SPECTRUM CONSIDERATION FOR FUTURE RADIO SERVICES FROM A TECHNICAL PERSPECTIVE

FINAL REPORT OF PHASE 1 OF THE STUDY

Contract No. 041ST 36100-05538/A

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EXECUTIVE SUMMARY

This study contract, as reported herein, was awarded to ADGA Quebec Limited by the Department of Communication. It consists of a two phase study to investigate the spectrum characteristic, eg. bandwidth, propagation losses delay spread and directionality, required by different users of the electromagnetic spectrum and identifies the spectral bands best matching these characteristics. This report covers phase 1 only which covers two subjects.

- Technologies to be used in Future Radio Service
- Spectrum Requirement and Potential Allocations.

The study identifies the base technologies, the system concepts and techniques that can be implemented from these technologies and hence the type of services that might be available and affordable.

The key base technologies were found to be; see Annex B

- A/D convertors
- Digital signal processing
- Linear integrated circuits
- Microprocessor
- Antennas

The key applied technologies were found to be; see Annex C

- Digital Speech encoding
- High level modulation technique
- Channel access protocol
- Electronically steered antenna
- Adaptive equalization

Future Radio Services were found to be largely digital in nature. Hence efficient data services could be readily accommodated within a radio primarily intended for speech. Hence added value services would be readily affordable. The use of intelligent access protocols would make the radio far more user friendly. Then combination of low cost and ease of use would make the use of radio for more prolific. In many instances it would compete and possibly take over from existing wire line services. The resulting demand for spectrum makes it essential that spectrum utilization be highly efficient. This objective is best accomplished through the optimum allocation of spectrum based upon the matching of desired characteristics with the obtainable characteristic from the various frequency bands.

Despite the rapid evolution of technology few fundamentally new services can be predicted. Instead a number of existing services will be merged thereby enabling subscribers a range of service attributes using a common RF device. Cordless telephone, cellular radio and MSAT (or SHARP) will likely converge to form a universal mobile telecommunication service offering voice, data, facs, low definition video and possibly high quality audio (broadcast) reception.

Services will greatly expand in the fields of application and in the areas of coverage. For example radar technology, in conjunction with mobile radio and leaky feeder could well form the basis for a vehicle guidance system facilitating collision avoidance, lane way guidance and route selection. A number of technology evolutions will have implications upon spectrum efficiency. Perhaps the most significant are low rate digital speech codecs, error correction coding and mobile trunking.

The low rate speech codes not only reduce the bandwidth (with respect to FM) required for speech but they allow modes of operation not readily accomplished by other means. In particular time division duplex allows full duplex operation or repeater operation using a single RF frequency. Also it allows efficient time division multiplexing of many speech or data, channels onto a single RF carrier in both point to multipoint as well as point to point services.

Error correction coding is significant as it allows the use of smaller fade margins. The consequent reduction in transmitter power reduces the interference environment particularly due to intermodulation.

Mobile trunking provides an effective manner of allowing small user communities access to radio facilities that could not be economically justified on a stand alone basis. Although trunking provides a much better utilization of the radio channel, approaching one Erlang per channel compared with 0.1 Erlang for non trunking systems with an equivalent grade of service, the extra capacity is likely to be taken up by the small user communities.

Based upon the current and emerging technologies an estimate of spectrum requirement was developed for the intra city, intercity and rural areas. These requirements were found to be fairly similar, largely as a result of the global or wide area coverage of wideband systems such as radar and satellite services. However in all cases the total spectrum requirements for systems below 20GHz was found to exceed the available spectrum.

By considering the coverage areas, coherent bandwidth, modes of operation and desirable physical attributes, a preliminary mapping was performed to show the type of service best suited to various parts of the frequency spectrum. This is shown in a diagrammatic form in Figures 1a through 1d of the main report in which both frequency and location (or service range) is identified against each of the major types.

The preliminary mapping is then overlayed to show the predicted spectral requirements of each of these major services. This is shown in Figures 2a through 2d. Although many existing allocations fit quite well with the allocation plans, shown in Figures 2a-2d, some revisions are obviously necessary to completely accommodate all services in this near optimum manner. The planned phase 2 of this study will address the reallocation requirements and provide a possible methodology by which a transition could be accomplished.

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1 INTRODUCTION

1.1

Under contract to the Department of Communication ADGA Quebec are conducting a study to identify:

a. the likely trends in radio services over the next 20 years,

b. the technology which will be required to support these future radio services and;

c. the bands of the spectrum most suitable for these future radio services (including existing services where gains may be accrued).

The work of the studies falls into two phases separated by a further study to be undertaken internally by the DOC. The tasking for the external study phases is as follows:

Phase 1 has two study taskings:

Task 1 Technologies to be used in Future Radio Service

Task 2 Spectrum Requirements and Potential Allocation

Phase 2 has three further tasks:

Task 3 The complete picture of the future trends of radio services over the next 20 years.

Task 4 The Technology supporting the introduction of the new systems and services.

Task 5 <u>The Use of the Frequency Spectrum</u>

The DOC internal study will provide a high-level overview and scenario for the future radio services in the years beyond 2000.

1.2 <u>The Scope of this Report</u>

This report will cover Phase 1., and its findings, together with those of the DOC Internal Study, are intended to form the input to the study Phase 2.

The tasks of this Phase 1 Study have been defined as follows:

Task 1 <u>Technologies to be used in Future Radio Service</u>

a. To review the propagation characteristics of radio transmission for the frequency spectrum from 30 MHz to 100 GHz;

b. To identify the various service and system types; and

c. To identify the frequency bands suitable for these service and system types, giving consideration to the desired reception of, and the potential interference between, the service types.

The service types could include: point to area, point to point, earth to space, troposcattering, ionospheric propagation, in-building, etc.

Task 2 Spectrum Requirements and Potential Allocation

To identify the future trends of radio services over the next 20 years, based on projected user demands and the development of new technologies, focusing on the following areas, with an emphasis on personal communications:

a) within the city
b) within the rural area
c) within space
d) inter-city and between city and rural area
e) between city and space and between rural area and space.

1.3 References

The following references have been used:

a. The Radio Communications Model, annex A of Schedule No. 1 to the Contract No. 041ST.36100-05538/A

b. A Study of Market and Technology Trends in Radio Communications, ADGA Study C0815 1989/90

c. Telecommunications Industry Associations, Digital Cellular Systems Standard TR45.3.

d. CSP International Report on Deregulation of the Radio Spectrum in the U.K, 1986.

e. NTIA Telecom 2000, October 1988.

f. ADGA study report C0834, A study of Future Spectrum Requirements for Mobile Communication in Canada.

g. Proposed Utilization of the Radio Spectrum in the Range 0.890-10.68 GHz by the Fixed Service, 1981. DOC Study Report.

h. Independent Review of Defence Radio Spectrum, DTJ/MOD 1988.

1.4 Abbreviations and Mnemonics

The definitions of the abbreviations and mnemonics used in this report are listed at annex A.

2 TASK 1

2.1 General Technical Background

Over the past few years the rapid evolution of technology has brought about a major change to the cost, quality and ease of use of radio based communications and radio determination services. With these improvements the acceptance by both the business sector and the general public of these radio based systems has greatly expanded. As a consequence of the market's greater awareness of the value of radio services, there is further demand for improvement and even the introduction of new services.

2.2 The Radio Communications Model (Ref. a)

The radio communications model constructed for the purposes of this study consists of the 5 spheres of communications, as listed under Task 2 above, within and between the 3 domains of the city, the rural area and space. The current and emerging non-broadcast radio services and systems appropriate to these 5 spheres area listed below. Note this list is not exhaustive:

a. Within City (also referred to as Intra-city).
conventional land mobile, (Portable and land mobile), cellular, digital cellular, GSM, trunked mobile, paging, cordless phones, PCN (CT-2, CT-3, and DECT) UMTS and FPLMTS, in-building office systems, radio microphone, fixed services, and radiolocation.

b. Within Rural Areas (intra-rural).
As a. above plus multipoint services (MCS).

c. Within Space.(intra-space).
Inter-satellite, space operations, space research.

d. Inter-city and between city and rural area.
Mobile, Cellular, fixed satellite, fixed.

e. Between city and space and between rural area and space.
Geosynchronous and low orbiting satellite for radio-determination, radio navigation ,land, maritime, and aeronautical mobile communications.

Within the same radio service categories are systems with widely different characteristics to provide different service features. Fixed Services, for example include microwave systems having different traffic capacities and involving different traffic distribution such as point-to-point, point-to-multi-point, intra-city data links, and in-building systems. Further mobile systems include dispatch, interconnect and paging systems. In addition some of the systems and services belong to more than one ITU radio service category, e.g. Communications between earth and space stations is an essential characteristic of fixed satellite and meteorological satellite services.

2.3 The Approach

In this Phase of the studies, a model will be created which will incorporate the known propagation characteristics over the frequency band 30MHz to 100GHz and the demands of users based upon their primary domains of operation, e.g., city, rural and space, and the interaction between these domains.

The utilization of particular base and applied technologies within these user demanded services will be examined and mapped against categories of service and optimum frequency bands within the systematic model.

The base and applied technologies to be considered, are those which form the main thrust of current development activities. They are based upon the consultations with industry and review of the published literature, as reported on previously by ADGA (Ref b.).

It must be recognized that some unpredictable innovative technologies will likely emerge, which could well be employed in a manner not identified within the systematic model, due to the entrepreneurial nature of the radio service marketplace. Despite the difficulty of predicting innovative techniques and applications, some allowance for their introduction should be made, both, in the spectrum allocation procedures and at the spectrum observation centres.

2.4 Base Technologies for use in Radio Services

The base technologies are the use of analogue/digital converters, of digital signal processing, of linear integrated circuits, microprocessors and their software, of bulk effect and electro-optical devices, and of sophisticated antenna designs. The details involved in each of these areas is listed at Annex B.

2.5 Applied Technologies

The Applied Technologies for consideration are in the spheres of modulation, channelisation, channel access, operating modes, extended coverage, mobile telephone, user features, spectrum management, and multi-path reduction. Annex C contains a table showing the development of standards covering these areas.

2.6 Future Radio Services

Similarly categories of radio services have been developed, also based upon the published literature and consultations with both manufacturers and service providers, covering Radio dispatch, Radio telephone, Radio data, Radio imagery, Radio determination, Non-Commercial Broadcast, Radio Paging, Radio Extensions, Fixed Links, and Industrial, Scientific Medical (ISM):
which are listed at Annex D.

2.7 Transmission Methods

In addition to the functionality and performance of the equipment or systems, the baseline technologies allow exploitation of different modes of radio frequency propagation. Depending upon the communication range and traffic throughput requirements, the propagation mode can be selected to best suit a particular application. The typical applications usually associated with the propagation modes are Surface wave, and Ionospheric (limited use above 30MHz), Meteor scatter (40 to 110MHz), Troposcatter, Atmospheric (Terrestrial), Space/SHARP, Leaky Feeder and Optical, the details of which are listed at Annex E.1

3 PROPAGATION RELATED APPLICATIONS

The propagation characteristics as a function of frequency are fully defined in Annex F. The significant characteristics that affect choice of propagation mode and choice of system parameters for a specific application are briefly described below :

The significant characteristics are:

- the environmental location of the communication stations
- the desired communications range
- the desired bandwidth
- the desired receiver performance

3.1 Summary of Propagation Modes

3.1.1 Surface wave propagation

For communicating stations up to 200km apart frequencies up to 8 MHz, propagating in a surface wave propagation mode, provide a direct communications path along the earth's surface. The attenuation experienced in the current flowing in the surface in this mode of transmission over sea water is much less than that experienced over land or fresh water. Ideally therefore the surface wave mode is best suited to above-water marine applications.

The practical size of shipborne antennas limits the lower useful frequency range to about 2MHz for ship based transmissions. Lower frequencies are best suited for transmissions from land based stations where there are fewer restrictions in the size of the antenna.

The frequencies employed in surface wave propagation are subject to high ambient noise levels, and multi-path signals exist which are reflected from the various ionospheric bands in the atmosphere. Both these phenomena may cause reduction in communications receiver performance and bandwidths are limited to not more than 10KHz. However, receiver performance can be improved through the use of adaptive equalizers that constructively combine the multipath signal components.

3.1.2 Ionospheric propagation

Ionospheric propagation is utilised for transmissions in the frequency range from 100KHz to 30MHz, which are directed away from the earth's surface to achieve, by refraction from the ionospheric layer, greater communications ranges (< 3000km) than are possible with surface wave propagation. High noise levels, multi-path, and at times the small frequency window, combine to limit the coherent bandwidth for much of the time. Consequently ionospheric propagation is best suited to single channel per carrier communications for voice or data.

However as one of the only modes capable of providing very long range communication without the use of intermediate relay points, it is essentially a mode used for communication between remote regions. Greater reliability of operation can be achieved in this mode through the use of automatic channel scanning and automatic channel evaluation techniques.

The low cost of receiving equipment versus the relatively high cost of transmitting equipment makes the ionospheric propagation mode well suited to broadcast type applications though reliable communications can only be achieved in a target area by changing frequency with the changes in the height and the density of the ionised layers.

