as current modems do, giving subscribers Internet access over existing subscriber lines at bit rates up to 25 times faster than over a conventional 56 kbit/s modem.

8) *Very high-speed digital subscriber loop (VDSL)*

VDSL systems are intended to provide very high bit rates (tens of Mbit/s) over short distances (hundreds of metres). Maximum bit rates envisaged in asymmetric VDSL systems are up to 52 Mbit/s in the downstream and up to 6.4 Mbit/s in the upstream direction, depending on subscriber line length. For symmetric VDSL systems, the maximum bit rates envisaged are 34 Mbit/s for each direction.

4.4.1.2 Coaxial cable-based systems

Coaxial cable is more expensive than copper pairs but is more suitable for transmission of high-frequency signals or high-speed data. Nowadays, coaxial cable is used to connect subscribers to data services of 2 Mbit/s or above, or to transmit analogue TV signals to the home. The use of coaxial cable systems in rural areas remains doubtful, as newer technologies are already in operation (e.g. TV broadcasting by satellite).

4.4.1.3 Optical fibre-based systems

Fibre in the access (FITL) applications comprise the following access configurations which could be used in rural areas:

– narrowband and/or broadband line circuits at the subscriber distribution interface (FTTC – fibre to the curb);

– narrowband and/or broadband line circuits at the feeder distribution interface (FTTCa – fibre to the cabinet).

The FTTH (fibre to the home) application does not seem to be an adequate configuration in rural areas for some years to come.

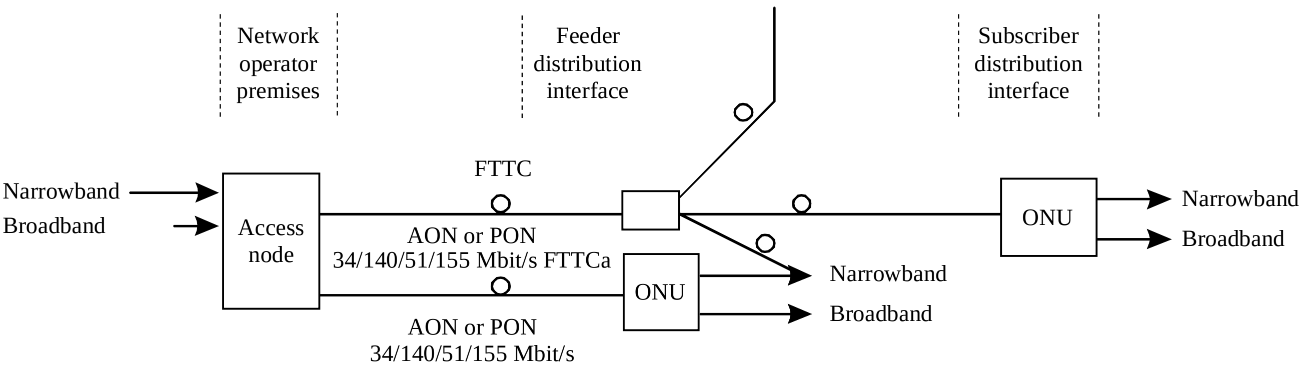
In the FTTC scenario, both the primary and secondary networks are fibre based, which means that the total distance between the local exchange and subscriber premises can be up to 20 km using passive optical network (PON), and even more if active components are introduced in the secondary distribution network (active optical network – AON). For the last few hundred metres between the subscriber distribution interface and each subscriber, copper pairs or coaxial cables (hybrid-fibre coax) are used. It is important to note that in rural areas, where terrain conditions are often very difficult, the FTTC is, at present, an expensive way of providing POTS and/or ISDN.

FTTCa is a more suitable approach to the provision of narrowband and broadband services in rural areas, although radio-based solutions are in most cases likely to prove more cost-effective.

ITU-T Recommendations G.981, G.982 and G.983 cover in detail the topic of optical line systems for local and access networks.

FIGURE 6

Fibre to the curb and fibre to the cabinet applications



AON = active optical network
O = fibre optic cable
ONU = optical network unit
PON = passive optical network

Adapted from Alcatel Telecommunication Review – 3rd quaterly 1996.

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4.4.2 Radio systems

4.4.2.1 Terrestrial systems [3, 22, 24, 25, 26, 27, 28, 29, 30]

A local access traditionally consists of copper pairs, either underground or overhead.

In the past, wireless communications have been almost exclusively used for connecting subscribers in remote or inaccessible areas.

It is only recently, with technological development, that wireless technologies have come to be seen as a viable alternative to the traditional wireline local access.

The possibility of using wireless links to establish the last segment of subscriber access is now regarded as an attractive option for at least five reasons:

1) Radio technologies make it possible to implement networks more cheaply and in less time than with wireline systems. It may be either the permanent solution in scarcely populated areas or a first step in areas where the population is not yet stabilized, giving time to ensure that a wired access system is worthwhile, and if so, to install it.

2) Wireless access technologies allow for a smooth evolution of the network, and hence, investment, following market demand.

3) The cost of installing and maintaining radio access equipment is generally lower than for wireline networks, in sparsely populated areas.

4) Fixed wireless access represents an important market for network operators and manufacturers. Standardization efforts have been made that allow economies of scale in manufacturing equipment. Deregulation opens the door for competition. This situation drives prices down.

5) Digital technologies support any type of telecommunications service, up to multimedia, depending on data rate required and frequency bandwidth available.

However, wireless technologies used in frequency spectrum (a limited natural resource) and the associated cost must be considered in comparison with copper-based systems.

Note that there are two approaches for providing a fixed wireless access: one is to deploy a wireless access system which is an extension of a fixed network connected to the nearest local exchange, while the other is to set up a cellular network which is a complete network, *per se*, providing mobility at the expense of service transparency

Description of the main technologies

There is a great variety of fixed wireless access systems available on the market. Such systems can be grouped into three major categories: fixed radio access systems, digital cordless systems and cellular systems.

1) *Fixed radio access systems*

a) *Point-to-point microwave radio-relay systems*

Microwave radio-relay systems are well-suited for the transmission of digital signals over large distances in difficult geographic and topographic conditions. Large-capacity systems (> 34 Mbit/s) are used for the interconnection of switching exchanges or the transmission of TV signals. Medium- and low-capacity systems (≤ 34 Mbit/s) are used to connect digital concentrators, remote subscriber units, etc., to the parent exchange. They may also be used to connect a group of remote subscribers to the host exchange (unconcentrated traffic).

b) *Simple channel radio systems*

Operating in the VHF or UHF frequency bands, such systems are particularly suitable for connecting one or two subscribers to a concentration point or distribution cabinet over distances up to 60 km. The use of repeaters is possible; however, in the case of analogue systems, their number is limited. One of the drawbacks of such systems is their rather poor spectral efficiency, which limits their use on a large scale within the same area.

c) *Point-to-multipoint microwave radio systems (PMP)*

Frequency and time division multiple access (TDMA) PMP systems have for many years been used in a very large number of countries to provide the connection from the exchange to the subscriber terminal point.

TDMA PMP systems consist of one central station and several hundred remote stations, either repeater stations – with or without subscriber facilities – or terminal stations. These systems have the following main characteristics:

- capacity: 30, 60 or 120 circuits of 64 kbit/s each. Systems with a capacity of up to 240 circuits of 32 kbit/s are under development;

- frequency bands used: 400 MHz (see Note), 1.5 GHz, 2 GHz, 2.4 GHz, 2.6 GHz, 10 GHz;

NOTE – In general, the frequency bands used for fixed radio services are those allocated for each region by the ITU Radio Regulations (see Article S5 of RR).

- several thousand subscribers;

- low power consumption for remote stations (terminals and/or repeaters), enabling the use of solar energy.

Thanks to the modularity of the equipment, remote stations can be equipped for the connection of a single subscriber, a few subscribers or several tens of subscribers. This allows the system to be easily expanded at least cost according to demand.

Besides telephone transmission (typically with a P.01 grade of service), TDMA PMP systems can, in addition to voice and data, carry services such as facsimile (Gr. 3), ISDN and Internet. The interface with the exchange is either analogue or digital (up to 2 Mbit/s).

The subscriber interface is generally analogue two-wire, but digital wireless connection to the subscriber's premises is also available.

End-to-end transparent digital systems enable operators to implement any network architecture in the local access.

2) *Digital cordless systems*

These systems have been primarily designed for indoor residential and business cordless applications. They offer limited mobility and are very suitable for solving the "last-mile" problem. The following standards have been established:

– in Europe: cordless telephone second generation – CT2 digital enhanced cordless telecommunications – DECT,

– in Japan: personal handyphone system – PHS,

– in USA: personal access communications systems – PACS.

a) *CT2-based wireless access systems*

CT2-based wireless access systems provide a connection between the customer's premises and the public switched telephone network using the CT2 standard, adopted by 26 countries in Europe, Asia and North and South America. The radio link is transparent to the subscriber, who uses regular telephones, modems or fax machines connected to standard telephone jacks. These wireless access systems are based on the CT2/CAI standard and operate in the 800 MHz (see Note) frequency band. A wireless access system enables operators to provide a radio-based drop-wire alternative to traditional copper lines. Such systems offer high-quality voice transmission, and are capable of originating and receiving with the ability to originate and receive voice, data and fax calls of a quality that is comparable to that provided by wire line systems.

These wireless access systems are particularly attractive for high-density urban and suburban applications where an existing feeder network exists. They are also suitable for scattered rural villages where the distance between settlements precludes the use of higher-frequency-range systems. The frequency band 864-868 MHz (see Note) is widely used, but other frequencies could be provided to eliminate spectrum clearing delays.

NOTE – In general, the frequency bands used for fixed radio services are those allocated for each region by the ITU Radio Regulations (see Article S5 of RR).

Frequency planning is simplified through the use of dynamic channel allocation, alleviating initial system deployment and subsequent extensions. Dynamic channel allocation ensures that the best available channels are always used, calls being handed-off to a clear channel if interference is detected.

b) *DECT-based wireless access systems*

Digital enhanced cordless telecommunications (DECT)-based systems use a combination of time division multiple access (TDMA) and time division duplex (TDD). This eliminates the need for expensive RF filtering, and enables the use of compact, lightweight and low-cost handsets. DECT operates in the frequency band 1 880-1 900 MHz (see Note). The spectrum is divided into 10 carriers, each with 12 TDMA time slots, providing a total of 120 voice channels. Speech is coded at 32 kbit/s, twice the rate used for GSM and providing effective toll quality. Maximum peak power for both base stations and handsets is 250 mW, although dynamic power control typically reduces this to around 60 mW. However, because this is peak power (i.e. only present for the duration of the transmitted time slot), the average transmitted power is 10 mW or less, resulting in a significantly extended battery life compared to cellular handsets or conventional analogue cordless telephones.

NOTE – The radio parameters have been defined in the frequency range 1 880-1 937 MHz to facilitate the introduction of DECT in non-European countries where the basic DECT frequencies are not available.