3.1.3 Meteor Scatter

The highly ionized trails generated by the constant bombardment of small meteorites can be exploited in the frequency band 30 to 110MHz where the scattered electromagnetic energy is returned to earth in a small elliptical area between 400 and 1000 km from the transmitting site. As each trail lasts for at most a few seconds, communications must employ short burst of high speed transmissions initiated on the receipt of a sounding signal which is continuously transmitted by the central receiving station. This communications mode is well suited to the transmission of stored data collected over relatively extended periods.

The small ionized trail of each meteorite results in small footprints at both the transmitter and central receiver sites. Hence co-channel meteor burst systems can operate within the same general geographic area with low probability of mutual interference provided that the central receiving stations, (and/or the transmitting stations), are separated from each other by the diameter of a single footprint.

3.1.4 Tropospheric scatter

Tropospheric scattering allows the line-of-site propagation frequencies in the VHF to SHF range to be received at the earth's surface at distances over the horizon from the transmitter out to 300 km. However high path losses require the use of large aperture antennas and the resultant directivity best suits point to point circuits. The small multi-path delay spread provides a large coherent bandwidth so that traffic capacity is usually limited by the received power available in accordance with Shannon's law. Flat multi-path fading is usually compensated through a combination of frequency and antenna diversity.

The high cost of these techniques limits their use to transmissions over inaccessible terrain or water where repeaters can not be economically installed.

3.1.5 Atmospheric (or free space) propagation

Atmospheric propagation refers to the situation in which the gradient in the refractive index of the atmosphere constrains the transmission to follow the earth's curvature. Except for a few relatively small frequency bands, the qualitative characteristics of atmospheric propagation are very similar throughout the whole of the frequency band of 30MHz to 100GHz.

The main differences are that; at lower frequencies, 30MHz to 100MHz, occasional ionospheric propagation can also occur resulting in long range co-channel interference. At frequencies above 10GHz, progressively higher attenuation due to atmospheric absorbtion is experienced and, at 60GHz a very high attenuation occurs due to absorbtion by oxygen.

Of greater significance to the use of the atmospheric propagation mode is the quantitative differences that occur across the frequency band. These are:

a. The free space path loss of dipole antennas is a function of frequency squared.

b. The required path clearance (Fresnel Zone Clearance) to minimize multi-path fading is a direct function of frequency.

c. The size of antennas is a function of frequency.

d. The minimum size of obstacles that cause obstruction losses decreases linearly as the frequency increases.

e. The probability of low loss multi-path reflections from man made structure increases linearly with frequency.

f. At lower frequencies, atmospheric refraction extends the radio horizon beyond the visual horizon for a large percentage of time.

Atmospheric propagation is generally limited to near line-of-sight ranges. For fixed stations large coherent bandwidths are generally available, but these may be subject to deep slow fading, as the refractive index changes. For mobile stations fast fading due to multi-paths and smaller coherent bandwidths are more typical. The coherent bandwidth is determined by the spread in multi-path delay (proportional to the inverse of the bandwidth) and it is therefore largely independent of frequency. However for the short range low power systems, which generally utilize higher frequencies, the multi-path delay spread is mostly less than a few microseconds thereby allowing bandwidths of the order of 500KHz and greater. For longer range systems the multi-path delay spread can be up to 20 microseconds therefore restricting the coherent bandwidth to less than 50KHz.

For these reasons high capacity systems serving intra-city down-town areas are best achieved through the use of higher frequencies in the band, whereas rural systems are best served through the use of the lower band frequencies.

3.1.6 Space / High Altitude Relay

Except near the earth's horizon, the propagation to and from a space or high altitude relay platform is essentially free space propagation. This offers a very wide coherent bandwidth. For the space based repeater, propagation losses are essentially independent upon the geographic separation between earth stations. For the high altitude relay stations the variance in propagation loss is limited to 20dB. However, the effective signal variance can probably be limited to less than 3dB, through the use of an appropriately shaped antenna pattern.

The reduction in path loss variance is an important factor in system design. Intermodulation products can be better controlled by limiting the dynamic range, and code division multi-plexing can be used in a spectrum efficient manner.

As with atmospheric propagation, the path loss between dipole antennas increases as the square of the frequency. Therefore the lower frequencies are better suited to low capacity (usually mobile) systems whereas the higher frequencies can be used for high capacity fixed systems.

The large coverage area of these space / high altitude relay systems is also of great value for radio determination type services.

They are not however considered suitable for landing aids since they do not provide a fixed reference point.

3.1.7 Leaky Feeder

In reality this is not a propagation mode but more a form of distributed antenna. Propagation from the leaky feeder to the mobile terminal is, due to the very short range involved, very close to free space propagation.

System performance is limited by the propagation loss along the leaky feeder and by the small size of the cable openings. The useful frequency range is around 30 to 400MHz.

3.1.8 Optical

Two modes of optical or infra-red propagation are considered. The free space mode is completely restricted to line of sight. The high attenuation caused by water vapour or CO_2 can restrict the use to specific frequencies where the path goes through the atmosphere to either space to space communications or specialised terrestrial applications.

The second mode is not restricted to line of sight, but uses fibre optics (optical waveguides) either for high volume point to point communications or as a component of an RF system. In the latter mode the optical fibre is directly modulated by an RF signal prior to transmission. At the receiving site demodulation allows accurate recovery of the frequency and phase of the original signal. At this stage, if required, the signal can then be amplified and transmitted further-a-field via an RF antenna. This concept allows the operational areas of broadcasts (and their interference zones) to be reduced or two partially overlapping areas to be covered by the same RF frequency with minimal degradation in the overlap zone.

4 SUMMARY OF TECHNOLOGY TRENDS

4.1 Five year projections of Technology

4.1.1 Cellular Systems

The demand for cellular systems is expected to increase in this period, resulting in spectrum congestion in the 800-900MHz cellular bands. The existing analogue based systems will likely commence being phased out and replaced in North America with digital systems to be located in the same frequency band. These will employ a six slot TDMA scheme within each of the existing 30KHz FDMA channels. The expected characteristics are defined in Telecommunications Industry Associations TR 45.3, Digital Cellular Systems and are summarized in Annex G.

As privacy is becoming an increasingly important factor in such communications systems, a growing number of subscribers can be expected to take advantage of low cost digital encryption as these systems are implemented. However this will not affect the paging and access channels which will remain unencrypted.

4.1.2 Trunking Systems

The facilities available within the 800MHz trunking systems offer many operational advantages to users, not the least is access to an interference free channel which would otherwise not be available. The other advantages include: automatic identification, selective calling, priority allocation, and priority interrupt as well as the higher channel capacity provided through the trunking advantage.

The extension of the employment of trunking techniques to equipment using the lower UHF (400MHz) and upper VHF (170MHz) bands these features will be provided as standard rather than custom features. The application of trunking techniques are expected to be of significant value to Safety and Utility services which often require unimpeded access to wide area coverage in emergency or disaster situations. Both central repeater and distributed multi-site repeaters systems are likely to be implemented. The high cost of the trunk control systems will, in many cases, result in multiple users sharing by subscribing to either a private or a public carrier system.

It should be noted that trunked systems for the most part use half duplex, (i.e., the repeater operates full duplex whilst subscribers operate 2-frequency simplex), unlike non-trunked systems in which single or two frequency simplex operations predominates.

4.1.3 <u>Fixed Service</u>

Common carrier fibre optics trunks will have expanded to provide a network between most Canadian cities and urban centres. Heavy route microwave and fixed satellite services will provide backup capabilities only on these routes.

Light route microwave and/or fixed satellite services will continue to provide spurs to smaller communities from the main trunks.

4.1.4 Analogue narrowband systems

A number of analogue narrowband systems have been proposed using signal bandwidths of either 12.5KHz FM or 5KHz ACSSB. With the development of TDMA digital channels, having bandwidths of 30KHz (3 x 10Kbps) as proposed for digital cellular (see Annex G), it is not expected that the narrowband analogue systems will find widespread application. They may however be used as an interim solution in areas of the spectrum which are heavily congested or where 10KHz channels are not cost effective eg. MSAT.

It should be noted that emergency service operations (APCO) favour the use of 10 KHz digital radio using FDMA rather than TDMA because it enables simplex operations outside of the range of a repeater.

4.1.5 Mobile and Aeronautical Data Applications

Mobile and aeronautical data applications will increase particularly for short pre-formatted messages. Data modulation techniques for use with analogue FM or AM (aeronautical) radio will be driven by cost consideration and will remain low to medium speed. Higher data rates will evolve only for use with digital radios.

Research is likely to start into the application of the principles of voice controlled computers to the compilation of standard digital messages with the aim of reducing the signal time period occupancy. For example the statement :

"Joe, have you got another job for me ?"

could be transmitted as :

'Where next ?'

4.2 Ten Year Projections of Technology

4.2.1 Personal Communication Networks

Personal Communication Networks (PCN) will likely be implemented for intra-city downtown areas of North American cities to provide a wireless telephone service for mainly business applications. The PCN will connect, probably via the PSTN, to both wireline and cellular subscribers. Cellular will continue to dominate for mobile application but the increasing congestion of its frequency spectrum will drive more and more subscribers towards PCN, with consequent expansion of PCN coverage and, with the added advantage of spectrum utilisation being more efficient.

4.2.2 Mobile satellite

Mobile satellite will provide mobile telephone services to thinly populated areas not economically served by means of cellular or PCN systems. The transfer from one system to another will be transparent and the cost to the subscriber will be independent of the system in use.

Aeronautical users will largely switch to satellite operation for purposes of air traffic control and public correspondence during this period.

Both band and aeronautical satellite services could evolve from the maritime mobile satellite services as currently available from INMARSAT. Even where separate satellite systems are deployed the use of spectrum and earth coverage footprints will require close co-operation between service providers.

4.2.3 Stationary High Altitude Relay Platform (SHARP)

Subject to the successful solution of the airframe energy requirements, SHARP could find wide application for both mobile telephony and mobile dispatch systems. The slow variation in the propagation loss between SHARP and a mobile throughout the greater part of the service area simplifies the design of power control loops, required to ensure that all CDMA signals at the receiver are at near equal power levels, therefore it is considered the best suited to the use of spread spectrum CDMA technology.

4.2.4 Micro-processor techniques

The application of micro-processor techniques, which will be highly reliable and low cost, will be spread to:

a. dispatch type mobile radio systems, will allow, through automatic channel monitoring, the adoption of "send and forget" types of operation for mobile data . The short transmission times involved will allow large numbers of users per radio channel and therefore be spectrum efficient.

b. radio determination services which will become operationally integrated with a number of mobile radio applications, providing automatic tracking of the position of mobiles.

c. digital radio which will also facilitate the wider availability of digital radio telemetry and its use. In a number of applications this will require semi-continuous transmission at high data rates.

4.2.5 Fibre Optics

Fibre optic subscriber loops will become generally available within major cities. These may be used for business purposes to provide high speed data and video networks. They will also become the dominant mode of connection for PCN base stations.

4.2.6 Fixed Satellite Services

The use of fixed satellite services as permanent long range communication trunks is expected to plateau and eventually decline as fibre optic networks are established. Instead fixed satellite systems will be used more for transportable systems to provide high capacity on a temporary basis, eg. for outside broadcast or disaster relief, and for lower capacity multipoint systems. The low capacity systems will make use of VSAT technology to provide affordable terminals directly to user groups rather than via the common carriers.

4.3 Twenty Year Projections of Technology

4.3.1 PCN Trends

4.3.1.1 First Generation Technology

By the year 2000 PCN type systems will be available in many intra-city areas and most of the population will have experienced wireless telephony having made the mental adjustment of accepting usage in public places. Cost permitting it is therefore possible by the year 2010 that a personal telephone will be combined with a watch and as such will have universal use. The addition of an automatic alarm would be simple and a particularly valuable advantage to achieving personal security because the small cell sizes should allow rapid location of a person in distress.

For people subject to medical problems, the personal communications device could perhaps be linked to medical monitoring equipment, giving freedom where movement would be otherwise constrained.

4.3.1.2 Second Generation Technology

The impact of such personal communications devices upon PCN would be largely a matter of network capacity and second generation PCN type services offering additional functions would require a change in technology to avoid imposing further demands upon the spectrum. Enhancement will be required in medium speed data capacity, in video capability and in radio determination capability.

a. Medium Speed Data. The use of PCN for the interconnection of laptop or desk top computers is a distinct possibility, should there be a lack of wireline facilities in the event that wireless telephony becomes common place. The application would be complementary to, and not a replacement for LANS, which in general require a transmission rate of ten or more megabits/second.

b. Video Capability. Interpersonal communications ideally combines both audio and visual interaction. For those with unimpaired hearing, audio can be by far the most cost effective means of information transfer. However video transmission is important for deaf people and in addition enables better understanding of audio information, - " a picture is worth a thousand words". Though miniature vidicon technology and the small screen TVs provide the necessary enabling technologies, the most difficult problem for an acceptable personal video phone is the camera placement.

Camera systems will be developed which will focus-in and track individual or group voice sources, but the occasional personal feelings of inconvenience and invasion of privacy at being in full view will also have to be taken into account before the benefits of a universal personal video phone system will be obtained. Until such camera systems exist it is concluded that PCN video services will be limited to the business more than private sphere and to fixed imagery similar to a digital FACS.

4.3.2 Mobile Satellite Trends

As a result of the development of a second generation reusable launch vehicle, the launch cost per payload pound will decrease. Multiple low earth orbit satellites could therefore be more economically deployed, allowing PCN type terminals to be used via a satellite link. The provision of universal PCN services to remote areas would therefore be less restricted by the necessity for a large user demand and the contingent demand for spectrum. The cost of the satellites could also be reduced because the design would be less driven by considerations of satellite launch mass.

4.3.2.1 UMTS

As part of the European RACE project, Gibson, Vadgama and Macnamee, have indicated a possible course for the development of a Universal Mobile Telecommunication service. This would be based upon the evolution of a common air interface derived from the currently planned GSM and PCN standards. A major step in this direction has recently been brought about by the ETSI decision to adopt the GSM standard for the Digital European Cordless Telephone (DECT).

It is considered that UMTS would be comprised of two levels of service. A unified service level having data rates of up to 2 Mbits, see table 4.1 for a definition of services and rates provided within the unified service level, and a broadband service with data rates up to 30 Mbits. The unified service could be provided by a number of service operators depending on the nature of the application and the required coverage. Table 4.2 provides a possible mapping of coverage and operators. UTMS unified service is assumed will use basic 2 Mbits per carrier channels, each employing adaptive equalization, subdivided into time slots that are dynamically assigned to users on an as required basis. Both high density micro cell and medium density macro cells will be provided to give coverage to 95% of the population. Total coverage may be provided by the further overlay of satellite based hypercells. The Spectrum requirements are estimated at 200 MHz. For lowest cost of the UTMS infrastructure it is strongly urged that the spectrum allocation should be below 3 to 4 GHz.

4.3.3 Vehicle Guidance

Highway congestion and pollution will likely force the widespread provision of automatic vehicle guidance and collision avoidance systems. Many of the enabling technologies are currently under development but widespread application will require standardization on a North American if not a world wide basis. The system design will be difficult. It must operate in all weather conditions, be free of interference either unintentional or malicious, be low cost and fail safe in operation. Possible techniques could include, buried leaky cable for lane alignment, short range radar for automatic vehicle separation, real time display of traffic situations to enable drivers to make appropriate route selections, and interactive data to permit drivers to select a destination for purposes of automatic guidance by a central computer.

SERVICE TYPE	Information Rate
DIALOGUE	
Voice	4-16kb/s
Telex	16-64kb/s
Facsimile	16-300kb/s
Data	1k-2Mb/s
Electronic Documents (Text/Graphics)	100k-2Mb/s
Low Resolution Videophony	64k-2Mb/s
MESSAGING	
Paging	1-10kb/s
Voice Mail	4-16kb/s
Electronic Mail (Text)	100-500kb/s
Electronic Document Mail (Text/Graphics)	100k-2Mb/s
Low Resolution Video Mail	64-2Mb/s

SERVICE TYPE	Information Rate
RETRIEVAL	
Voice based Library	4-16kb/s
Music Library	200k-1Mb/s
Videotex	64-2Mb/s
Data	1k-2Mb/s
Electronic Document Library	1-2Mb/s
Still Picture / Low Resolution Video Library	64k-2Mb/s
DISTRIBUTION / NARROWCAST	
Voice	4-16kb/s
Music	200k-1Mb/s
Data	1k-2Mb/s
Low Resolution Video	64k-2Mb/s
Teletex	100-500kb/s

Table 4.1 A Preliminary List of Potential UMTS Services

CELL TYPE	COVERAGE	OPERATORS
Public Satellite Macro Micro	Everywhere outdoors Almost everywhere High traffic areas	PTTs or Cellular Operators
Semi Public	Public Buildings (Stations,Airports Hotels,Exhibitions)	PTTs Cellular Co's Entrepreneurs
Private Business Domestic	Business premises (Wireless PABX) Home & Garden	User Co's Office Landlords Individuals

Since these cells will be operated by different organisations, installed at different times, and overlaid on/under each other, careful frequency planning and management will be necessary.

Table 4.2 UTMS Coverage and Operations

5 USER DEMAND

5.1 General

In the previous section expected Technology trends and their impact upon radio services were discussed. In this section the requirements of users are investigated with a view to determining the nature and volume of future radio services required to satisfy the future social/economic conditions.

The user requirements reported herein have been assembled from a number of studies conducted in Canada and internationally over the past few years. As such they represent the opinion and forecast of a much larger body of users than could be assessed within the scope of this project. The major sources of information include CSP International Report on Deregulation of the Radio Spectrum in the U.K. (ref. 1.3d), NTIA Telecom 2000 (ref. 1.3a) and AGDA's study Market and Technology Trends in Radio Communications (ref. 1.3b).

Although radio based services include navigation, radio location and various remote sensing applications, the majority of applications considered here are communications. Where these other services are required they are therefore treated as adjuncts to communication services.

5.2 Entertainment

Broadcast entertainment will involve the growing use of radio frequencies for production aids, e.g.

- Radio microphones
- Reporter and Camera control (Duplex voice between reporter, camera operator and director)

- Audio and video links (In support of outside broadcast, news gathering, etc.)

5.3 Fixed (and fixed satellite) Services

5.3.1 General

This section is concerned with those parts of the spectrum allocated for use by fixed services, namely point-to-point telecommunication links between fixed sites. The transmissions may be wholly terrestrial or be relayed by satellites. A comparison of the costs of leased lines and private fixed links indicates that there is substantial latent demand for the latter, which may be based upon a desire for greater reliability of access and for greater security of commercial interests.

5.3.2 Present Pattern of Usage: Fixed Links

The civil fixed link radio spectrum is allocated between two major user categories. These are Public Telecommunication Carriers, and private users.

(a) **Common carrier (CCs)**
CCs use fixed links as an integral part of their transmission systems; radio fixed links represent approximately 90% of the trunk traffic carrying capacity of the Canada's public networks.

(b) **Private Users**
The remaining portion of the spectrum is allocated on a link by link basis to organizations that operate private links or networks.

5.3.2.1 Private users comprise four groups

a. Private sector (e.g. Monitoring and control of Oil production, base station links for private mobile radio (PMR) systems, paging companies, other companies)

b. Public Sector Enterprises(e.g. Public Utilities, Waterway Authorities)

c. Public services (e.g. Health Authorities, Solicitor General on behalf of police and fire services, Transport Canada, etc.)

d. Broadcasters

5.3.2.2 Private user application of Fixed Links

These different groups use fixed terrestrial radio links in the following principal ways:

a. **Waterway Authorities** make use of fixed links for radar remoting, radar control, voice communications between barriers on rivers, control of tanker warning lights, and tide recording.

b. **Security Services and PMR Operators** use fixed links for circuits to base stations for their mobile radio services.

c. The **Solicitor General** uses fixed radio links to connect control centres to radio stations for mobile radio use for emergency service vehicles.

d. **Public Utilities and Other Industry** use radio fixed links primarily as a private backbone network for voice and data communications, and for scanning telemetry.

e. **Oil Operators** use troposcatter and line of sight links to effect data and voice communications between control stations and oil rigs. Troposcatter is usually limited to offshore facilities.

f. **Health Services** use radio fixed links for base station connections as part of mobile radio services for ambulances and emergency vehicles. In addition, they use telemetry for emergency alarms (e.g. medical alert, etc.) and biotelemetry.

g. **National Defence** used fixed services in HF, MF and microwave bands for purposes of tactical and strategic communications.

h. **Broadcasting Organizations** use radio fixed links extensively for TV and radio distribution and also for internal connections to studios. In addition a few links are dedicated for stereo radio transmission.

5.3.2.3 Future Demand for Fixed Links

Research indicates that demand for fixed links among private users is affected primarily by the following factors:

a. **Costs of Alternatives.** The major alternatives are private circuits of various kinds from CCs, though some classes of user, especially the public utilities, are empowered to install their own wireline systems, and may therefore compare the costs of radio with these.

b. **Desire for system integrity.** When a network which must have high availability and reliability is being designed (e.g. telemetry/telecontrol networks for power/water utilities, police mobile radio networks), the ability to own and operate and maintain the fixed links in the network is seen as a major advantage.

c. **Access to sites remote from suitable CC facilities.** Broadcasters in particular need to transmit wideband signals to remote hilltops which are ideal sites for broadcasting transmitters. However in many cases, CC wideband routes do not pass these sites. Offshore facilities are similarly not served by CC facilities.

d. **Flexibility in network design.** Microwave radio networks are very flexible. They can be designed to improve reliability in various ways, for example, by incorporating geographic alternate routing, or duplicate radio equipment. Duplicated control centres, such as for the public utilities, can also be provided for.

e. **Range of applications permitted.** Demand is critically dependent on the number of applications permissible. Corporations, datacasters, entertainment TV distributors, and mobile radio system operators are classes of users which have expressed interest in increasing their use of microwave fixed link radio.

5.3.2.4 Cost of Alternatives

Cost of alternatives to radio systems is probably the most important single factor in determining the level of private user demand. Many types of user mention other factors, such as reliability and control, as equally important. Nevertheless in most cases where alternatives to radio which are significantly cheaper can be found, then these are preferred and effort is put into developing network designs which have equivalent reliability and availability.

5.3.2.5 Desire for System Integrity

Many organizations require telecommunication networks which will be very reliable in use. These networks are often complex and geographically extended, and it may be particularly critical that they are available in adverse conditions.

They are used in situations where "safety of life" is frequently a criterion, such as the control of gas supply and storage networks, the collection of air or sea radar data, or communication with emergency services. In these situations, network designers aim for 100% availability.

Network designers argue that their network reliability target is easier to achieve with self-owned and operated radio than it is with CC provided links, for the following reasons:

a. physical alternate routing and duplicated transmission equipment can be introduced as and where required

b. the user organization has complete end-to-end control of both the network and the attached devices

c. time-consuming discussions as to where a fault lies - in the CC network, or in user-owned terminal/tandem equipment - avoided

d. control of all aspects of maintenance means that engineers can attend a fault at any time and under the **direct** control of the network manager.

5.3.2.6 Access to sites remote from CC facilities

In many cases, CCs have always made additional charges for providing services to points remote from their existing network. Hence microwave links are a particularly attractive proposition to those users with requirements for transmission capacity to remote sites, such as the broadcasting authorities.

5.3.2.7 Flexibility in Network Design

Radio systems are highly flexible from the perspective of the user. They can be installed anywhere that local geography will allow, they can be moved much more easily than wireline systems, and, as discussed above, appropriate levels of reliability can be built in. These are seen as significant advantages by many existing and potential users, including broadcasters, utilities, corporations and mobile service operators.

5.3.2.8 Potential new types of use include

a. PBX links for general business use (typically multi-channel telephone/data leased-line substation).

b. Wider range of PMR base-station links.

c. computer-to-computer high-speed data links.

d. entertainment distribution to homes (microwave video distribution system or MVDS) and also microwave fixed links as part of cable networks.

e. cellular and mobile radio "trunking" systems, i.e. links between base-stations, and between base stations and central switches.

5.3.2.9 PBX links

There is significant potential demand from corporations for microwave radio links to form part of corporate private networks. It has been established that radio systems are only generally cost-effective for links of about 10 voice circuits or more which in typical private networks are used as inter-PBX trunks. Approximately half the potential radio links are short distance (i.e. about 5-40 km in length) and half long distance (over 40 km).

5.3.2.10 PMR Base Station Links

For these users, single voice circuit and control channel ("1 + 1" systems) are applicable, but cost analysis shows that CC leased lines are normally cheaper than the use of radio. Research shows that a significant minority, for reasons of control, or difficulty/cost of obtaining CC links to inaccessible base station sites, nevertheless prefer radio. The great majority of these have short distance applications, but 5% will fall into the long-distance (40km+) category.

5.3.2.11 Computer to Computer High Speed Data Links

We define high-speed here as being a transmission rate of 2Mb/s or more. For simplicity all these links will be either 2Mb/s or 8Mb/s, though the "database extension" type of application could conceivably generate higher speed applications in future. Typical growth to be expected in these links can be seen from UK studies of demand for such links which indicate total demand rising at 25% per year.

5.3.2.12 Cable Distribution of Entertainment Programming

The use of microwave video distribution systems (MVDS) has become established in North America, and has been strongly advocated by some cable TV and entertainment interests. The application in a full commercial setting would require some very wide bandwidths (e.g. 250 MHz) but re-use could be high. (Cable systems are by their nature geographically separated, and the application is primarily for short-distance links within the coverage area of each network).

5.3.2.13 Cellular and Mobile Trunking Systems

The cellular radio operators have a major requirement for multiple voice circuit and high speed data links to each cell base station. Except in the intra-city area cellular base stations are being positioned to achieve wide coverage, many of the links are therefore long. 40% would be over 40 km in length, with the remainder being under 40 km. Of the current radio systems, 2Mb/s digital systems at 7.5 GHz appear ideal for this application, with 8Mb/s systems being used on higher traffic routes. Mobile trunking services will similarly generate a need for inter-base station fixed links.

5.3.3 Fixed Satellite services

5.3.3.1

Entertainment broadcasting applications are specifically excluded from this study.

5.3.3.2 Data broadcast systems

Data broadcasting includes both those systems which are strictly one-way, and those which are primarily one-way, but provide a narrow-band return path. Such networks can be engineered currently by means of terrestrial leased lines, and some near equivalents already exist. Satellite systems have the potential to be much more cost-effective as the number of receiving stations rises.