DECT provides voice and data ISDN compatibility, full encryption and seamless handover. Time slots can be combined to provide high-capacity data transmission (up to 384 kbit/s). Dynamic channel allocation removes the need for a complicated radio-frequency planning and there are no dedicated control channels. The system continuously scans and selects the best available RF channel.

DECT has a capacity of around 10 000 Erlangs/km^2, or around a hundred times that of the existing cellular networks.

c) *PHS-based wireless access systems*

PHS-based wireless access systems are designed for PSTN/ISDN, and use the basic PHS technologies described in Recommendation ITU-R M.1033. The access method being TDMA/TDD and with a user bit rate at 32 kbit/s PHS wireless access systems are capable of supporting high-speed data, and are suitable for high-traffic areas such as urban and suburban areas, with the adoption of a micro-cell structure.

The systems allow telephone terminals to move in a limited area, and are therefore also referred to as limited mobile telephone systems.

d) *PACS-based wireless access systems*

The personal access communications system (PACS) air interface has been approved as a standard by the American National Standards Institute (ANSI). The PACS air interface standard has a frequency division duplexing (FDD) mode and a TDD mode. PACS can be interfaced with ISDN networks, with GSM networks at the GSM A-interface, or with POTS networks.

PACS supports wireless access in multiple operating environments. It is optimized for low-mobility environments including outdoor pedestrian (public wireless access), indoor residence (home cordless), indoor business (wireless PBX) and indoor commercial (wireless access in airports, railway stations, shopping centres, etc.). PACS air interface is capable of supporting vehicular mobility, although the system is not optimized for this.

PACS operates in the following transmit frequency bands:

– base stations 1 930-1 990 MHz;

– subscriber stations 1 850-1 910 MHz.

It is worth noting that both DECT and PHS systems can be interconnected with some TDMA point-to-multipoint systems, so that the connection between the last remote station of the PMP system and the subscriber premises is based on DECT or PHS technology. This end-to-end transparent digital system enables operators to take full advantage of radio technology, regardless of the network architecture characteristics. Furthermore, limited mobility can be provided to subscribers.

3) *Cellular systems*

a) *Analogue cellular systems*

Analogue cellular systems such as the advanced mobile phone system (AMPS), nordic mobile telephone system (NMT) and total access communication system (TACS) have been extensively used and, where specifically modified to provide fixed service, provide a simple and low-cost alternative to copper wire.

b) *Digital cellular systems*

Although primarily designed to provide mobility, digital cellular systems may also be used for fixed wireless access applications. The different standards are described below:

- *D-AMPS/TDMA-based wireless access systems*

  These are digital wireless access systems based on TDMA technology and fully compliant with IS-54/IS-136 US standards. They offer digital voice quality and conversation security, and may be configured to operate in the 400 MHz or 800 MHz frequency band. In addition to voice services, fax and low speed data services are also supported. This additional capability set is available on an optional basis wherever the market need arises.

- *IS-95 CDMA-based wireless access systems*

  IS-95 CDMA-based wireless access systems are based on the IS-95 US standard and provide a digital fixed wireless access system which incorporates proven switching and networking technologies. Such a system comprises switching and radio site equipment. A basic system includes controller, base station controller (BSC) and base transceiver stations (BTS). Each BSC is connected to one controller switch. The controller interfaces with both the Signalling System No. 7 network and the public switched telephone network (PSTN).

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

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

  Other characteristics of IS-95 CDMA-based wireless access systems are:

  – the radio link supports up to 45 active calls per sector per 1.25 MHz, with flexibility for growth;

  – the sector capacity of a CDMA-based system is flexible. During abnormally high usage hours, the system can automatically allocate dynamic resources to accommodate the increased load with minimum loss of voice quality;

  – each cell supports a maximum range of several tens of km under good propagation conditions;

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

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

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

Spread spectrum techniques have attracted a lot of attention in the field of mobile communications. In the mobile environment, practical considerations make the full potential of asynchronous CDMA difficult to realize. For fixed wireless access, with fixed subscriber equipment, and the benefit of directional antennas, it is likely that the benefits can be attained with much lower complexity than in mobile systems.

Asynchronous CDMA systems such as those based on IS-95 standard are interference-limited, unlike FDMA and TDMA capacities which are primarily bandwidth-limited. Thus, any reduction in interference converts directly and linearly into an increase in capacity.

At least one manufacturer has developed a quasi-synchronous CDMA point-to-multipoint system, using closed-loop timing control in both directions to ensure synchronous reception of all traffic channels. The capacity of such a system can be considered to be only code-limited. Such a system delivers a substantial increase in basic spectral efficiency over IS-95 CDMA systems. It conforms to the relevant ETSI standards (EN 301055 and EN 301124).

- *GSM-based wireless access systems*

  GSM networks are now operating worldwide. They are based on a widely accepted standard – allowing multi-sourcing – that has proven its reliability: there are now more than 100 million GSM subscribers all over the world, on several hundred networks. GSM networks operate either in the 900 MHz, 1 800 MHz or 1 900 MHz frequency range, depending on which is available.

  Some specific systems include an extremely "feature rich" offering, with services such as Centrex and Virtual Private Network (VPN), which have allowed further operators to enter these markets.

  Additional revenue can be generated in a number of different ways, for example by offering:

  – additional capabilities such as personal screening profiles, on a pay-per-use or subscription basis;

  – services such as voicemail notification, which encourage traffic on the network;

  – services such as corporate network interlinking and tariffing, which give access to lucrative market segments;

  – added value capabilities, such as short-message-based traffic or weather information.

- *Composite CDMA/TDMA-based wireless access systems*

  These wireless access systems utilize a composite code division/time division multiple access (CDMA/TDMA) technology that is fully compliant with J-STD-017/IS-661 standards. Such systems have a modular architecture which allows them to be used as a stand-alone system with switching or as an adjunct to existing central office switches. A basic system would include a BSC, BTS and subscriber units located on the subscriber's premises. The BSC is connected to a switch which interfaces with the public switched telephone network (PSTN) or other switches owned by the service provider.

  The BSC interfaces with the switch at one end, and with multiple sites containing BTSs at the other end. The BTSs support the establishment of IS-661 over-the-air CDMA/TDMA connections with subscriber stations. Depending on the desired cell capacity (number of subscribers), multiple BTSs may be deployed at each cell site.

  The use of spread-spectrum technology provides an additional benefit in the form of a wide range of cell size. Systems can serve cells less than 400 m in diameter or over 22 km in diameter for highways or rural areas.

  Use of TDMA technology within a cell permits the subscriber unit to initiate and control the hand-off when the signal strength approaches the limit of the value required for voice quality. This makes the system very simple and enables it to be switch independent, since the switch does not need to monitor signal strength or keep track of neighbouring cells.

  The number of subscribers supported by any one cell site is variable. However, the use of combination spread spectrum and of TDMA technology makes it easy to engineer the capacity of the system. It does not depend on the mobility speed of the unit, interference, talk/silence ratio or other factors which affect pure CDMA systems.

  Composite CDMA/TDMA wireless access systems offer the best of CDMA and TDMA technologies, and are specifically designed for the fixed wireless access environment, with the full benefits of PCS capability:

  – the radio link may support up to 16 simultaneous calls per sector per 2 MHz;

  – unlike other wireless access systems, the sector capacity is not decreased by speed of mobile units, interference, etc.;

  – each BTS is designed to support a maximum range of about 10 km under good propagation conditions.

4.4.2.2 Stratospheric systems [11]

Stratospheric Telecommunications Service, referred to as STS, is a future wireless technology under development which will use stationary platforms in the upper atmosphere to deliver (high-density) fixed wireless service. The platforms consist of an extremely strong, lightweight, multi-layer skin containing buoyant helium-filled cells, a station keeping system comprising a GPS (global positioning system) and an advanced propulsion system, a telecommunication payload, solar panels for daytime power and fuel cells for night-time power.

Platforms located over individual markets will provide broadband wireless service such as videophone and digital telephony, and also high-speed Internet access. Because each platform serves an individual market, STS services can be tailored by an individual country to meet its communication needs. At an altitude of 21-23 km, and with a 1000 km diameter footprint, STS can meet urban, suburban and rural communication needs alike, and provide an economical way of linking rural to urban areas. Platforms will be connected to the PSTN via gateway ground stations, and platforms may be interconnected to each other to provide regional and global communication coverage. Operating frequencies will be in the 47.2-47.5 and 47.9-48.2 GHz frequency bands.

These unique, lighter-than-air platforms will offer a broader class of low-cost wireless services. Some attributes of STS contributing to this low cost include remotely-controlled platform guidance to reduce deployment and positioning costs, the high altitude (above 99% of the atmosphere, and therefore less subject to wear and tear caused by weather conditions), low transmission power requirements and better line-of-sight to the platform’s antennas than is the case with ground-based services. Deployment of STS for trial is expected to begin in 1999.

4.4.2.3 Satellite systems [31, 32]

To satisfy the needs of basic telecommunication services in rural and isolated areas, satellite technology presents some advantages over other technologies. Virtually any type of telecommunication service can be provided almost anywhere in the world, at a cost that is not a factor of geographical distance or topography, using geostationary and non-geostationary satellite systems. However, at present, the cost is prohibitive for many end users in poor rural areas.

4.4.2.3.1 Fixed-satellite services (FSS)

FSS provide voice, data and video services from satellites in geostationary orbit. These services rely on a fixed terrestrial infrastructure for transmission, reception and distribution.

Advances in satellite technology have made it possible to use much higher levels of satellite transmit power. This, coupled with innovative earth station antenna design and the introduction of digital coding and compression techniques, has significantly reduced the size and cost of antennas and the bandwidth needed for the transmission and reception of services from the geostationary orbit. This lower cost has, in turn, made possible the expansion of existing services and the introduction of new services in developing countries, serving the needs of remote and rural areas. The use of such advanced techniques as time division multiple access (TDMA) and demand assignment multiple access (DAMA), (see Note) including bandwidth on demand, makes it possible to utilize optimally a high-cost resource (the satellite) and to implement a rural telecommunication system in an efficient manner.

NOTE – DAMA is a usage-based, state-of-the-art service for thin-route PSTN services with either high or low connectivity requirements and provides small users an easy solution for digitizing their networks. Instant, dial-up connectivity between a large community of users, with one channel providing direct connectivity and dynamic switching to all users in the network, makes DAMA a cost-effective solution for thin-route operators. DAMA can be used for voice, data and facsimile.

The FSS can be used to provide trunk links between small towns originating enough traffic to justify a permanent assignment of capacity. The access link between an isolated user (or group of users) and the PSTN can be provided through the combination of very small aperture terminals (VSAT) and fixed wireless access technologies. RTOs should take into account the possible double hop problem.