5.3.3.3 Video conferencing

Video conferencing systems have been planned and tried out since 1971 but, until a recent surge brought about by the Gulf War, market development has been slow and 15 years later the number of video conferencing studios is still only measured in tens rather than hundreds. One of the major barriers has been the cost of transmission via terrestrial networks, particularly for multi-point conferences or presentations.

Now, compression to 2 Mb/s of the video and audio signal is commercially feasible though compressors are still costly items. In the next 10 years we can expect further considerable improvements in transmission cost-effectiveness with compression to 768 or even 384 Kb/s becoming commonplace, and consequently a substantial increase in the number of sites equipped with video conferencing facilities.

5.3.3.4 Two-way Private Links

On a strict point-to-point basis, satellite systems are not an economic alternative to terrestrial facilities over short distances. It is only at distances of over 800 km that point-to point satellite systems are expected to be economic over the next decade.

Satellite systems are much more cost-effective in a data or message network spanning medium and long distances (100 km or more), in which a large number of outstations are connected to a smaller number of nodes. In Canada it is estimated that around 200 companies could require satellite terminals in an average of 8 locations each. This gives a total of 1000 earth stations.

These earth stations would transmit data at 9600 b/s on average, but they would only transmit for about 2 hours per day. Therefore for a 5;1 peak to average ratio, the total satellite throughput would peak at about 6.5 Mb/s, corresponding to a spectrum bandwidth of about 3.25 MHz at 2 bits/Hz.

5.4 Mobile Services

5.4.1 Characteristics

Mobile systems vary considerable in their characteristics and among the factors distinguishing different services are:

a. The area over which mobility is required, ranging from strictly local systems, such as the current generation of cordless telephones and future generations of intra-site wireless PBXs, and wide area systems, which require regional, national or indeed international mobility

b. The rate of information transfer required, particularly whether the requirements is for medium to high bit rates, to accommodate voice, image or large scale data transfer, or for low bit rates for paging, alarm or tracking purposes

c. Whether the application is for a private use or for interconnection to public telephone services.

d. Whether the radio system is to be terrestrial or satellite based.

5.4.2 Demand Trends

5.4.2.1 Public Mobile Telephone Services

Although they are based on different technologies, cellular and non-cellular mobile systems are treated together from the standpoint of demand analysis, because users regard them, to a considerable extent, as substitutes for one another.

Since the introduction of cellular service the industry's expectations of demand growth have repeatedly been exceeded. The competitive structure of the network operation industry (with two competing operators), and the falling prices of mobile units help to stimulate demand to levels higher than that expected even a year ago. In rural ares there is not the same universally perceived need for mobile radio systems, and market demand for such systems is insufficient to justify the cost of a full cellular base station. Such areas will continue to be served by non-cellular wide area radio systems, until this is considered to be no longer viable from the viewpoint of transparent transfer from one system to another.

5.4.2.2 Private Mobile Radio

Private mobile radio systems constitute a relatively mature market by comparison with public mobile telephony. In analyzing the market for private mobile radio services it is important to take account of the considerable variety of application and user categories.

Five categories of licensee can be distinguished, by the manner of the sophistication of their spectrum planning and use:

a. The very large users.

b. Large service providers, which operate chains of common base stations, sometimes linking them into small scale trunked systems to increase spectrum efficiency.

c. Medium size users.

d. Common base station operators and message handling companies.

e. Small individual licensees, using one or a small number of base stations.

5.4.2.3 Dispatcher Services

A useful distinction can be drawn between two somewhat different applications of private mobile radio. On the one hand there are "dispatchers", licensees who use mobile radio to control the movement of vehicle or other mobile fleets. Examples are taxi companies, security companies, operators of road transport services, and courier organizations. On the other hand there are users who require private mobile radio essentially for keeping in touch with an office or other headquarters location on an occasional basis, or for co-ordination of work activities on a minute-to-minute bases, eg on a building site, at an airport or railway station, etc.

This distinction is important because dispatcher users require PMR in essentially the form it is currently provided, and would have little opportunity to migrate to newer services such as cellular radio or alphanumeric paging. These users also make fairly intense use of channels, the containing factor is usually the ability of the human dispatch operator to occupy the channel fully, rather than a technical constraint.

5.4.2.4 Non-dispatcher services

The non-dispatcher users constitute a very different demand picture both in terms of their current usage profile and their ability to migrate to competing systems in the future. Usage levels are often very low, perhaps as little as a few messages a day per mobile rather than several tens of messages. The nature of their requirements is such that a cellular telephone (or sophisticated paging device) may not only be an acceptable but actually a superior substitute in some cases.

5.4.2.5 Trunked PMR Systems

Demand forecasts are based on the assumption that the availability of higher quality service versus PMR dispatch, on these trunked systems will further stimulate demand.

Demand for private mobile radio systems by the emergency services must be analyzed somewhat differently. The intensity of use of the mobile units in this type of application is considerably higher that the average, and the need to maintain fast access to the network, even in times of congestion, places different requirements on the system.

5.4.2.6 Cordless Telephones and related developments

The demand for cordless telephones has been considered in two separate stages. First there is the increasing requirement among residential users (and to some extent the business community) for cordless telephones which simply allow the user to move some distance from an otherwise conventional telephone terminal. Demand in this area has grown explosively.

Enthusiasm for cordless telephones has been stimulated to a considerable degree by the general liberalisation of terminal equipment attachment policy which has allowed customers to purchase telephone sets from a wide range of models, at an increasing number of retail stores.

The second factor which can be expected to stimulate demand for cordless telephone sets is the availability of second generation digital systems. These systems allow users to overcome two of the present shortcoming of the first generation systems, namely a propensity towards poor sound quality and lack of security.

The concept of a cordless telephone has two natural extensions.

a. The development of cordless PBXs for use on business premises. These would allow company employees to wander freely around a site without losing contact with the telephone system.

b. In the longer term, cordless telephones could be integrated with cellular, PCN or other wider area systems to provide mobility across premises, throughout the country or beyond.

5.4.2.7 Radio Paging

Radio paging usually provides the user with an audible tone or "bleep", indicating that some action should be taken, though some systems additionally incorporate a one or two-way voice capability to clarify why a "bleep" message has been sent. The notified user typically has to locate a conventional telephone in order to respond to the message.

Alpha-numeric paging is a development of tone-only paging in which the transmission not only alerts the user to the presence of a message but also provides a brief text message through a display on the receiver unit. Further refinements of the paging concept are technically possible. One is to provide intelligence within the receiver unit so the "bleep" alarm is sounded only under certain message conditions for example a broker could set his pager to "bleep" if one of a number of preselected financial commodity or stock prices moves outside a given range.

Growth is forecast to continue for two to three years, and slow down slightly thereafter. A factor constraining very long term growth is the expected partial substitutability of cellular and other voice mobile radio devices for paging units. Whereas the growth in paging units is relatively modest, we do expect a continuing increase in the average sophistication and range of features of each unit.

5.4.2.8 Maritime Mobile Satellite Services

The worldwide INMARSAT system has a long run potential demand of some 100,00 mobiles. The system allows transmission of voice, telex, and data at 9.6 kbits/s, 56 kbits/s and 1 Mbits/s.

5.4.2.9 Aeronautical Mobile Satellite Services

The planned aeronautical mobile satellite services will accommodate voice and data at 400-600 bit/s and 4.8-9.6 kbit/s. The demand for this service is likely to be high. Initial experience with domestic systems operated by airlines in the United States is encouraging, and it is reasonable to expect that commercial airliners will routinely be provide a passenger service in due course.

5.4.2.10 Land mobile satellite service

It is not expected that satellite services will compete effectively with other land mobile systems (notably cellular) for most voice traffic in well populated areas. There may be an appropriate role for satellite systems in remote areas, in which cellular coverage is uneconomical, and for low speed data applications, including paging.

5.5 Twenty Years Perspective

5.5.1 General

In attempting to forecast the types of communication systems that will be required in the 10 to 20 year time frame it is worthwhile to consider some of the social and economic issues that can be expected to drive these requirements.

A number of these issues have been outlined by NTIA and are reproduced herein as appropriate. Others have been derived from consideration of the requirements of other ADGA clients, eg. Ministry of Health, Ministry of Solicitor General, Transport Canada, Dept of National Defence.

5.5.2 Demographic factors

Several demographic factors will contribute to this development.

a. Because of low birth rates in the Sixties and Seventies, the labour pool will be relatively smaller. Selective immigration will ease possible shortages of skilled and professional workers, but could result in continued shortages in less skilled positions. Some upward pressure on wages will continue for the rest of the century and the resulting higher wage rates should give business an added incentive to automate, placing greater reliance on information resources.

b. Yet another contributing factor will be the trend towards an older, more affluent, population. The Canadian population on average has been growing older over the past two decades, and this trend is forecast to continue over the next decade. The median age could be 38 by the year 2000. While an aging population ordinarily implies a lessening of demand, particularly for consumer durables, housing, and some other commodities, the fact that disposable household income levels should be higher tends to offset the drop in demand.

c. Contributing to the expectation of greater demand, reflected in higher retail and service sector sales, is the increase in single-individual households as the median age when individuals first marry continues to rise, and divorce rates remain high. These trends are expected to continue. On average, these single-individual households should have substantial disposable incomes.

d. The number of two-income households should continue to rise steadily, as an increasing percentage of women seek work outside the home. If current trends continue, estimates are that between 65 and 80 percent of working age women will work outside the home by the turn of the century, compared with about 56 percent today. This trend, in turn, should place a premium market value on time saving (and thus leisure time-maximizing) goods and services.

5.5.3 Future Business Trends

Business-related communications and information usage and expenditures today reportedly represent some 60 percent of the overall market, and are growing faster than individual residential or non-commercial applications. Experts forecast this growth will continue. The efficiency and other gains associated with the increased application of information technologies, however, should affect various sectors of the business economy differently. Information services have emerged and should become an increasingly important factor of production for retailing and associated financial services generally over the next few years.

5.5.4 Retailing

Semi-skilled workers have traditionally constituted a large portion of the retailing work force. The infrastructure needed to provide them with pertinent information services is almost fully in place today. For example, most major retailing companies already rely heavily on computerized point-of-sales terminals linked with sophisticated inventory and purchasing systems through communications.

The use of radio rather than wireline communications within the retail industry will be largely determined by cost, service flexibility and the nature of each undecided retail operation.

Greater use of private radio systems could be anticipated to reduce the service charge for common carrier provided services. Initially this would likely influence long distance service charges and/or dedicated wireline rentals. In the event that usage charges are applied to local cells many more retail operations could be expected to use private radio systems.

It is noted that a similar requirement for interconnection of health care facilities has been already been expressed by Ministry of Health officials purely on the basis of saving cost.

The radio systems needed for such applications would likely be in the form of point-to-multi-point networks. Digital transmission using relatively high data rates would be necessary to provide voice, data and imagery. Network access protocol would be to give priority to voice traffic at all times. Multiple simultaneous voice circuits between different points in the network would be necessary.

Growths in retail electronic banking, in sales of consumer electronics such as microwave ovens, and in mail order sales, have closely paralleled the rise in the percentage of women working outside the home, and reflect the surge in demand for convenience commodities and services. Retailers in general can reasonably expect to employ information systems to meet this demand, both by offering "teleshopping" and similar services, and providing customers with new electronics-based product options.

5.5.5 Financial Services

Securities trading today is essentially electronic, and global. In addition, although today a majority of financial services transactions may still be accomplished conventionally, more and more will be handled electronically. Home Banking, where transactions in individuals accounts are carried out at home, will increase.

5.5.6 Manufacturing

International competition especially should continue to drive manufacturing toward increasing reliance on the communication of information as a means of stimulating productivity, improved product quality, and innovation. Investment in "information resources" today constitutes about 24 percent of annual business equipment investment overall. The primary emphasis in recent years has been on more closely linking product development, manufacture, distribution, and retailing, so improving the "through-put efficiency" of companies' overall business processes. The growing use of computer-aided design and manufacture, even in smaller and more traditional markets,and the wider interfacing requirements of major projects in the engineering, auto, aerospace, and computer spheres today are involving the increased electronic transfer of large amounts of data between companies. The improvement in such communications appears to have facilitated the design of better products and to have!made commercial operation feasible on a broader scale and it has tended to raise the level at which any economies of industrial scale and scope become a factor.

General Motors, for example, in recent years has moved to develop sophisticated computer and communications systems linking thousands of design and manufacturing facilities, retailing outlets, maintenance centres, and suppliers worldwide, with the aim of substantially reducing the time involved in production and delivery scheduling, and of minimising the associated financing costs. Manufacturer and dealer computers will be increasingly linked via communications.

Also contributing to demand, particularly for international telecommunications, has been the emergence of distributed global manufacturing by multinational corporations as a dominant commercial reality.

In Canada resource based industries and agriculture are likely to be the major users of radio rather than wireline communications. These will likely have to be in the form of point-to-multi-point networks in which most terminals are mobile. They will extend the current dispatch type communication to include process control functions.

5.5.7 Service Industries

Information resources will also become an increasingly important component for the service industries which today comprise nearly three-quarters of the economy. This growing reliance in the labour-intense service sectors on communications and computer services is seen to be a proven means of boosting productivity. Current services such as cellular mobile radio and paging offerings already are integral value-producing components of many service sector endeavors.

As service costs fall mobile radio services stand to become even more ubiquitous. More intensive use of the radio spectrum, coupled with the larger financial commitment of users, will complicate spectrum management tasks and require the current regulatory approach change toward one that offers substantially greater flexibility and efficiency.

The type of radio communications used by the service industries is expected to remain predominantly voice. Digital techniques will be used to improve the use of the spectrum. Navigation and vehicle location features are desired by users but these will only become affordable by using micro-processor techniques.

5.5.8 Defense and Related Applications

Since the Sixties, there has been an enormously greater sophistication in defence systems equipment, which have placed greater reliance upon communications, command, control, and intelligence systems to maximize the efficient use of defense resources. These have resulted in heavy demands on the use of the radio frequency spectrum.

This demand is severely aggravated by the need for antijamming and or low probability of intercept systems, because not only do they increase the instantaneous bandwidth, but they also preclude the use of many spectrum management strategies. However evolving from these requirements are technologies that allow enhanced capabilities for the use of the radio spectrum without the need for specific frequency co-ordination. The spread spectrum, interference cancellation and antenna beam steering technologies developed for the military are being implemented in civilian applications.

5.5.9 Public and Related Services

5.5.9.1 Law enforcement

As the population of Canadian cities increases, changes in law enforcement responsibilities will arise. Generally the need for law enforcement activities is found to rise more rapidly than the population density. Hence the need for efficient, reliable and securable communications will continue to increase. It should be noted that despite obvious benefits to police activities that could occur from secure communication media pressure for on the spot news reporting has, and will largely continue, prevented the widespread use of this mode.

5.5.9.2 Surface Transportation Control

There will be an increasing demand for telecommunications and information services as a component of an overall local, provincial, and federal surface transportation management control program. To reduce commuter congestion, metropolitan area authorities already are employing traffic control systems which are computer and communications dependent.

No experts forecast that the public appeal of the automobile will dissipate, consequently, more sophisticated, communication dependent systems for managing use of motor vehicles will be needed. These could likely extend to the automatic control of vehicles, which would likely require several elements such as vehicle guidance, collision avoidance and driver destination request.

5.5.9.3 Improved Educational Facilities

Substantially greater reliance on telecommunications and information services by the educational community is likely as an aid in primary, secondary, college, and post-graduate or adult education. Additionally, business education and training expenditures are likely to grow.

5.5.9.4 Meeting Health Care Needs

Health care systems today are oriented more toward meeting acute care needs through hospitalization, whilst the future requirements are more likely to involve preventative and longer-term chronic-care medical services. Compounding health care challenges are the ageing population, and the sheer cost of current systems. Telecommunications-assisted health care appears to be more cost effective, as well as better able to provide services keyed directly to preventative and long-term care needs, and making possible health care services in an individual's home, avoiding for the ageing population de-personalizing institutional care.

While not a substitute for current health care systems, such telecommunications-assisted systems constitute a potentially valuable supplement and seem highly likely to be pursued. These requirements will involve the use of small radio telemetry system that can be worn by selected patients as they move around and an infrastructure by which telemetry data can be received from a number of patients over a wide area. At first local receivers will be fitted only within patients normal habitats. The receiver would relay data either by means of wireline connection or by a multi-point-to-point radio system. Through the use of preset threshold levels in the medical monitoring equipment transmission of data would be restricted to abnormal conditions and although the instantaneous bandwidth may be several KHz, the overall transmission capacity should be quite low.

6 TASK 2 - SPECTRUM REQUIREMENTS AND POTENTIAL ALLOCATIONS

6.1 Introduction

The radio services and propagation characteristics appropriate to the frequency band 30 MHz to 100 GHz were identified in task 1 and reported in sections 1 through 5. In task 2 both the services and frequency bands best suited to supporting these services are considered in respect to their distribution between service areas.

6.2 The Derivation of New Service Spectrum Requirements

Where possible the projected traffic volume for mobile services and for other existing and new services has been developed using the population density and user penetration concepts developed in previous studies conducted by ADGA (ref. 1.3f). These projections are preferred to extrapolations of the existing growth curves, which do not adequately allow for saturation levels, or changes in growth rates due to technology improvements. The expected bandwidths required in intra-city, inter-city and rural areas for the year 2001 are summarized in the following paragraphs.

6.3 Mobile Services

The bandwidth requirements for the various services are as shown in Table 6.1. Source ref.f. unless shown by asterisk, in which case the bandwidth requirements are developed in subsequent paragraphs.

Table 6.1 Mobile Service Bandwidth Requirement

SERVICE	BANDWIDTH REQUIREMENT MHz (YEAR 2001)			
	INTRA-CITY		INTERCITY	RURAL
	AVERAGE CITY HAMILTON	LARGE CITY TORONTO		
Mobile Telephone	60.0	60.0	25.5	3.8
Mobile Dispatch	55.0	110.0	24.5	1.3
Personal Telephone	44.8	44.8	11.3	(<)1.0
Paging	9.0	18.0	3.0	(<)1.0
Aeronautical Mobile	37.0	37.0	2.0	8.0
Maritime Mobile			1.8	0.5
Mobile Data	16.9	16.9	3.9	(<)1.0
Outside Broadcast Audio*	22.0	22.0		4.4
Radio Microphone*	70.0	70.0		
TOTAL	246.0	389.0	72.0	21.0

Note: It is the trunked mobile dispatch and the paging services which show increased requirements in the larger city.

6.3.1 Outside Broadcast Audio Links

High quality digital stereo links are assumed to be required, to support TV outside broadcast, each with a bandwidth of 220 KHz (Bandwidth based upon advanced digital proposed for SBSS services). At least one audio link would be associated with each camera position therefore the minimum bandwidth required is 4.4 MHz to support 20 camera crews.

The audio links could be required to operate directly to studio (s) over ranges up to 30 km. The co-ordination distances associated with mobile system of similar range are 125 km.

Allowance should therefore be made for as many as 100 separate audio links within the co-ordination range. The required bandwidth is therefore 22 MHz in a large city.

6.3.2 Radio Microphone

The spectrum requirements for radio microphone systems are assessed based upon their potential use in theatre productions in the centre of a metropolitan area. A total of seven independent systems are assumed. Frequency reuse outside of the cluster of seven should be feasible.

Although major productions may involve a cast of around 100 it is unlikely that more than 50 channels per productions would be required. These should all be high quality audio with a audio bandwidth of not less than 15 KHz. Either wideband FM (200 KHz) using FDMA or 64 kbps digital speech using TDMA could be used. The latter may offer greater flexibility and the potential to allocate time slots on a dynamic basis thereby providing some spectrum savings.

The potential bandwidth requirements based on FM are:

7 x 50 x 200 KHz= 70 MHz

This could possibly reduced to 20 MHz through the use of dynamic TDMA channel allocation.

6.4 Fixed Services (based on DOC Forecast) [ref 1.3 g]

Table 6.2 Fixed Service Bandwidth Requirement (MHz)

SERVICE	BANDWIDTH (MHz)		
	INTRA-CITY	INTER-CITY	RURAL
Trunks-Intra-Cellular*		70.0	70.0
Low capacity*	1500.0	800.0	1500.0
Medium capacity*	500.0	600.0	2000.0
High capacity*	500.0	5000.0	150.0
Wireless LANS*	900.0		
Multi-point Distribution	250.0		2400.0
Outside Broadcast (Video)	2400.0		
TOTAL	6050.0	6470.0	6080.0

6.4.1 Intra-cellular Trunks

As a result of the rapid expansion of cellular systems there is, dependant upon the switching architecture employed, a potentially large growth in the capacity of the inter-cell site links. For a system providing highly distributed switching the link capacity will be proportional to the volume of traffic subject to cell handovers plus the volume of traffic to the nearest PSTN gateway. Clearly this will be highest for very small cells but these could be economically connected by fibre optics.

For architectures employing centralized switching all traffic must be forwarded to the central switch or switches. The peak capacity is equal to the total volume due to all cell sites.

Furthermore since frequency reuse on tandem point-to-point connections is generally only possible at every second repeater, then the overall point-to-point spectrum requirements could be three times the peak due to the busiest link.

It was estimated, (ref f.), that by 2001 some 138 000 cellular subscribers could exist in a city of 600,000. At .02 Erlangs per subscriber the total traffic in the busy hour amounts to 2760 Erlangs. By extension and assuming central switches are provided for population bases of 6 million, then in the worst case the total spectrum requirements could be as high as 2x10x27.6 MHz = 552 MHz due to the use of 10 KHz bandwidth digital voice channels.

In practice it is reasonable to assume that central switches would be located in major metropolitan areas. Within these areas fibre optic links could be used. The spectrum requirement for inter-cell links are therefore more likely to be based upon rural requirements. Since approximately 25% of Canada's population lives in rural areas the overall spectrum requirements are more likely to be reduced to around 25% or 138 MHz. This should be more or less equally divided between intercity corridors and rural area coverage systems.

6.4.2 Low Capacity Trunks

Total spectrum requirements predicted by DOC in 1981 [ref. 1.3g) were 3.882 GHz. Low capacity system will generally not be used on major trunks. They are more likely to be deployed for business and industrial applications that by common carriers. These low capacity systems are expected to be fairly uniformly deployed between intracity and rural applications.

6.4.3 Medium Capacity Trunks

Total spectrum requirements predicted by DOC [ref. 1.3g] were 2.6 GHz. These are expected to be largely used by common carriers for spurs to smaller towns. Some intra city use of 500 MHz is anticipated but this will largely reuse frequencies used in rural areas.

6.4.4 High Capacity Trunks

Total spectrum requirements predicted by DOC [ref. 1.3g] were 7.325 GHz. These were largely for use on intercity trunks. Some long term reduction in this requirements is expected to be achieved through the introduction of fibre optic cables. However at least 5 GHz should be retained over the next 20 years for intercity, 500 MHz for intracity and 150 MHz for rural.

6.4.5 Wireless LANS

An average bandwidth of 10 MHz per LAN is assumed so as to be compatible with cable based LANS. Short ranges of less than 250 metres are also assumed although larger distances could be provided through the use of point to point gateways. The number of independent LANS within a city centre is estimated based upon a typical city block of 250 metres square and an average building height of 30 floors. The total office population in this block is 135 thousand of which 20% could be connected to LANS. If the average size of LAN is 100 terminals then 270 independent LANS could be used.

Without frequency reuse this could require a bandwidth of 2.7 GHz. However a floor to floor frequency reuse factor of 3 would result in a total bandwidth requirement of 900 MHz.

6.4.6 Outside Broadcast Video Links

The set-up time required for outside broadcast, in which cables are used to link cameras to a central control mode, restricts the flexibility of broadcast companies to provide real time coverage of many newsworthy events. The use of radio links from camera to control mode would provide greater flexibility and reduced cost.

Assuming 20 cameras (multiple networks) providing studio quality video are required the total bandwidth could be 120 MHz for NTSC signals or as much as 2.4 GHz for HDTV digital signals. Considering the current level of interest in HDTV it is recommended that the 2.4 GHz requirements be used for planning purposes.

6.5 Radio determination

Since a number of radio determination techniques provide large area coverage no attempt will be made to separate them into different areas. The forecast bandwidth requirements are based upon current allocations except where otherwise indicated by an asterisks in which case the spectrum requirements are discussed in a subsequent para.

Table 6.3 Radio Determination Bandwidth Requirements (MHz)

Navigation	MHz	Location	MHz	Guidance	MHz
GPS	20.0	Primary radar	2000.0	Vehicle guidance	10.0
Wayside beacons	5.0	Secondary radar	20.0	ILS	4.0
DME/TACAN	255.0	RDSS	16.0	MLS	60.0
VORS	8.0	Speed radar	50.0	Glide path	7.0
		Vehicle Collision avoidance*	200.0		
TOTAL	288.0		2286.0		81.0

6.5.1 Vehicle Collision Avoidance Radar

The necessary bandwidth for 3 metre range resolution is 100 MHz. Discrimination between own vehicle and other vehicle radar returns could be achieved through phase coded pulses. A code length of 32 bits will allow up to 1 billion individual codes. Error protection will likely extend this code to 48 bits thereby providing essentially zero probability of false code recognition. The resultant RF pulse length is around 0.5 Msecs. For a 3 metre resolution and a velocity of 30 metres/second (60 mph) a minimum pulse repetition rate of 10 pulses per second is required. This will likely be increased by a factor of 10 to ensure a high probability of target detection. Even so the duty cycle is low at 0.005%.

The two way path inverse 4th order loss appropriate to a 100 metre range will allow a one way inverser 2nd order interference range of 10,000 metres to an oncoming vehicle. Therefore at 100 metre separation as many as 100 oncoming vehicles could directly illuminate the radar receiver. In more heavily congested traffic situations, obstruction due to other vehicles will preclude direct illumination of a receiver by much more than the 100 vehicles forecast for open road conditions.

The radar receiver would therefore be in receipt of interfering signals for not more than approximately 0.5% of the time. Given the code discrimination capability of the 48 bit coded sequence this is considered acceptable and a single channel bandwidth of 100 MHz should suffice for all general purpose vehicles. An additional channel should however be provided for special purpose vehicles such as police cars, ambulances etc.