Another important advantage of FSS for system planners is the ease with which they can meet unforecasted traffic loads. In places where traffic loads are difficult to estimate, operation can be initiated with a few circuits and the capacity adjusted simply by adding more channel equipment at the location in question until a satisfactory grade of service is achieved. FSS with DAMA provide an efficient way to service a multiplicity of low-traffic stations. In addition, some provide a centralized tool for traffic control and traffic-growth analysis.

4.4.2.3.2 Global mobile personal communication systems (GMPCS)

One of the advantages of global mobile personal communications by satellite (GMPCS) systems is that they provide mobility and are therefore well-suited to rural areas. Where cellular telephony currently provides mobility within a limited region, low Earth orbit (LEO), medium Earth orbit (MEO) and geostationary orbital (GEO) satellite systems can extend the geographic coverage of these networks and broaden the user base to include more geographically disadvantaged persons.

Currently the technically feasible options for providing a communication service to hand-held-mobile or otherwise transportable terminals are:

i) low Earth orbit (LEO – up to 1 500 km altitude); there are three types of LEOs:

- little LEOs for data communications (store and forward);
- big LEOs mainly for mobile telephony and data up to 9.6 kbit/s;
- broadband LEOs for multimedia, including voice and data up to 1.5 Gbit/s.

For more information on this technology please refer to [33];

ii) medium Earth orbit (MEO – 8 000 to 20 000 km); and

iii) geostationary orbit (GEO – 36 000 km).

To cover the Earth fully, LEOs require around 40-288 satellites, MEOs need 6-20 satellites and GEOs need 3-6 satellites.

The choice of orbital configuration has to take into account not only the quality of service that will be delivered to the user, but also the feasibility and technical risk of the satellites themselves and the problems of procuring and managing the required number of satellites.

4.5 Technology trends

New products and systems are currently under development that will contribute to the expansion of reliable, high-quality telecommunication services in rural areas. The following examples are worth mentioning:

4.5.1 Wireline systems

One manufacturer is testing the possibility of using the local area power distribution system as a bearer for telephone signals. If such testing proves to be successful, this approach would allow, in some instances, for combined development of the power and telephone networks.

4.5.2 Wireless systems

Other manufacturers have designed a wireless system comprising as many subscriber nodes as are required. In addition to providing digital access for the subscriber, each node routes calls to any other node in the network and records billing information. Call detail records and administrative information is downloaded over the air each night to a PC-based administrative centre. Calls to and from the PSTN are automatically routed to and from a gateway node. This approach eliminates the need for radio base stations or local switching, enabling the network to start out as small as required and without major outlay, and thereafter to grow in response to demand. The equipment operates in the VHF or UHF frequency bands, does not require any detailed radio planning and is easy to install. Calls to nodes at large distances (more than 50 km) are made across the network, with the intermediate subscriber nodes acting as repeaters. Calls between two subscribers in the network do not need to be routed through a gateway node. Such a system, which can operate on a stand-alone basis, could be described as a multipoint-to-multipoint wireless system. Each subscriber node can handle two subscriber lines, whether residential or payphone or data.

By the beginning of the next century, the GSM system will be enhanced to support a native packet mode called GPRS (General Packet Radio Services). GPRS will offer user bit rate support up to 100 kbit/s and will require the new network elements SGSN (Serving GPRS Support Nodes) and GGSN (Gateway GPRS Support Nodes).

Thanks to their modularity, GSM products allow full flexibility in making the network evolve.

It is capable of providing voice, fax, data and message services to subscribers.

ITU-R [34] is exploring the evolution and migration of existing mobile telecommunication systems towards a recommended International Mobile Telecommunications – 2000 (IMT-2000), previously known as future public land mobile telecommunication systems (FPLMTS). IMT-2000 systems are third-generation mobile radio systems which are scheduled to start service in the first decade of the next millennium. They will provide access by means of one or more radio links to a wide range of telecommunication services supported by the fixed telecommunication network (e.g. PSTN, ISDN), as well as to other services specific to mobile units. A range of mobile and fixed-terminal types is envisaged, linked to terrestrial or satellite-based networks. Key features of IMT-2000 are:

– 184 kbit/s (for full mobility) [35] and 2 Mbit/s (for limited mobility) [36] data bit rate to support any kind of digital services up to multimedia;
– a high degree of commonality of design worldwide;
– compatibility of services within IMT-2000 and with fixed networks;
– high quality of service;
– use of a small low cost pocket terminal worldwide.

It will operate in the 2 000 MHz frequency band. Further details on IMT-2000 may be found in references [34].

5 Technical and economic comparison

The provision of telecommunication infrastructures in rural and remote areas of developing countries, in a timely and efficient manner, is a major challenge to administrations and operators. The investment required is large, and the systems installed will have a minimum lifetime of one or more decade. It is therefore essential that the right decisions be taken on the choice of technologies and system configurations.

TABLE 11

Main advantages and disadvantages of the various technologies

	Advantages	**Disadvantages**
Copper cables Copper-based systems	– Quality – Simple technology – Can cover long distances – Non-frequency dependent	– Large up-front investment – Limited length and bandwidth (without additional equipment) – Maintenance – Lengthy deployment
Optical fibre	– Large bandwidth and, therefore, high capacity – Long distance – Quality	– Maintenance – Large up-front investment – Lengthy deployment
High-capacity microwave radio	– Long distance – Quality	– High cost of infrastructure (towers, power plants, buildings) – Line of sight required
Low- and medium-capacity microwave radio	– Quality	– Line of sight required
Single-channel radio	– Connection of isolated subscribers to local exchange (or concentrator) at distances over 50 km – Multivendor sourcing	– Interferences in the VHF/UHF frequency bands (analogue systems) – Line of sight usually required

TABLE 11

Main advantages and disadvantages of the various technologies *(continued)*

	Advantages	Disadvantages
FDD-FDMA PMP systems	– Connection of a limited number of subscribers located some 50 km max. from the local exchange (or concentrator) – Multivendor sourcing	– Interferences in the VHF/UHF frequency bands (analogue systems) – Limited data transmission capability
TDMA PMP systems	– Full service transparency (voice and data transmission incl. ISDN, Internet services) – Coverage area of several hundred kilometres with repeaters – Several hundred stations – Several thousand subscribers – 2-wire or 2 Mbit/s interface with local exchanges of any type – Modular design allowing for easy expansion at minimum cost – Low power consumption – Subscriber interface can be 2-wire or wireless	– Proprietary systems – Line of sight required – Limited vendors
Digital cordless systems CT2	– Voice and limited data transmission – CT2/CAI standard – Ease of planning – Possibility of interfacing with TDMA PMP systems – Proven [low-cost] technology	– In process of being phased out – Limited range – Limited mobility
Digital cordless systems DECT	– Connection to PSTN and ISDN – Pan-European standard – High traffic-loading capacity (around 10 000 E/km^2) – Multivendor sourcing – Frequency planning not required – Use of any type of telephone set, including DECT mobile handset – Encryption and authentication – Fixed wireless access profile – Easy interface with TDMA PMP systems – Interworking with GSM – Mobility in a limited area – Multivendor sourcing	– Limited coverage – Susceptibility to multipath delay spread on long paths
Digital cordless systems PHS	– Connection to PSTN – Direct handset-to-handset communications – Encryption and authentication – Interface with Japanese TDMA PMP systems – 2-wire, V5.1 or V5.2 interface with the local exchange	– Limited mobility – Limited vendors

TABLE 11

Main advantages and disadvantages of the various technologies *(continued)*

	Advantages	Disadvantages
Digital cordless systems PACS	– Connection to PSTN – Interface with ISDN and with GSM networks (at the A-interface) – High capacity – Optimization for low mobility – Evolution path for PCS – Multivendor sourcing	– Not yet fully proven
Analogue cellular systems	– Transmission of voice and low bit rate data (≤ 4.8 kbit/s) – Proven technology – Low cost – Coverage area of one base station: around 35 km – Rapid deployment – Multivendor sourcing	– Low capacity may result in the need for several base stations – Speech quality rather poor – Spectrum efficiency – Lack of security – Not transparent to PSTN unless specifically designed for fixed wireless access applications
Digital cellular systems D-AMPS	– Transmission of voice and data – Proven technology – Compliance with IS-54/IS-136 CAI standards – Compatibility with AMPS analogue cellular system – Multivendor sourcing	– Need for a controller at the local exchange site – Voice quality
Digital cellular systems IS95-CDMA	– Transmission of voice and low-speed data – Compliance with IS-95 standard – High capacity – Ease of planning – Multivendor sourcing	– Range depends on traffic load – Interface with local exchange needs a controller
Digital cellular system GSM/DCS	– Transmission of voice and data (14 kbit/s in the near future) – European standard, widely accepted – Efficient use of spectrum – Proven technology – Multivendor sourcing – Interworking with DECT and packet data extension (available by year 2000) – Multivendor sourcing	– Up-front investment high – Voice quality – Limited data transmission (for the time being)
Digital cellular systems Composite CDMA/TDMA	– Wide range of services (telephony, data, etc.) – Compatibility with all PSTN switches – 2-wire, V5.1 and V5.2 interfaces – Expansion to PCS – Wide range of cell sites – Compliance with IS-661 and J-STD-017 – Multivendor sourcing	– New design
Stratospheric systems	– Broadband wireless services, including multimedia	– Not yet available

TABLE 11

Main advantages and disadvantages of the various technologies *(end)*

	Advantages	**Disadvantages**
Fixed satellite systems	– Provision of trunk links – Provision of access link between isolated subscribers (or clusters of subscribers) using VSAT and conventional WLL technologies, when no other technology can be deployed at reasonable cost – Very large coverage area – Multivendor sourcing	– High up-front investment costs (satellite, launching, etc.) but shared by many operators/investments – Voice quality depends on speech coding
GMPCS	– Provision of telecommunication services (voice and/or data, Internet, paging) to virtually all places on the earth – Direct access to satellites from fixed or mobile terminals – Dual mode terminals (satellite and terrestrial for some) – Several operators	– Cost of deployment – Price of a one-minute call too high for the time being for people living in developing countries – Most of the systems are not yet in service – Limited vendors – Systems hardly interoperable with each other

5.1 Technical comparisons between technologies

Table 12 below compares the various technologies which could be used for the provision of rural telecommunication infrastructures.

This technical comparison is not intended as an exhaustive or detailed analysis, but provides a general guide as to the relative performance of the different types of system in certain specific areas.

The following criteria have been chosen:

– technological complexity: this refers to the complexity of the technology itself and to the number of components required to deploy it (for instance, mobile switching centre, base station controller, etc.);

– speech quality;

– data capability;

– power consumption: this criterion does not refer to the subscriber premises equipment, except in the case of GMPCS;

– mobility/roaming;

– ease of planning: in the case of radio systems, this criterion refers mainly to frequency planning, propagation studies, etc.;

– modularity: this indicates the capacity of the system to connect additional subscribers without the need for network re-engineering;

– ease of network growth;

– compatibility with PSTN;

– compatibility with ISDN;

– services offered.