The choice of frequency band should be such as to minimize degradation of range in bad weather conditions whilst permitting small size antennas and low cost implementation. The frequency range between 30 GHz and 50 GHz appears best suited.

6.6 Overall Spectrum Requirements

The preceding discussion has largely focused on the civilian non-broadcast use of the RF spectrum. The predicted requirements are based upon near optimum assignment strategies assuming a largely uniform distribution of traffic and system implementations that provide a high traffic efficiency for all assigned channels.

It has been shown by other DOC sponsored studies, that spectrum assignment efficiencies currently achieved for mobile systems in major metropolitan areas are around 25%. Therefore the total bandwidth requirements for mobile services could therefore be quadrupled. Note: heuristic reassignment techniques based upon actual demand can improve this efficiency to nearly 100% depending upon the density of transmitters. However reassignment involves some cost and disruption of existing users and hence the more conservative figure of 25% is used to represent the worst case.

These spectrum allocations must be made available in consideration of the allocations required for other services. In particular satellite based services i.e. Fixed Satellite, Mobile Satellite Feeder Links, Earth Explorations Downlinks and Space Operation are allocated some 55% of the spectrum up to 20 GHz.

Below 1 GHz Broadcasting has traditionally occupied some 43.3% of the spectrum allocated below 1 GHz and above 1 GHz about 5%. As broadcast moves toward higher quality audio and TV services the overall proportion of spectrum allocation can be expected to remain at these levels or greater.

In addition studies in the UK [The Report by the Defense Spectrum Review Committee] show that between 1/3 and 1/2 of spectrum up to 3.4 GHz is assigned to government, largely defense, related applications. A similar requirement is expected to persist for the foreseeable future.

Finally this study has focused on readily identifiable requirements largely based upon extrapolation of known services. Some provision must be made for the continuing development of revolutionary services. Based upon the current rate of growth of new applications at least 10% of the overall spectrum could be required for revolutionary type services.

In consideration of the above the potential spectrum requirements developed in tables 6.1 through 6.3 for each of the intra-city, inter-city and rural areas may be summarized as shown in Table 6.4 below.

Table 6.4 Summary of Spectrum Requirements

SERVICE	BANDWIDTH (MHz)		
	INTRA-CITY	INTER-CITY	RURAL
Mobile (1)	1556.0	288.0	84.0
Fixed Services (2)	6050.0	6500.0	6150.0
Broadcast (3)	1500.0	1500.0	1500.0
Radio Determination (3)	2655.0	2655.0	2655.0
Government (4)	1500.0	1500.0	1500.0
Space (3)	11000.0	11000.0	11000.0
New concept	2426.0	2344.0	2289.0
TOTAL	26,687.0	25,787.0	25,178.0

Notes:
1. Based upon 25% spectrum utilization efficiency with respect to a perfect assignment 4 times total shown in table 6.1.
2. From section 6.4 and table 2.1.
3. Largely based upon current allocations, from ITU tables. No growth factors included.
4. Based upon 50% of band up to 3 GHz [ref. 1.3h]

Table 6.4 shows the expected requirements already exceed the capacity of the 0 to 20 GHz band from which the projected requirements have been derived and that the predominant requirements, driven by wide area coverage systems, are common to all three zones.

Therefore the flexibility to optimize frequency allocations based upon separate intra-city, inter-city and rural requirements is severely limited.

7 SPECTRUM ALLOCATIONS

7.1 Spectrum Allocations

The qualitative nature for spectrum allocation requirements, based upon propagation characteristics and the nature of service, were identified in section 3, the quantitative requirements in respect to a number of the services have been identified in section 6. In this section the mapping of preferred spectrum allocations, based upon consideration of the qualitative and quantitative requirements, on a service, frequency, and geographic area is provided.

For simplicity of presentation the mapping is shown in a graphical format and the geographic areas have been expanded into five groupings. These are:

In-Building	covering distance up to 100 metres and not required to penetrate the outside walls of buildings.
Intra-city	covering the distances up to 10 km and providing some in-building coverage for more general purpose applications.
Inter-city	covering distances from a few km up to about 100 km along fairly straight corridors.
Rural	covering distance up to about 200 km on an area basis.
Global (space)	covering ranges from 10 km up to several thousand km.

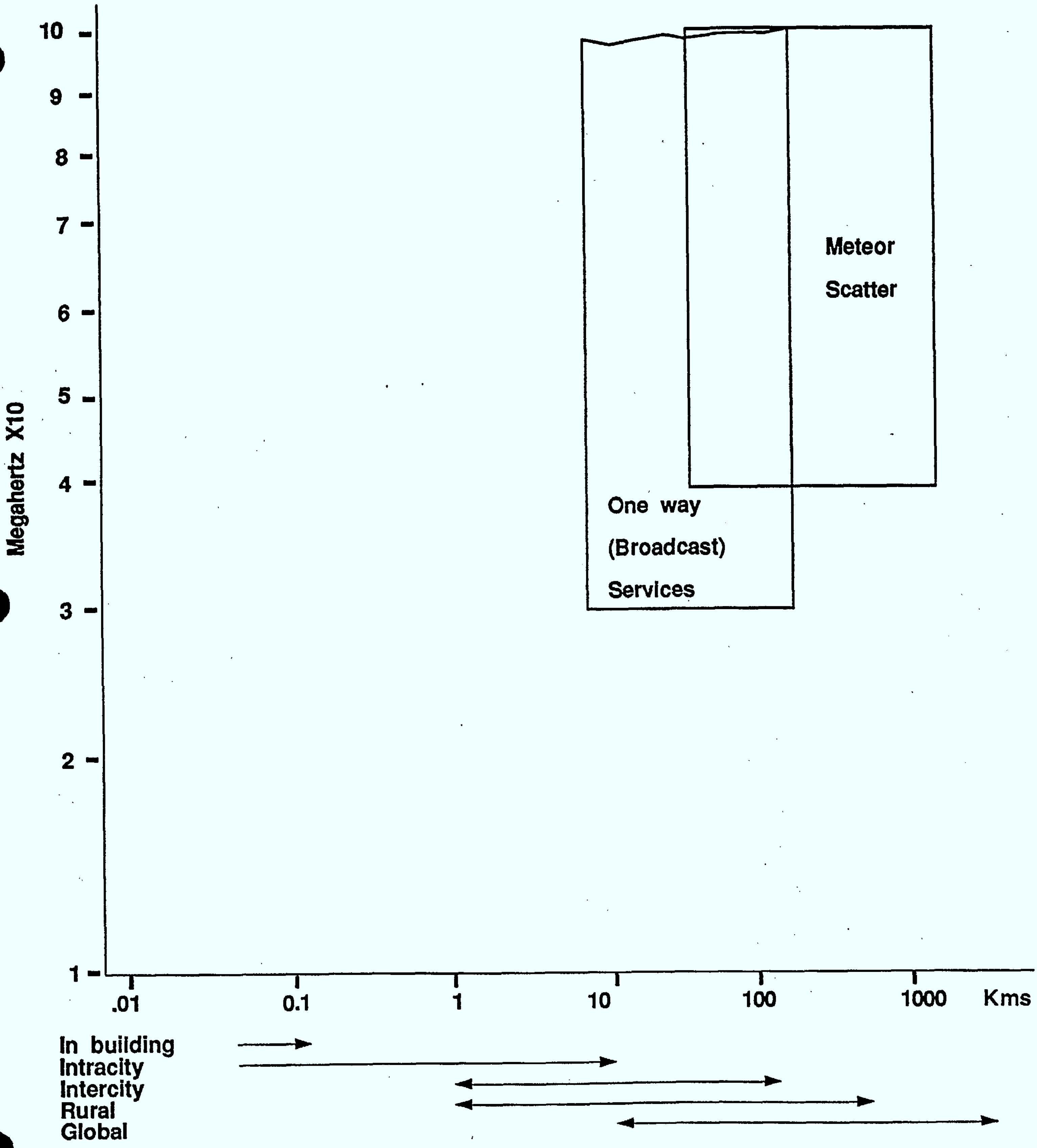
The frequency range 30 MHz to 100 GHz has been subdivided into four bands of each one decade wide.

A division of the spectrum into generic classes of service was made and is shown in Figures 1a through 1d. both frequency and area of use are shown for each generic class. The generic allocations take into account:

- propagation limits eg. meteor burst is limited to the frequency range 30 MHz to 100 MHz,
- propagation losses relative to the area(s) of operation eg., intracity, intercity, rural or global,
- coherent bandwidth available, and
- operational requirements such as antenna size and directivity.

The spectrum requirement, see section 6, by service category and service location were then overlaid onto the generic allocations to obtain the preferred allocations as shown in Figures 2c - 2d. These preferred allocations consider not only the matching of desirable attributes but also the overall bandwidth requirements and, to the extent possible, the existing allocations. In figures 2a for example, the shaded area from 30-40 MHz is designated for defence services. Ideally these would be of a broadcast nature but they could also be used for military tactical communications basis. This would be for a easier to manage than the preemption of mobile services currently allocated to this band.

The band 40 to 45 MHz would be used for military data collection. In this case the minimum range of about 50 Kms is dictated by the meteor burst footprint. However sharing with broadcast would not be feasible since these could be significant coverage overlap.



10
9
8
7
6
5
4
3
2
1
Megahertz X10
Meteor
Scatter
One way
(Broadcast)
Services
.01
0.1
1
10
100
1000
Kms
In building
Intracity
Intercity
Rural
Global

FIGURE 1a

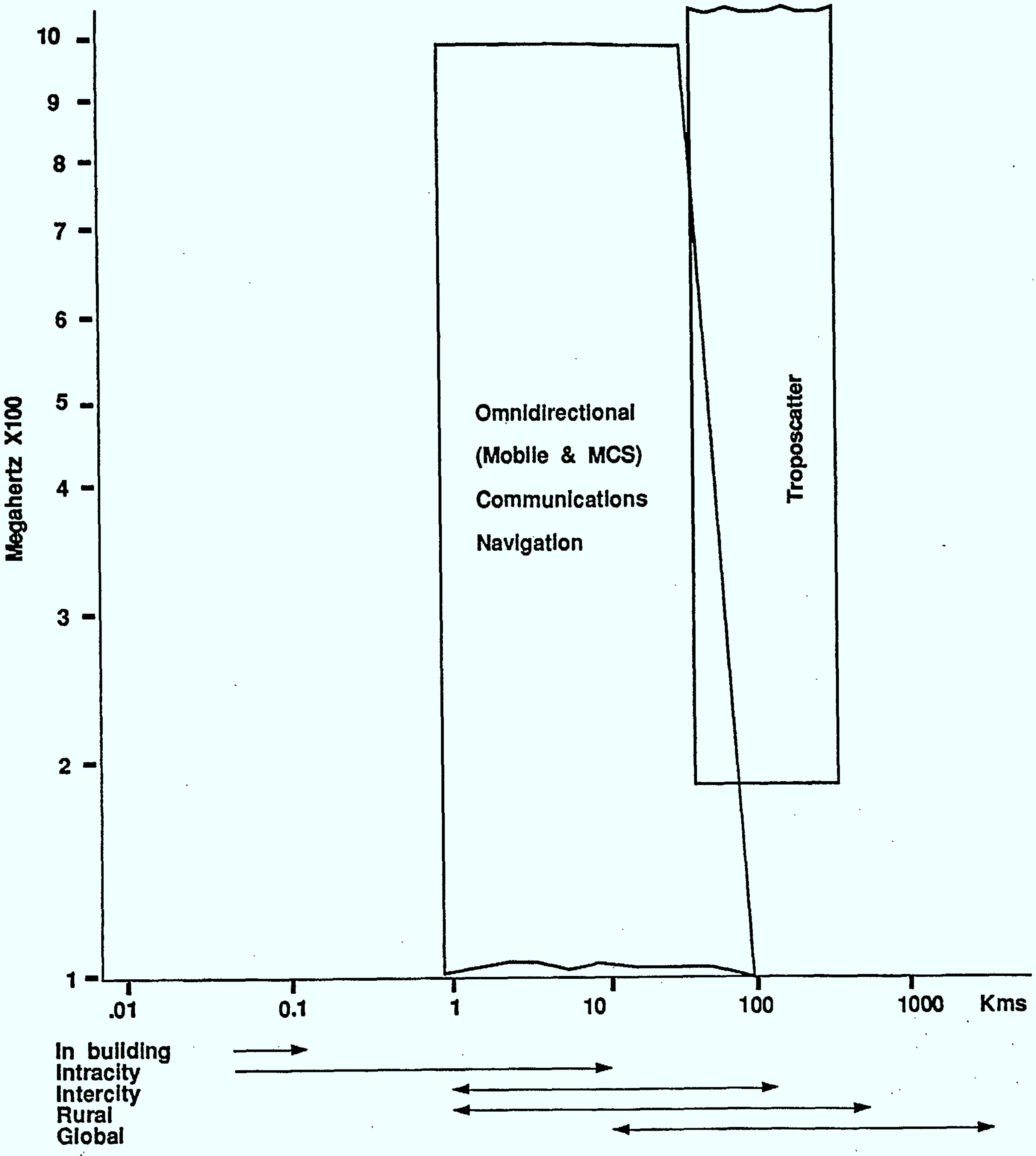
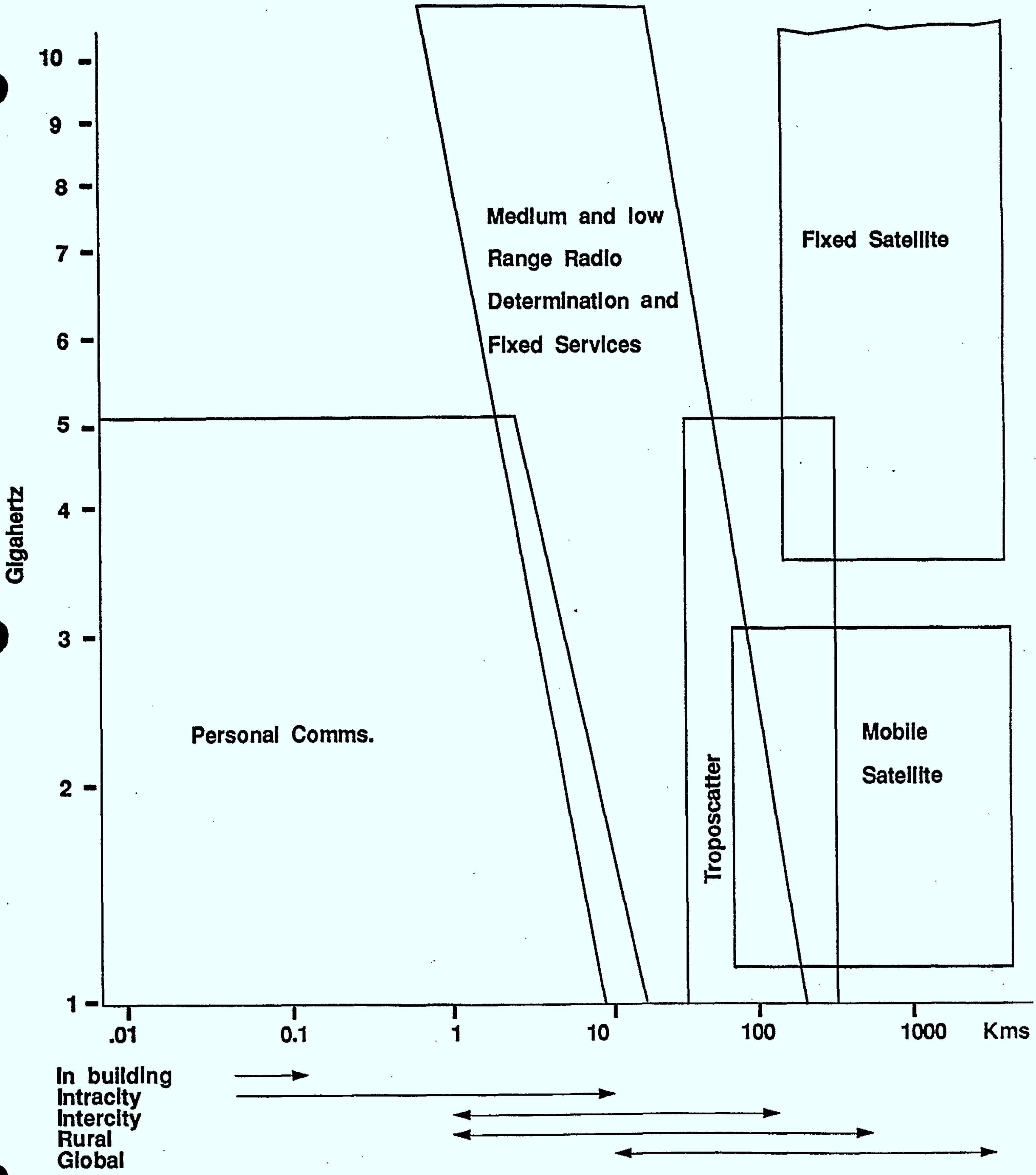

Megahertz X100
10
9
8
7
6
5
4
3
2
1
Omnidirectional
(Mobile & MCS)
Communications
Navigation
Troposcatter
.01
0.1
1
10
100
1000
Kms
In building
Intracity
Intercity
Rural
Global

FIGURE 1b



Gigahertz
10
9
8
7
6
5
4
3
2
1
Medium and low
Range Radio
Determination and
Fixed Services
Fixed Satellite
Personal Comms.
Troposcatter
Mobile
Satellite
.01
0.1
1
10
100
1000
Kms
In building
Intracity
Intercity
Rural
Global

FIGURE 1c

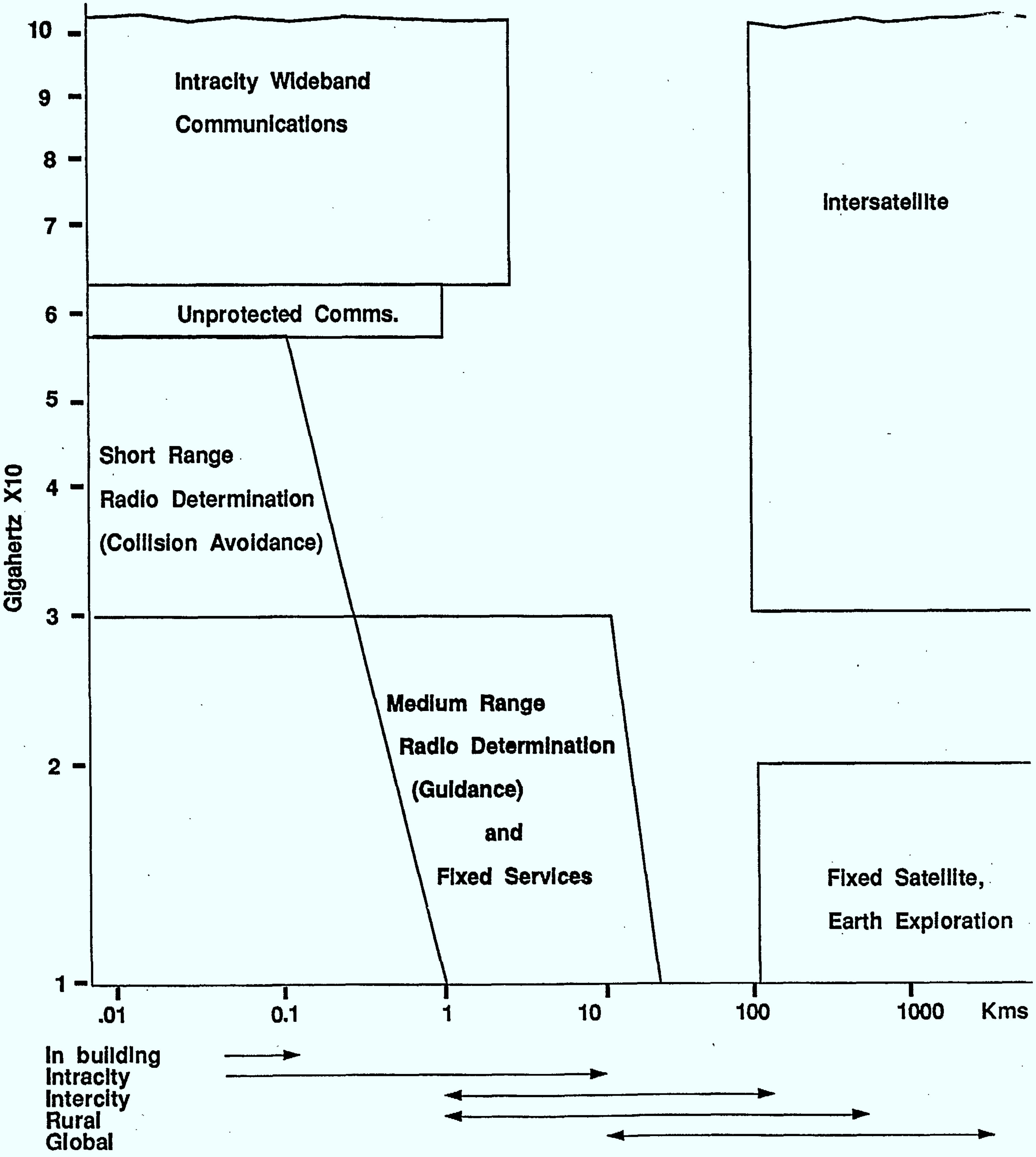

10
9
8
7
6
5
4
3
2
1
Gigahertz X10
Intracity Wideband
Communications
Unprotected Comms.
Short Range
Radio Determination
(Collision Avoidance)
Medium Range
Radio Determination
(Guidance)
and
Fixed Services
Intersatellite
Fixed Satellite,
Earth Exploration
.01
0.1
1
10
100
1000
Kms
In building
Intracity
Intercity
Rural
Global

FIGURE 1d

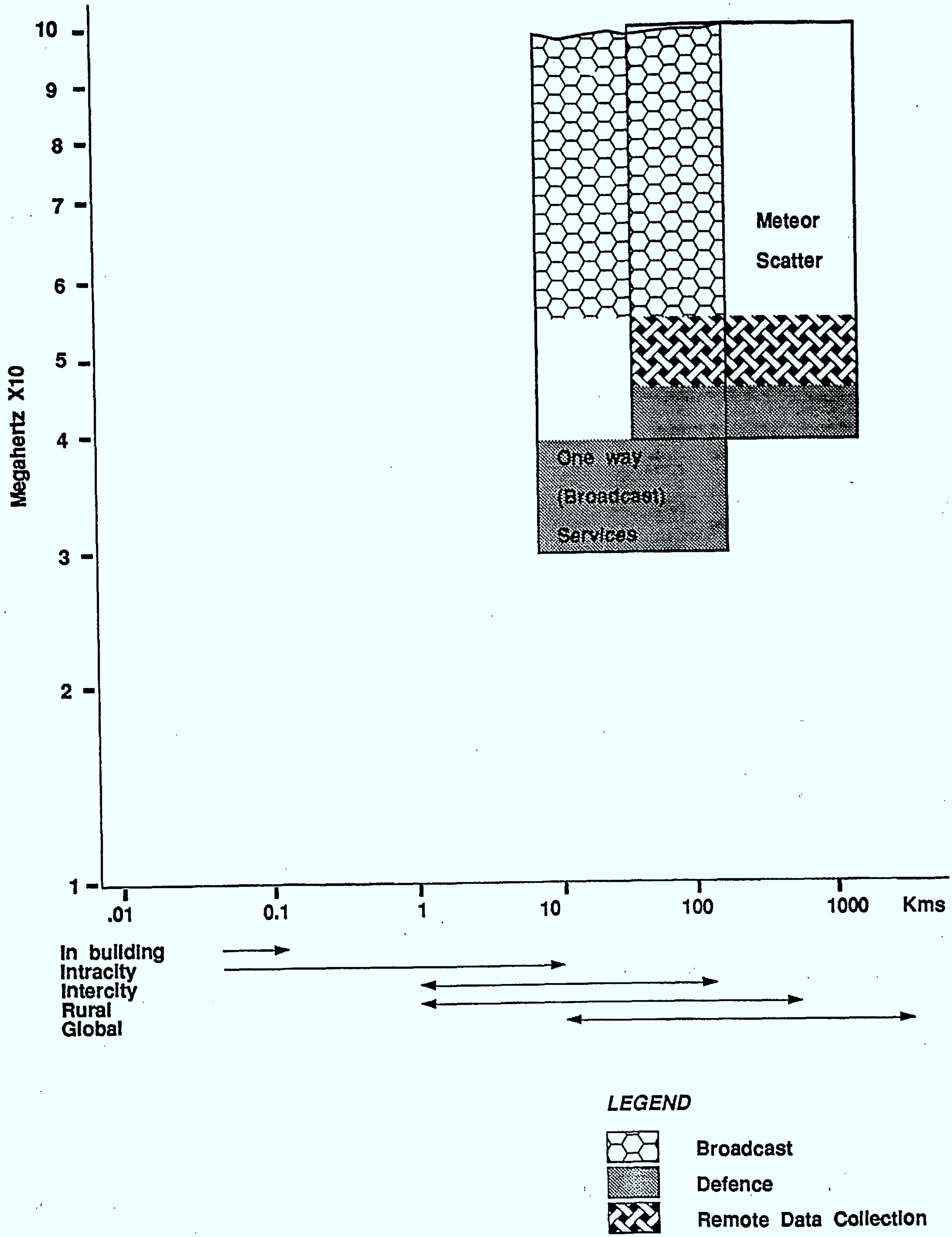

Megahertz X10
10
9
8
7
6
5
4
3
2
1
.01
0.1
1
10
100
1000
Kms
Meteor
Scatter
One way
(Broadcast)
Services
In building
Intracity
Intercity
Rural
Global
LEGEND
Broadcast
Defence
Remote Data Collection