TABLE 12

Technical comparison

	Copper-based systems	**Copper with x-DSL**	**Optical fibre**	**Microwave**	**Single-channel radio**	**FDMA PMP**	**TDMA PMP**	**DECT**	**PACS**	**PHS**	**CT2**
Technological complexity	Low	Medium	Medium	High	Low	Medium	Medium	Low	Medium	Medium	Low
Speech quality	Good	Good	Very good	Very good	Medium/good	Medium/good	Very good	Good	Good	Good	Good
Data capability	Medium	High	High	High	Low	Low	High	High	High	High	Medium
Power consumption	–	Medium	Low	Medium	Low	Medium	Low	Low	Low	Low	Low
Mobility/roaming	No	No	No	No	No	No	No	Yes, locally	Yes, locally	Yes, locally	Yes, locally
Ease of planning	Poor	Poor	Poor	Low	Medium	Medium	Medium to high	High	High	High	High
Modularity	–	–	–	Low	Low	Medium	High	High	High	High	High
Ease of network growth	Poor	Poor	Poor	Medium	–	Low	High	High	High	High	High
Compatibility with PSTN	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Compatibility with ISDN	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No
Services offered	POTS*	Advanced	Advanced	Advanced	POTS	POTS	Some advanced	Advanced	Advanced	Advanced	POTS

* Upgradable to advanced services with additional equipment.

TABLE 12

Technical comparison *(end)*

	Analogue cellular	**D-AMPS**	**GSM**	**IS95 CDMA**	**Composite CDMA/TDMA**	**Stratospheric systems**	**Fixed satellite systems**	**Rural switching**
Technological complexity	High	High	High	High	High	High	High	Low
Speech quality	Poor	Medium	Medium	Good	Good	Good	Good	Good
Data capability	Low	Low	Low to medium	Medium	Good	Good	Good	–
Power consumption	High	High	High	High	High	High	High	Low to medium
Mobility/roaming	Yes	Yes	Yes	Yes	Yes	Probably	Yes	No
Ease of planning	No	No	No	Yes	Yes	No	No	No
Modularity	Medium	Medium	High	Medium	Medium	Low	Low	Low
Ease of network growth	Low	Medium	Medium to High	High	High	High	High	Low
Compatibility with PSTN	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Compatibility with ISDN	No	No	No	No	Yes	Yes	Yes	No
Services offered	POTS	POTS	POTS	POTS	Some advanced	Advanced	Advanced	POTS
The GMPCS systems are not covered because there are too many variations. See reference [33].								

Some remarks

The use of a mobile cellular system to provide a fixed telephony service, especially with public telephones, may have certain drawbacks. Depending on the capacity of the particular cell that serves the public phones and the number of phones, the traffic patterns and the volume of mobile traffic, a cellular system normally designed for a Grade of Service (GOS) of 95% will experience a deterioration in the grade of service. In at least one country, it has been found that the number of uncompleted calls in the mobile service increased several times, while the GOS for the public phones deteriorated significantly.

The problem is that public telephones generate a lot of traffic. It is not uncommon for one PCO to carry as many as 100 to 200 mobile phone calls. This places an exceptionally heavy loading on a cell, effectively tying up a traffic channel almost permanently. When a number of PCOs are served by the same cell, there may be too little capacity left for the cell to provide an acceptable service. It can, of course, be argued that under such circumstances the system should be redimensioned to provide more capacity, for instance more cells should be provided, or the cell should be sectored. Such changes can only be made, however, at a substantial cost to the operator. Unless both the subscribers and the regulation authority are willing to accept a sub-standard public telephone service and a deterioration in the mobile service, the solution of using mobile cellular infrastructure to provide a fixed service is not satisfactory. However, a mobile cellular system could be used as a temporary measure in areas where there is no public fixed service.

In allocating spectrum and assigning it to operators, consideration should be given to the fact that some technologies are more spectrum efficient than others. A CDMA system, for instance, will, in certain cases, use about one-ninth of the spectrum that an AMPS system requires, and about one-quarter of the spectrum used by a GSM system – for the same number of users. This does not mean that CDMA technology is always the best choice, as other factors should also be taken into consideration. It is the operator’s responsibility to evaluate the merits of one technology against another in a given environment, for instance by assessing the performance-to-cost ratio of the various technologies being considered. This ratio can be expressed in the following manner:

$$\frac{\text{Performance}}{\text{Cost}} = \frac{\text{Quality} \times \text{Area coverage} \times \text{Range} \times \text{Capacity}}{(\text{Capital costs} + \text{AO\&M costs} + \text{Licence fee}) \times \text{Spectrum efficiency}}$$

During the planning of a wireless system, radio spectrum requirements and availability need to be examined (the cost of radio spectrum is also an important factor in the financial evaluation of a given project). Table 13 below shows some traditional frequency bands for operation of some wireless systems. The availability and use of radio spectrum is subject to local regulation. Consistent with ITU Radio Regulations and ITU-R recommendations and reports, the detailed frequency planning must take into account the precise service requirements (voice, data, traffic, fixed, mobile, fixed and mobile, range, etc.). It is important to note that such requirements might prohibit the use of a given wireless system, because, for instance, the available frequency spectrum is not sufficient to support the demand for services. Furthermore, the possibility of sharing spectrum between several operators in the same area must be considered.

5.2 What technology at what price? [3, 39]

To answer the above question one must first answer the following questions:

– What services (voice, data, video)?

– For whom (residential or business usage)?

– By whom (incumbent or new operator)?

– What performance (capacity, quality, GOS, reliability)?

– In what context (region, distance, environment)?

– With what infrastructure and subject to what equipment limitations (switching, transmission, distribution equipment, subscriber terminals, power supply, towers, cables, buildings, etc.)?

– Subject to which regulatory requirements?

The number of parameters to consider makes comparison very complex. The aim of the following is to provide comparative cost factors for both wire and wireless solutions, with reference to three models.

TABLE 13

Frequency bands for operation – terrestrial wireless access systems

- 400 MHz TACS-NMT-D-ANPS
- 500 MHz PMP systems
- 800 MHz AMPS-D-AMPS-CT2-IS95 CDMA
- 900 MHz GSM-TACS-NMT
- 1.4 GHz PMP systems
- 1.8 GHz DCS-DECT
- 1.9 GHz PCS-PHS-Composite CDMA/TDMA
- 2.0 GHz IMT-2000
- 2.5 GHz PMP systems
- 3.5 GHz Proprietary TDMA PMP
- 3.5 GHz Broadband CDMA
- 10.5 GHz PMP systems

Frequency

Communications to and from remote locations in rural areas are mostly provided via:

Case 1: the centre where the international gateway is installed;

Case 2: the hierarchically higher and/or main administrative centre;

Case 3: the "closest" centre from the point of view of regional and/or cultural links (regional town); this is the case where administrative divisions do not coincide with the development of telecommunication infrastructures.

The centres in cases 2 and 3 are important centres with a basic minimum telecommunication infrastructure (automatic exchange). They are also linked to the international gateway via a long-distance transmission system (trunk cable, radio-relay or satellite).

According to the definition of rural areas (see Section 2, § 2.1), the geographical or topographical features of such areas may include *inter alia*, lakes, deserts, forests and mountainous or snow-covered areas. Added to this is the distance between the rural locality and the centre to which it is attached. These aspects will greatly influence the choice of technology for the rural area service.

Moreover, the scarcity, or even total absence of public services (such as water and electricity), and of health and education services, means that economic activity is limited.

This situation explains the concerns about profitability of telecommunications in rural areas (if the importance of telecommunications for social and economic development, and their role in limiting rural exodus is disregarded).

"Universal access" means that any individual, regardless of social status, should have access to telecommunication services at affordable cost.

In rural areas, particularly in LDCs, the vast majority of people live in modest, not to say impoverished circumstances. Furthermore, their communication needs may be intermittent and infrequent. It is therefore not feasible to provide each inhabitant with an individual line. Instead, shared facilities (PCOs or multipurpose community telecentres) should be considered when planning telecommunication infrastructures in poor rural areas. The needs of private subscribers who wish to have individual lines at home or in their businesses should, of course, also be met, provided that they are prepared to pay the cost.

5.2.1 Scenarios

NOTE – According to the GAS 7 Handbook rural areas may be represented by four models (A, B, C and D) as follows:

– *Model A* (high population density): an area where the population density is relatively high for a rural district and where distances between neighbouring villages are fairly short.

– *Model B* (mountainous area): an area where villages are separated by mountains or hills, or where they are situated o a mountain or hill.

– *Model C* (ribbon type): an area where villages are strung out along a river or a road.

– *Model D* (scatter type): an area in which the population is sparse and widely scattered.

The three scenarios proposed below correspond to three commonly encountered situations.

a) *Scenario 1*: the so called "*remote*" configuration, which applies for instance to new urban or suburban areas linked to existing networks at a distance of 5-20 km (Figure 7).

b) *Scenario 2*: or "*star*" configuration, which is the extension of an existing zone around its centre to include new subscribers. This is typically the case in suburbs (Figure 8).

c) *Scenario 3*: or "*tree*" configuration, which covers a much wider, typically rural area where a large number of villages have to be connected to the nearest regional administrative/economic centre (Figure 9).

Extreme configurations such as deserts, islands or a few regions with a very scattered population whose potential subscribers are hundreds of km from the connecting exchange, have not been considered. In such cases, it is clear that techniques such as satellites or radio-relays will be the most appropriate, even though the cost may be high.

5.2.2 Technologies applicable to the scenarios

Without going into great detail, it may be said that the technologies applicable to the three scenarios should meet the following requirements:

– provision of links between rural areas and connecting exchange centres;

– provision of local connections within a single rural area.

For links with connecting exchanges, the following systems may be considered:

– multi-pair copper or fibre optic trunk cable;

– radio-relay;

– satellite (geostationary or non-geostationary).

For local links (or connections):

– multi-pair cables (copper, fibre optic);

– single-channel radio systems;

– point-to-multipoint radio systems;

– fixed cellular systems;

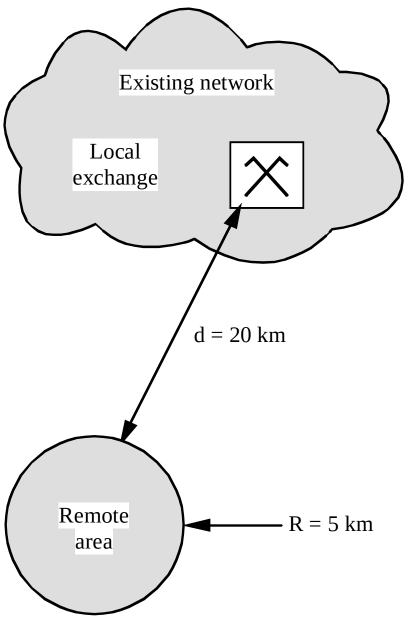
– cordless systems;

– satellite systems.

The above is illustrated in Figure 10, where the local access network refers to the entire network between the automatic exchange and the subscriber's premises. "CP" or "DP" could represent a remote subscriber access unit, a rural automatic exchange, a terminal station or a repeater station with subscribers.

FIGURE 7

Scenario 1 – Urban/suburban – Remote configuration

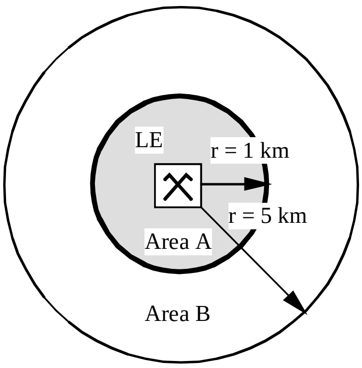


- Existing network
  - Spare capacity: : 2000 lines in LE
- New area
  - Environment type : suburban/urban
  - Number of subscribers : 300 to 1500
  - Subscribers density : 4 to 20/km^2
  - Subscribers type : Business PCOs
  - Traffic per subscribers : 100 mE/subscribers
  - Services : POTS
    : Fax group 3 and 4
    : ISDN (2B+D)
  - Grade of service : 1%
  - Deployment : fast (two years maximum)

d07

FIGURE 8

Scenario 2 – New urban/suburban area – Star configuration

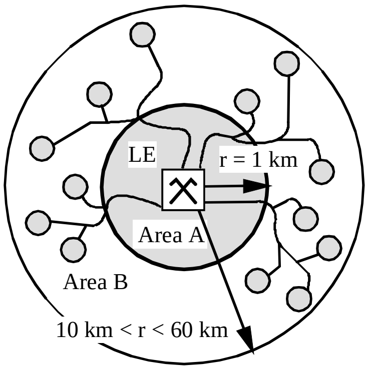


Area type:	**Center (A)**	**Suburbs (B)**
Number of subscribers	600-3 000	100-1 000
Subscribers density	200-1 000	2-20/km^2
Subscribers type	Business	Residential
Traffic per subscribers	100mE	50mE
Services	POTS Fax Group 3 and 4 ISDN access	POTS Fax Group 3
Grade of service	1%	1%
Deployment	5 years	5 years

d08

FIGURE 9

Scenario 3 – Small town and rural area – Tree configuration

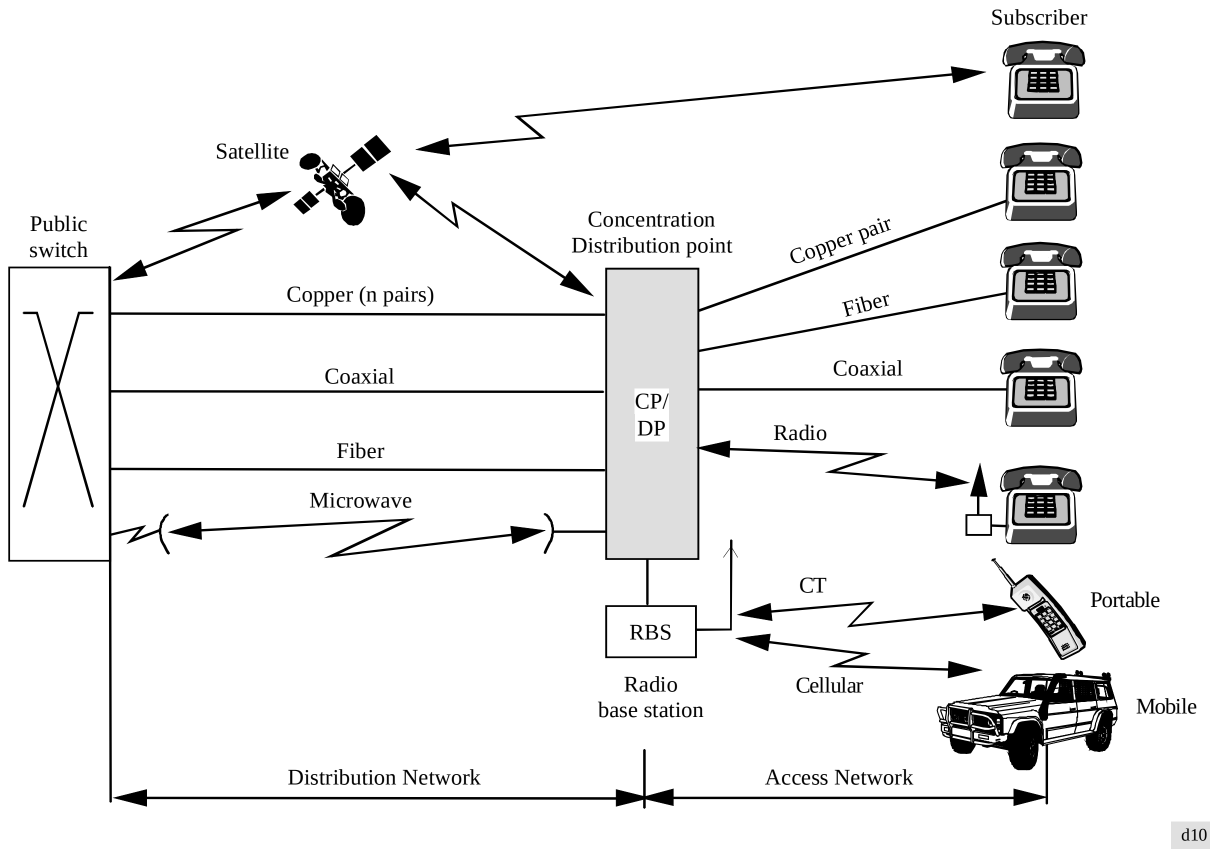


Area type:	**A**	**B**
Environment	Urban	Rural
Number of subscribers	600-3 000	20-1 500
Subscribers density	200-1 000	2-50 subscribers/cluster
Concentration/ number of clusters		10-30
Traffic per subscribers	100mE	50mE-80mE
Services	POTS Fax Groups 3 and 4 ISDN access	POTS Fax Group 3
Grade of service	1%	1%
Deployment	3 years	3 years

d09

FIGURE 10

Local access network definition



5.2.3 Technological compatibility and coherence

Referring to the definition of local access network in § 5.2.2, it may be recalled that both the access network and the distribution network may use either cable or wireless technology. In theory, most combinations can be used. However, other parameters such as geography, local constraints or even relative capacities, performance or the services supported may limit the number of possibilities. Hence the interest of studying the compatibility and coherence of technologies for models such as those described in § 5.2.1.

5.2.3.1 Compatibility

The existence or otherwise of a concentration point (CP)/distribution point (DP) in the local access network is the first compatibility factor between the different elements of the network. If the distribution point is co-located with the local automatic exchange, the subscriber access will use only one technology, and the issue of compatibility will be confined to the interface with the automatic exchange. On the other hand, if there are two subnetworks, i.e. when there is a concentration/distribution point, compatibility between the two subnetworks needs also to be examined.

5.2.3.2 Coherence

Although most juxtaposed technological combinations are technically possible, capacity, service and other factors generally limit the range of solutions. A compatibility/coherence matrix should therefore be drawn so as to restrict comparative studies to workable solutions.

Table 13 illustrates this procedure for the three models under consideration.

TABLE 13

Compatibility and technological coherence matrix for the three scenarios

Distribution network	**Access network**							
Technology	**Copper**	**Coax**	**OF**	**Cell.**	**MW**	**PMP**	**CT**	**Sat**
Copper	x			x	x	x	x	
Coax	x			x	x	x	x	
OF	x			x	x	x	x	
Cell.								
MW	x	x	x	x		x	x	
PMP	x			x			x	
Cordless (CT)								
Sat.	x	x	x	x	x	x	x	

5.2.4 Solutions for the three scenarios

Only a limited number of solutions appear realistic and significant for cost comparison purposes (Table 14).

5.2.5 Assumptions

In order to evaluate the cost of the different solutions, the following assumptions have been made:

1) The cost of subscriber radio terminals (fixed, mobile or portable) has been included in the calculation when radio is used in the access network. The cost of operating licences including frequency fees is not included.
2) Subscriber access is regarded as starting from the automatic exchange terminal.
3) Analogue and digital cellular systems have been evaluated separately and the cost of all equipment has been included (MSC and all the other necessary associated equipment). It has been assumed that there is no existing cellular mobile network.
4) The cost of all ancillary equipment, such as ducts and jointing chambers, has been included in the calculations.
5) Radio coverage has been estimated on the basis of normal transmission conditions without any major obstacle, and assuming that only subscribers' external roof antennas are needed.

TABLE 14

Solutions

	Technologies		
Models	**Solution**	**Distribution**	**Access**
Scenario 1	Solution 1 Solution 2 Solution 3	Copper Radio-relay Radio-relay	Copper Cellular Cordless
Scenario 2	Solution 1 Solution 2 Solution 3	N/A	Copper Cellular Cordless
Scenario 3	Solution 1 Solution 2 Solution 3	Fibre optic Pt-Multi-Pt Satellite	Copper Cordless Cordless

5.2.6 Cost comparison

The results of the cost comparison for the various scenarios shown in Figures 11, 12 and 13 indicate that:

a) Regardless of the model or solution envisaged, all the curves have the same hyperbolic form, i.e. the cost per subscriber decreases with the number of subscribers.

This is logical, since the high initial investment cost is shared among an increasing number of subscribers. The cost per subscriber therefore decreases along a hyperbolic curve until it reaches a constant cost, which corresponds approximately to the cost of the subscriber equipment, i.e. the subscriber terminal and accessories (antennas, etc.).

b) In *Scenario 1*, the urban/suburban "remote" configuration, for Solution 1 (copper) and Solution 3 (radio-relay + cordless), the initial infrastructure can support all potential subscribers and thus the cost per subscriber decreases slowly to reach the minimum. In other words, in a new "remote" urban/suburban configuration, all the cable ducts can be regarded as having been laid from the outset and only the drawing of cables through the ducts has to be taken into account.

In this case, the additional cost is less than with any other wireless solution, which also explains why, starting from a much higher initial investment, including the installation of ducts, the Solution 1 curve then crosses that of Solution 3.

Still in the same model, the Solution 2 curves (radio-relay + analogue or digital cellular) decrease up to the limit of the maximum number of subscribers which the base radio stations can support. At that point, the peaks correspond to the new investment required for new base radio stations and related equipment, such as power and radio-relays to link them to the automatic exchange. Then the curve declines again as for the initial investment.

At the final stage, the cost is higher for digital cellular than for analogue cellular, which in turn is more expensive than "cordless".

c) *Scenario 2* is a "star" urban/suburban configuration, which can support several hundred subscribers compared with 1 500 in Scenario 1 and 4 500 in Scenario 3.

The shapes of the curves are the same as in Scenario 1, but the scale is significantly different.

In all the solutions (copper, cellular or cordless), major investments are required at the beginning in order to cover the first ring of the new zone from the outset. Thereafter, investment will continue progressively as new subscribers are connected.

d) *Scenario 3* is a rural "tree" configuration. The peaks in all three solutions reflect the frequent additional investments needed each time a connection is made to a new cell or branch of the network. The shaded area in the curves shows the variation of cost per subscriber as a function of the distance from the automatic exchange.

FIGURE 11

Cost Comparison
Scenario 1 – Urban/suburban – "Remote"

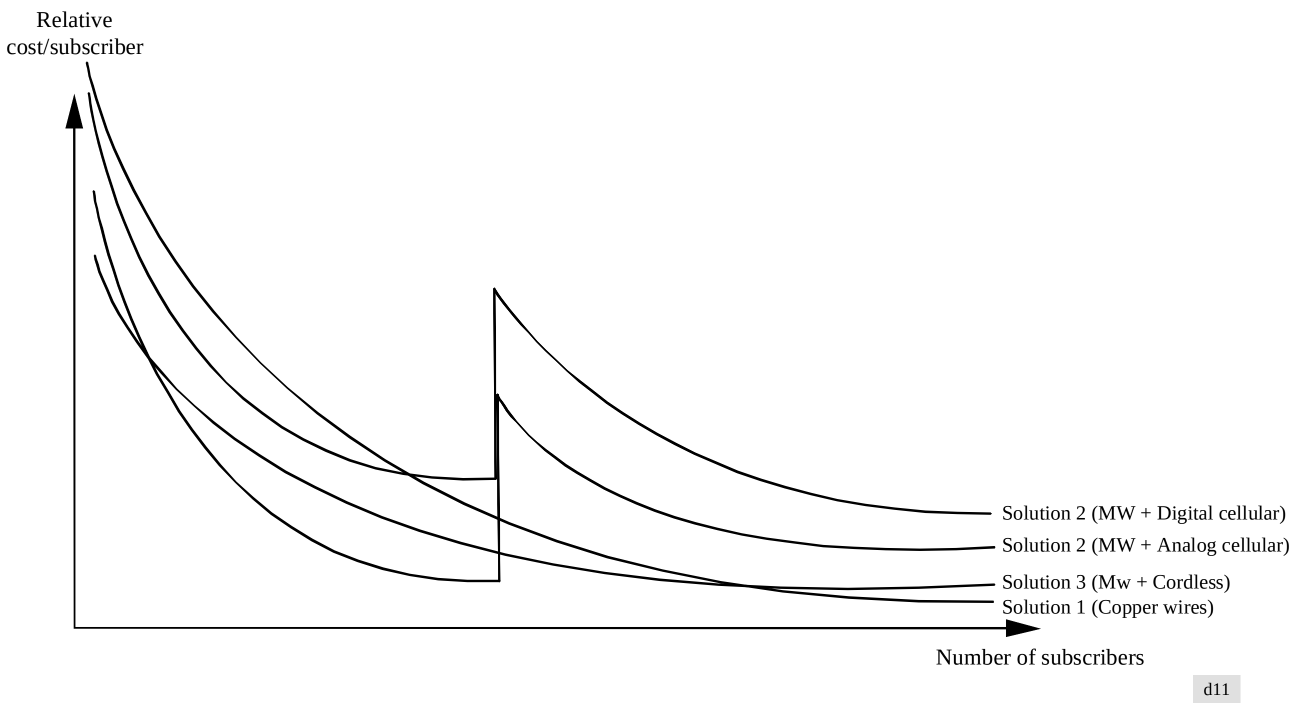


FIGURE 12

Cost comparison
Scenario 2 – Urban/suburban – "star"

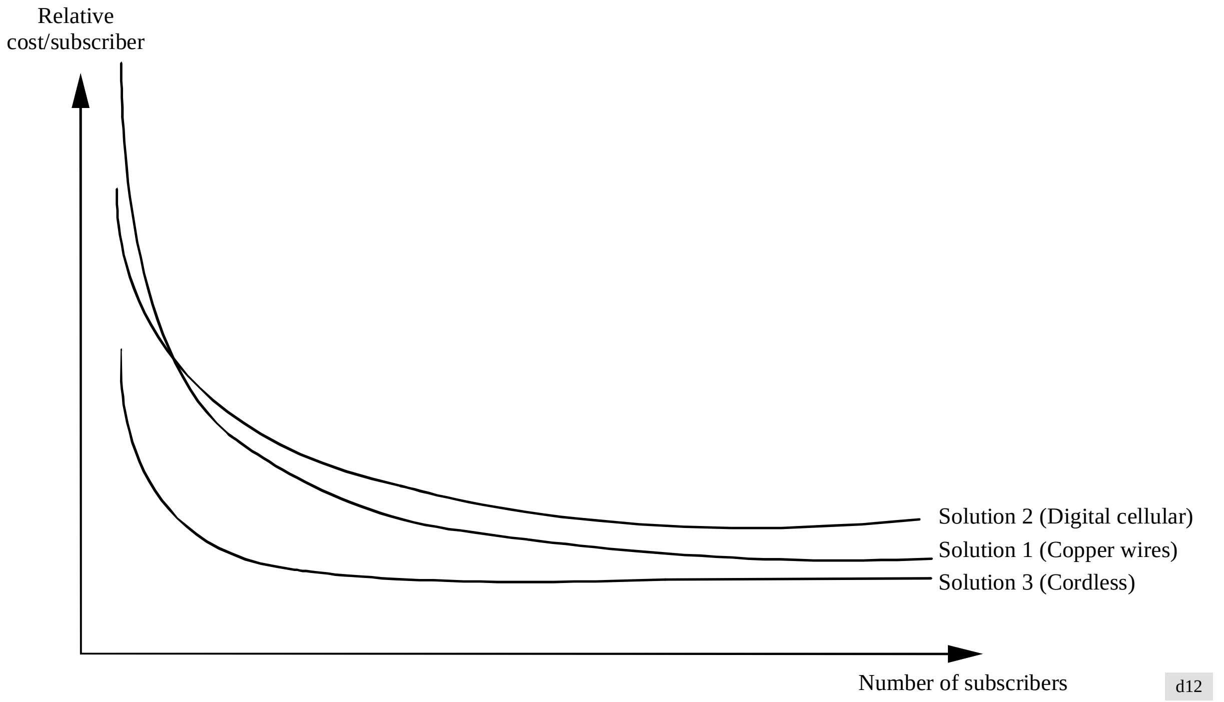
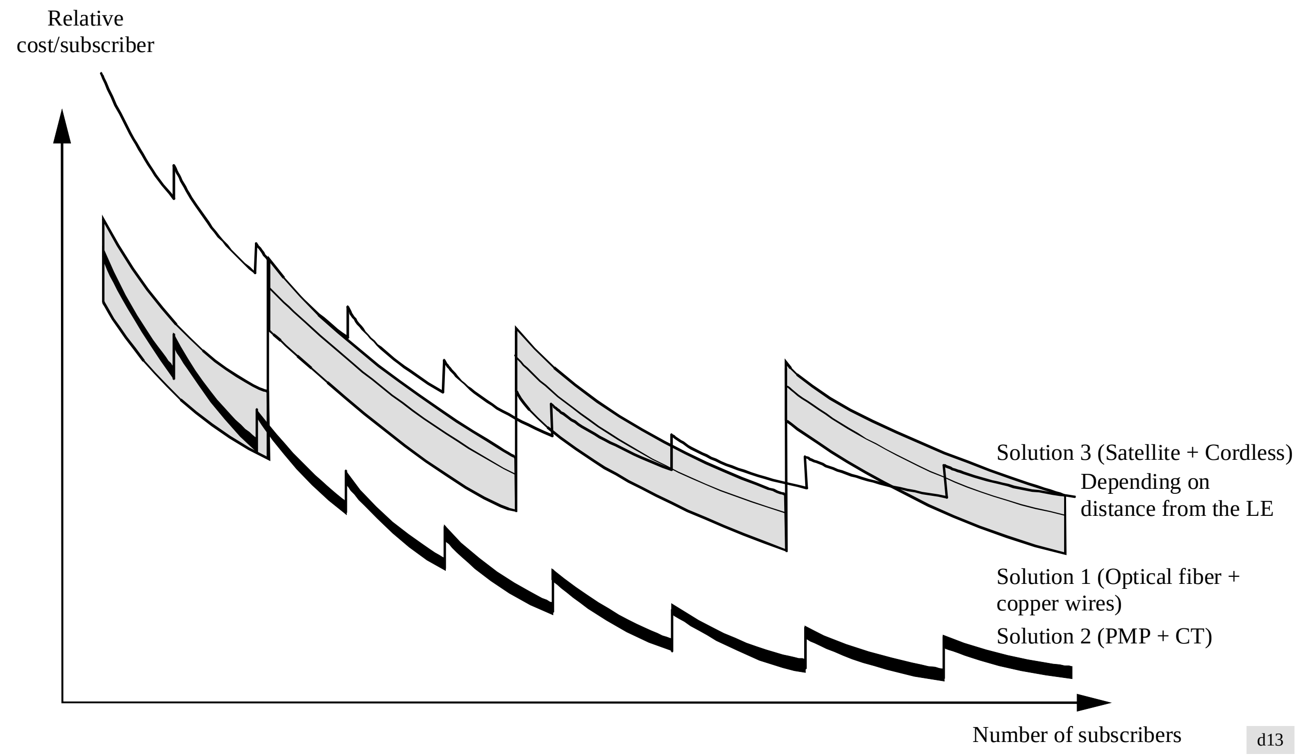


FIGURE 13

Local access – Cost Comparison
Scenario 3 – Rural – "Tree"



For Solutions 2 (PMP and CT) and 3 (satellite and CT), the frequency of the peaks reflects the new investments required for each new cell.

In Scenario 3, due to the low subscriber density in zone B and their low level of concentration (many small cells), Solution 2 with PMP and CT is the least expensive, while Solution 3 with the satellite is the most expensive.

It should be noted that GMPCS will be a serious contender in the near future in offering a low initial cost per subscriber (the handset). However, the "high" price of communications at the early stages may offset the initial cost advantage.

5.3 Conclusion

Provision of telecommunication services in the rural areas of developing countries was, until recently, a lengthy and expensive process. This was due to the fact that deployment of a copper network required a large up-front investment which was difficult to justify given the uncertainty of demand. Today, advances in radio technology make the task of providing the local access more rapid and cost effective in many cases.

The advantages of fixed wireless access are lower capital and operational costs, faster deployment and flexibility in network design. They are illustrated in Figures 14a to 14d. These four figures are sourced in reference [25].

Wireless systems will undoubtedly represent a significant share of installations in the next few years. This will concern not only new operators, but also existing PTOs in rural areas (as well as in new urban and suburban areas), where flexibility and low initial investment are the key issues.

Depending on the existing telecommunication infrastructure, the operator's strategy, the services to be offered, the cost and the local constraints, wired and/or wireless technologies can be used.

FIGURE 14a

Fixed wireless access

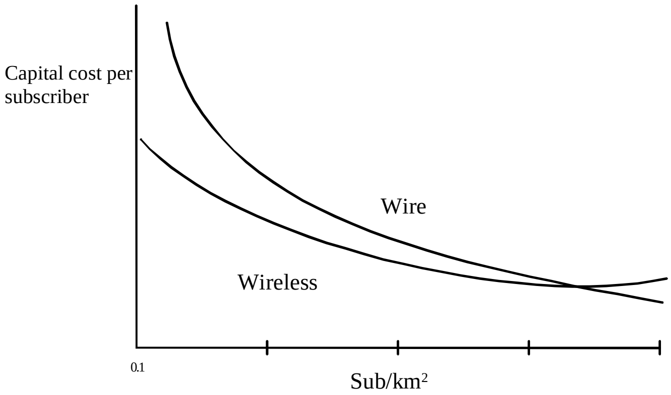


FIGURE 14b

Comparison of wireless and wireline systems in terms of operational costs

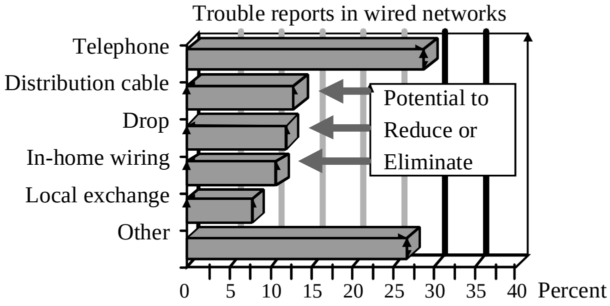


FIGURE 14c

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

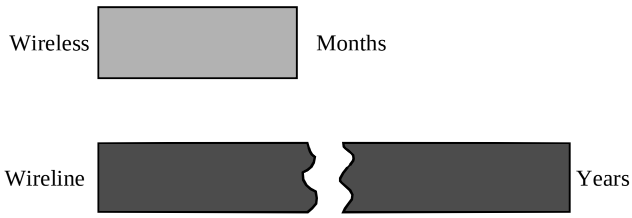
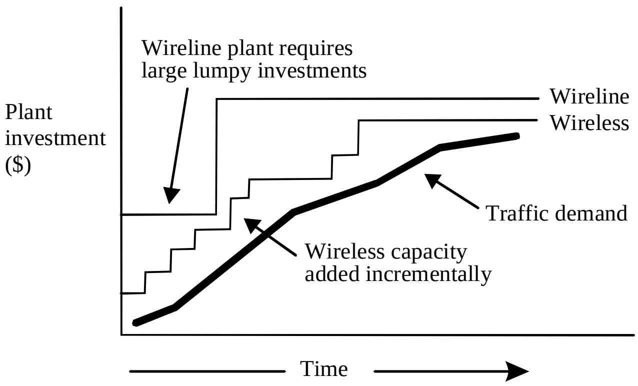


FIGURE 14d

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



d14

As shown by the curves in Figures 11 to 13, the total cost of the local access may vary considerably from one case to another. The curves also show that none of the proposed technologies is the cheapest in all models for any number of subscribers. This means that, to make the right choice, the operator will have to search for a solution enabling the initial investment to be recovered in the shortest possible time by capturing a sufficient number of subscribers, while at the same time safeguarding the flexibility to expand both technically and commercially at the lowest final cost per subscriber.

A number of wireless systems might be readily extended to support additional services, including mobile services. Nevertheless, wire networks should not be considered as “has been”. The IMT-2000 system will demonstrate its full potential in practice, and there is still room for the implementation of wire networks in rural areas, especially when the demand for advanced services exceeds the capabilities of the present and emerging wireless systems.

Table 15 below summarizes the services supported by the different technologies, while Figure 15 illustrates the positioning of technologies as a function of telephone penetration and of the distance to the nearest switching exchange.

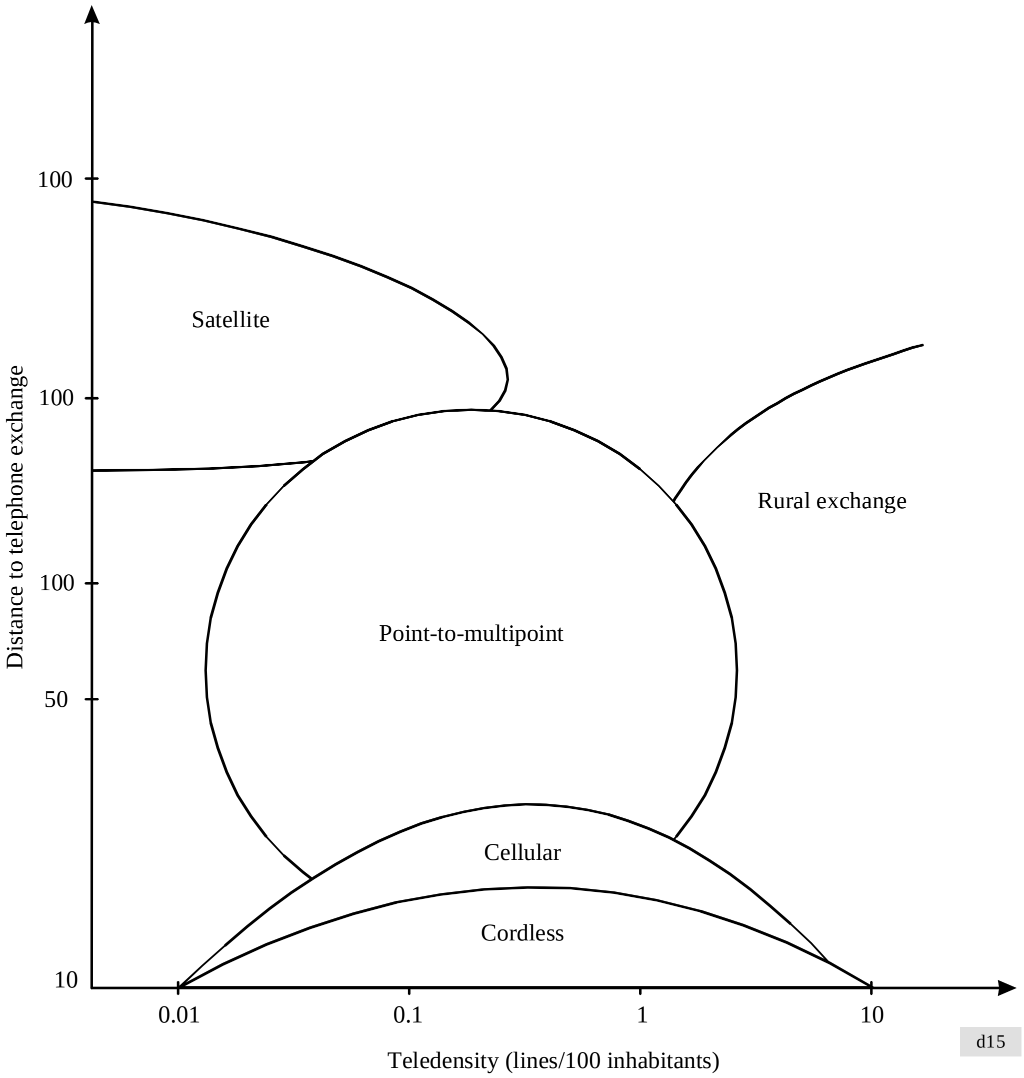
TABLE 15

Local access technologies and services (Non-exhaustive list)

Technologies		Services		
		Voice	**Data**	**Video**
Wired	Conventional copper pair	1 channel	Up to 19.2 kbit/s	Slow
	HDSL	30 channels	2 Mbit/s	Video conference
	ADSL	1 channel	19.2 or 28.8 kbit/s + 6 Mbit/s	On demand
	CATV	Possible	Limited capacity	Broadcast
	Opt. fibre	Variable up to 100 000 channels and over	Up to 10 Gbit/s	Multi-HDTV + interactive
Wireless	Analogue cellular	1 channel per freq.	Up to 4.8 kbit/s	No
	Digital cellular	Variable	> 2.4 kbit/s	No
	Microwave	n × 30 chan.	n × 2 Mbit/s	Broadcast
	Point-to-Multipoint microwave	n × 30 chan.	16, 32, 64 kbit/s or n × 64 kbit/s	Video conference
	Cordless	12 to 48 chan./BS	Up to 4.8 kbit/s or n × 32 kbit/s	Slow
	Satellite	Depending upon type		

FIGURE 15

Technology positioning



ANNEX I

Example of financial analysis

The purpose of this Annex is to suggest how a telecommunication operator might go about selecting the best financial alternative when faced with several technically equivalent offers [40]. The example given is purely illustrative and not based on any on-going project or particular technology.

Three offers, which are technically equivalent (service rendered, quality, etc.) but have slightly different financing, administrative, operational and maintenance costs, are considered.

Offer No. 1:

Total amount: 13 000 MU

MU = monetary unit

Financing conditions:
- 80% of the total amount financed over 10 years with 10% interest per year;
- 20% of the total amount covered by the operator's own capital.

Offer No. 2:

Total amount: 14 000 MU

Financing conditions:
- 20% of the total amount financed over 5 years with 10% interest per year;
- 80% of the total amount financed over 10 years with 7.5% interest per year.

Offer No. 3:

Total amount: 15 000 MU

Financing conditions:
- 30% of the total amount financed over 5 years with 10% interest per year;
- 70% of the total amount financed over 10 years, with a two-year grace period, with 9% interest per year.

1) *The following assumptions are made:*

a) the economic life of the project is 15 years;

b) the revenues generated by the project are as follows:

year 1 3 000 MU

year 2 4 500 MU

years 3 to 15 6 000 MU per year;

c) investment and implementation occur during year 0, so that the project starts generating revenues at the beginning of year 1;

d) Annual costs in respect of administration, operation and maintenance are estimated to be:

offer No. 1 2 340 MU (18% of investment)

offer No. 2 2 400 MU (17.1% of investment)

offer No. 3 2 460 MU (16.4% of investment);

e) depreciation is linear over the economic life of the project;

f) income tax is 33%;

g) the telecommunication operator's shareholders wish to receive a 5% dividend on the capital invested for the implementation of offer No. 1 (20% of 13 000 MU = 2 600 MU, i.e. a dividend of 130 MU per year) ;

h) for the purposes of evaluating the different offers, a discount rate of 10% is used.

2) *Criteria for comparison*

NOTE – An in-depth discussion on the selection of the best offer based on the NPV and IRR criteria can be found in reference [40]. The return profile of the different offers (NPV vs discount rate) could also be taken into account.

The following two criteria may be used for selecting the best offer:

– maximum net present value (NPV); and/or

– maximum internal rate of return (IRR).

Tables 1 to 3 and Figure A-1 show the detailed business plan for each offer.

The results are summarized in Table 1.

TABLE 1

Summary of results

Offer	**1**	**2**	**3**
Investment	13 000 MU	14 000 MU	15 000 MU
Net present value	5 278 MU	6 174 MU	4 669 MU
Internal rate of return	24%	36%	41%
This table shows that: – if the operator favours the highest net present value, then offer No. 2 should be selected; – if the operator favours the highest internal rate of return, then offer No. 3 should be selected.			

However, if the operator favours the highest internal rate of return together with the highest net present value during the first years of operation, offer No. 3 should be selected, as shown in the detailed calculation (Tables 1 to 3).

It should be noted that if the shareholders agreed not to receive any dividend during the economic life of the project, the net present value of offer No. 1 would reach 6 267 MU, the internal rate of return remaining about the same.

In conclusion, there is no clear-cut answer to the dilemma. However, this example shows that it is not always best to go for the cheapest investment. It is therefore important to carry out appropriate sensitivity analyses, which take into account other factors, such as hard currency inflows and outflows, as well as non-monetary factors.

TABLE 2

Net present value and IRR – Offer No. 1

Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Investment (C)	2 600 10 400															
Revenues (R)		3 000	4 500	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000
AO&M (A)		2 340	2 340	2 340	2 340	2 340	2 340	2 340	2 340	2 340	2 340	2 340	2 340	2 340	2 340	2 340
Depreciation (D)		867	867	867	867	867	867	867	867	867	867	867	867	867	867	862
Interest expenses (I)		1 040	975	903	824	737	641	536	420	293	161					
Profit (loss) before tax (RBT)		–1 247	318	1 890	1 969	2 056	2 152	2 257	2 373	2 500	2 632	2 793	2 793	2 793	2 793	2 798
Income tax (IT)		–	105	624	650	678	710	745	783	825	869	922	922	922	922	923
Profit (loss) after tax (RBT)		–1 247	213	1 266	1 319	1 378	1 442	1 512	1 590	1 675	1 763	1 871	1 871	1 871	1 871	1 875
Cash flow (CAF)		–380	1 080	2 133	2 186	2 245	2 309	2 379	2 457	2 542	2 630	2 738	2 738	2 738	2 738	2 737
Loan reimbursement (LR)		653	718	790	869	956	1 052	1 157	1 273	1 400	1 532					
Dividends (Di)		130	130	130	130	130	130	130	130	130	130	130	130	130	130	130
Net value (NV)	–2 600	–1 163	232	1 213	1 187	1 159	1 127	1 092	1 054	1 012	968	2 608	2 608	2 608	2 608	2 607
Net present value (NPV) $\tau = 10\%$	–2 600	–3 657	–3 465	–2 554	–1 743	–1 023	–387	173	665	1 094	1 467	2 381	3 212	3 967	4 654	5 278
IRR = 24%.																

TABLE 3

Net present value and IRR – Offer No. 2

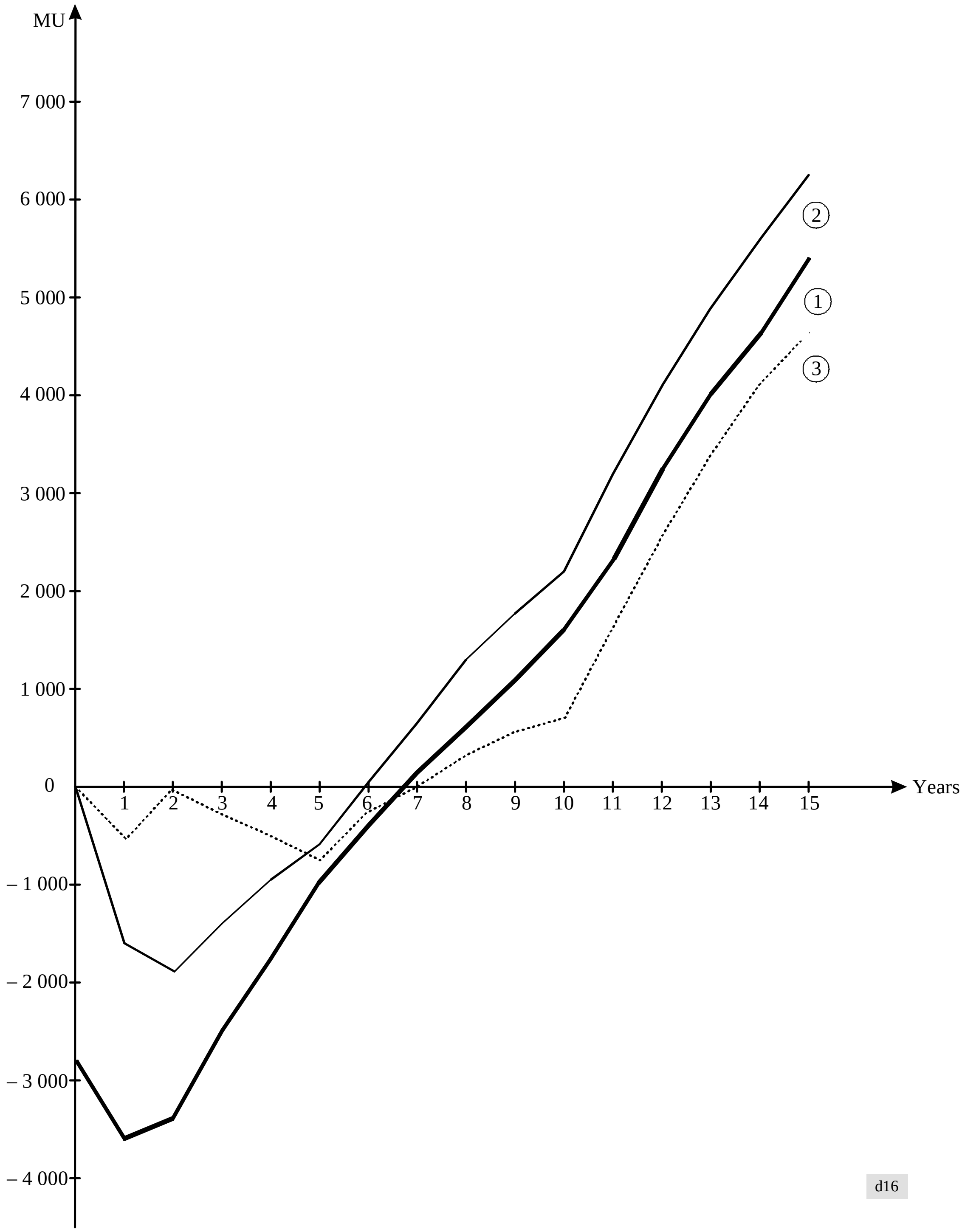
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Investment	14 000															
Revenues		3 000	4 500	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000
AO&M		2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400
Depreciation		933	933	933	933	933	933	933	933	933	933	933	933	933	933	938
Interest 20%		280	234	184	128	69										
Interest 80%		840	781	717	648	574	495	410	318	219	118					
Profit (loss) before tax		–1 453	152	1 766	1 891	2 024	2 172	2 257	2 349	2 448	2 549	2 667	2 667	2 667	2 667	2 662
Income tax		–	50	583	624	668	717	745	775	808	841	880	880	880	880	878
Profit (loss) after tax		–1 453	102	1 183	1 267	1 356	1 455	1 512	1 574	1 640	1 738	1 787	1 787	1 787	1 787	1 784
Cash flow		–520	1 035	2 116	2 200	2 289	2 388	2 445	2 507	2 573	2 671	2 720	2 720	2 720	2 720	2 717
Loan reimbursement 20%		459	505	555	611	670										
Loan reimbursement 80%		792	851	915	984	1 058	1 137	1 222	1 314	1 413	1 514					
Net value		–1 771	–321	646	605	561	1 251	1 223	1 193	1 160	1 157	2 720	2 720	2 720	2 720	2 717
Net present value $\tau = 10\%$	0	–1 610	–1 875	–1 390	–977	–629	77	705	1262	1 754	2 200	3 153	4 020	4 808	5 524	6 174
IRR = 35%.																

TABLE 4

Net present value and IRR – Offer No. 3

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Investment	4 500 10 500															
Revenues		3 000	4 500	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000
AO&M		2 460	2 460	2 460	2 460	2 460	2 460	2 460	2 460	2 460	2 460	2 460	2 460	2 460	2 460	2 460
Depreciation		1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
Interest expenses 30%		450	376	295	206	108										
Interest expenses 70%				1 123	1 021	910	789	658	514	357	185					
Profit (loss) before tax		–910	664	1 122	1 313	1 522	1 751	1 882	2 026	2 183	2 355	2 540	2 540	2 540	2 540	2 540
Income Tax		–	219	370	433	502	578	621	668	720	777	838	838	838	838	838
Profit (loss) after tax		–910	445	752	880	1 020	1 173	1 261	1 358	1 463	1 578	1 702	1 702	1 702	1 702	1 702
Cash flow		90	1 445	1 752	1 880	2 020	2 173	2 261	2 358	2 463	2 578	2 702	2 702	2 702	2 702	2 702
Loan reimbursement 30%		737	811	892	981	1 079										
Loan reimbursement 70%				1 131	1 233	1 344	1 465	1 596	1 740	1 897	2 069					
Net value		–647	634	–271	–334	–403	708	665	618	566	509	2 702	2 702	2 702	2 702	2 702
Net value τ = 10%	0	–588	–64	–268	–496	–746	–346	–5	283	523	719	1 666	2 527	3 310	4 022	4 669
IRR = 41%.																

FIGURE 16
Net present value



Formulae used in Tables 1 to 3

Let:

C = investment

R_k = revenues for the year k

A_k = AO&M expenses

D_k = depreciation

I_k = interest charges
RBT_k = result before tax
IT_k = income tax
RAT_k = result after tax
CAF_k = cash flow
LR_k = loan reimbursement
Di_k = dividends
NV_k = net value
NPV = net present value
i = interest rate
τ = discount factor
IRR = internal rate of return
A = annuity

Then:

$$RBT_k = R_k - A_k - D_k - I_k$$

$$IT_k = 0.33\ RBT_k$$

$$RAT_k = 0.67\ RBT_k$$

$$CAF_k = RAT_k + D_k$$

$$A = I_k + LR_k = C\frac{i}{1-(1+i)^{-n}}$$

n = number of years

or

$$A = I_k + LR_k = C(1+i)^2\frac{i}{1-(1+i)^{-n+2}}$$

where a 2-year grace period has been granted for the year k.

$$LR_k = C\left[\frac{i}{1-(1+i)^{-n}} - i\right](1+i)^{k-1}$$

or

$$LR_k = C(1+i)^2\left[\frac{i}{1-(1+i)^{-n+2}} - i\right](1+i)^{k-1}$$

$$I_k = A - LR_k$$

$$NV_k = CAF_k - LR_k - Di_k$$

$$NPV = \sum_{0}^{n} NV_k (1+\tau)^{-k}$$

IRR is determined such that:

$$\sum_{0}^{n} NV_k (1+IRR)^{-k} = 0$$

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