FIGURE 2a

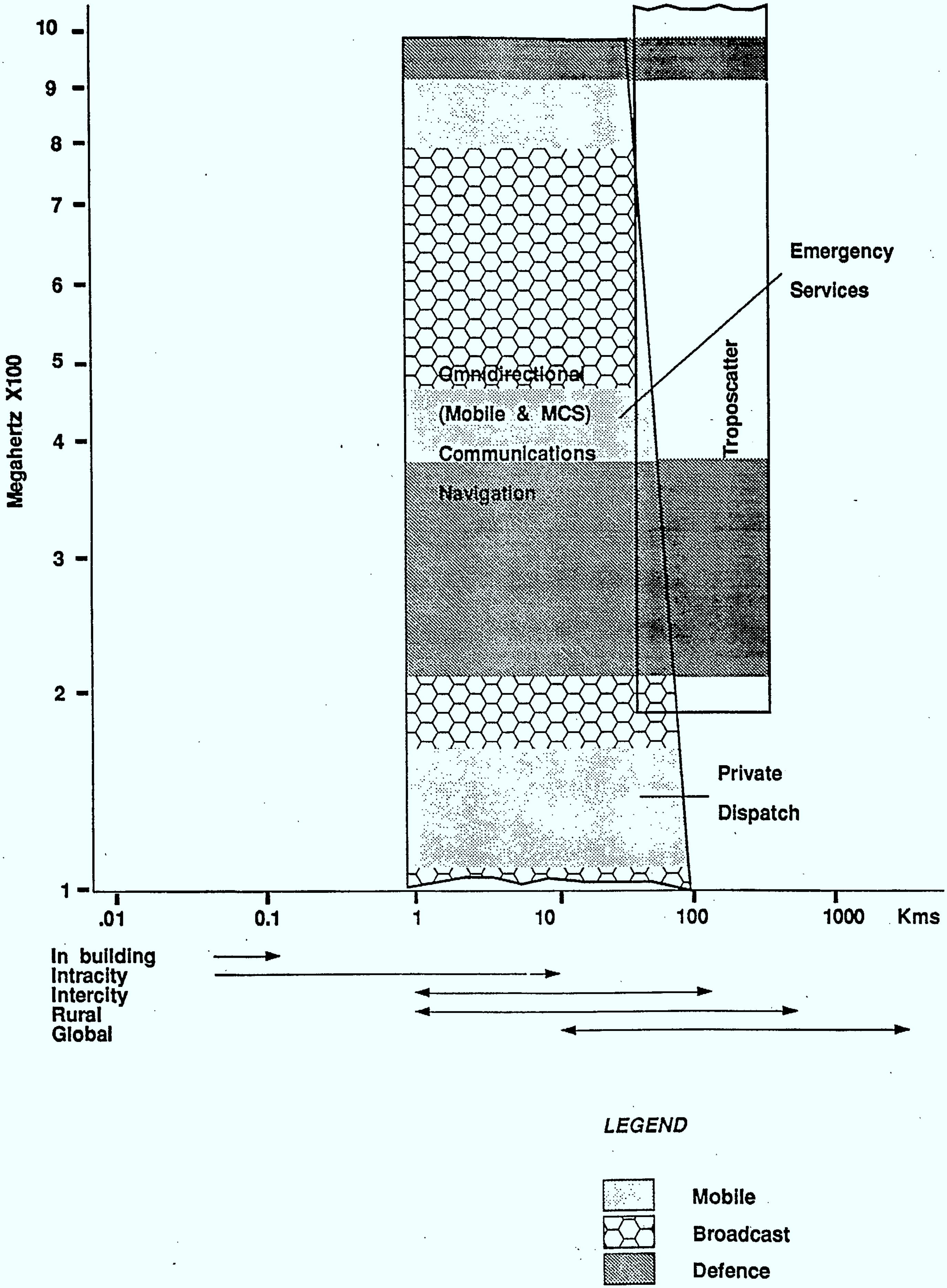
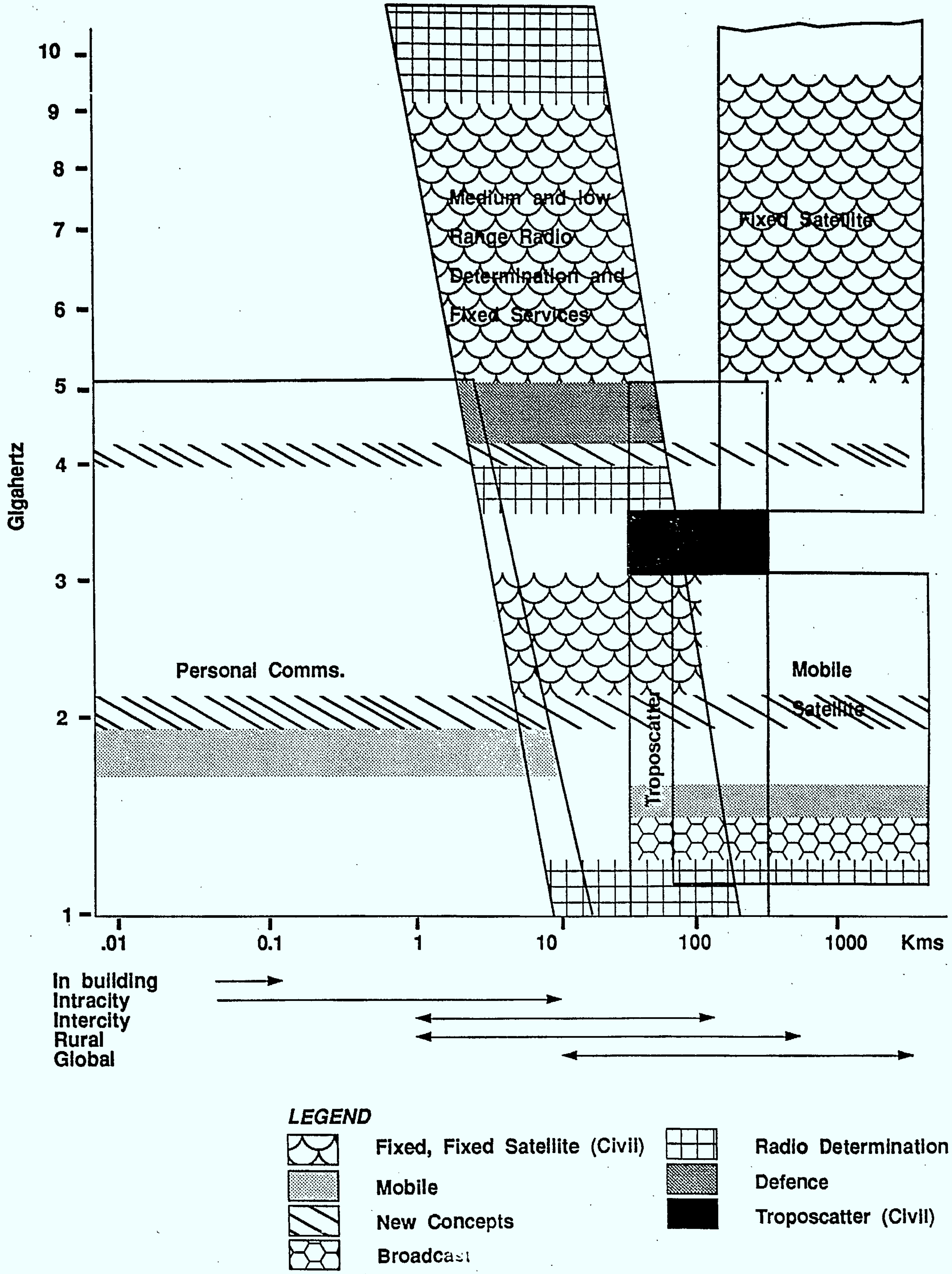

Megahertz X100
10
9
8
7
6
5
4
3
2
1
.01
0.1
1
10
100
1000
Kms
Omnidirectional
(Mobile & MCS)
Communications
Navigation
Emergency
Services
Troposcatter
Private
Dispatch
In building
Intracity
Intercity
Rural
Global
LEGEND
Mobile
Broadcast
Defence

FIGURE 2b



Gigahertz
10
9
8
7
6
5
4
3
2
1
.01
0.1
1
10
100
1000
Kms
Medium and low Range Radio Determination and Fixed Services
Fixed Satellite
Personal Comms.
Troposcatter
Mobile Satellite
In building
Intracity
Intercity
Rural
Global
LEGEND
Fixed, Fixed Satellite (Civil)
Mobile
New Concepts
Broadcast
Radio Determination
Defence
Troposcatter (Civil)

FIGURE 2c

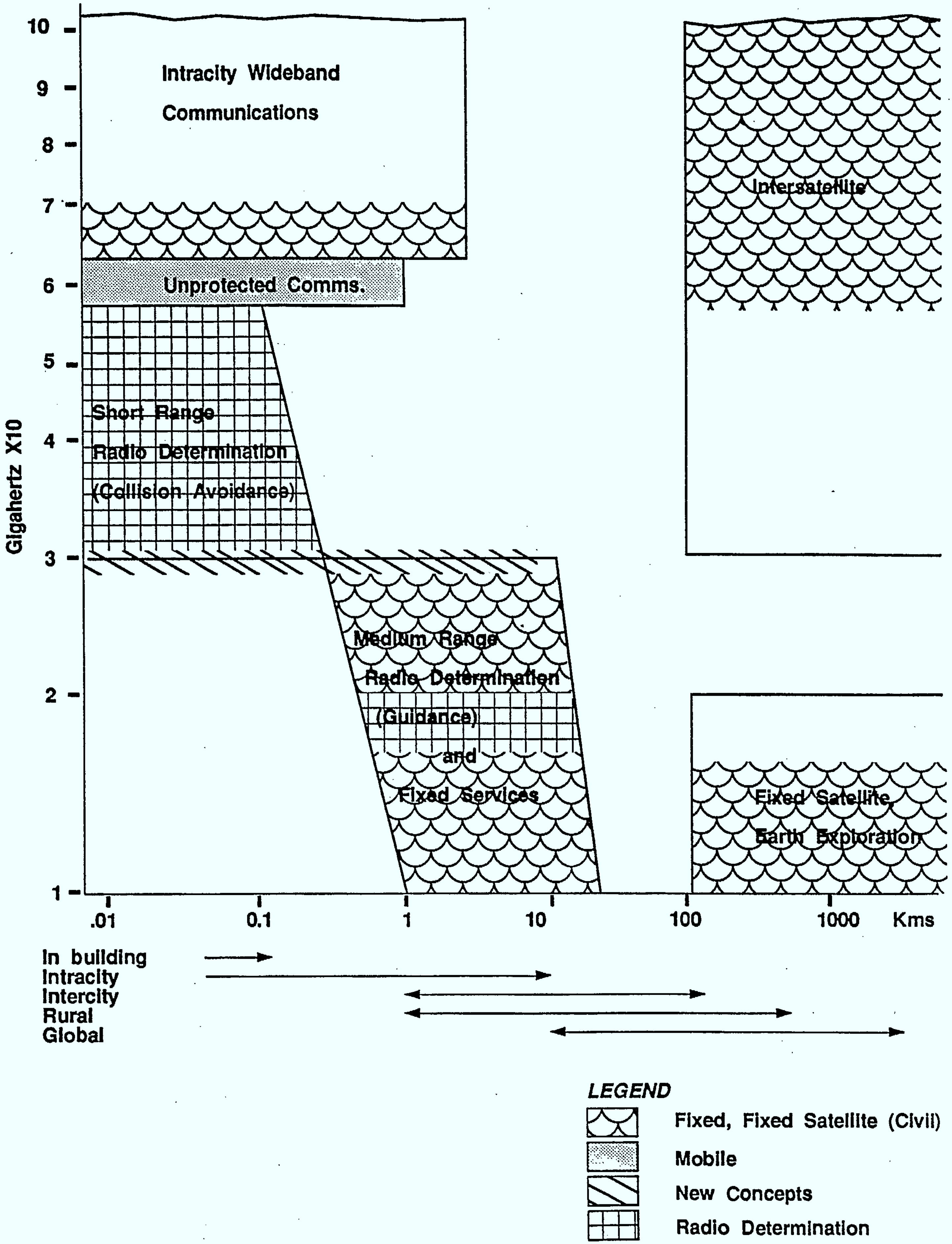

Gigahertz X10
10
9
8
7
6
5
4
3
2
1
Intracity Wideband
Communications
Unprotected Comms.
Short Range
Radio Determination
(Collision Avoidance)
Medium Range
Radio Determination
(Guidance)
and
Fixed Services
Intersatellite
Fixed Satellite,
Earth Exploration
.01
0.1
1
10
100
1000
Kms
In building
Intracity
Intercity
Rural
Global
LEGEND
Fixed, Fixed Satellite (Civil)
Mobile
New Concepts
Radio Determination

FIGURE 2d

In figure 2c however frequency reuse on a service location basis is shown between Fixed and Fixed Satellite services at frequencies above 5 GHz. Provision has also been made for new concepts with bands reserved at roughly 1.9 to 2.2 and 3.9 to 4.2 GHz. These bands have been selected to lie between other services so that expansion into these reserve bands would be possible if required by future growth. since it is not known what service location these new service concepts will operate in, the frequency reservation is made across all services locations.

7.2 A Generic Frequency Plan

In a parallel study for DOC "Development on New Spectrum Management Techniques" the ITU service categories were redefined into three basic applications:

Oneway or broadcast
Twoway (both fixed and mobile) and
Single point (radar)

Redefinition of the spectrum allocation shown in Figure 2a, 2b, 2c and 2d using the following criteria results in a simple allocation plan as shown in Figure 3.

a) The existing service categories can be reduced to a set of three service applications viz

- oneway or broadcast (including navigation)
- twoway mobile and fixed
- single point (radar)

b) The lower frequency bands up to about 5 GHz are best suited to omnidirectional services.

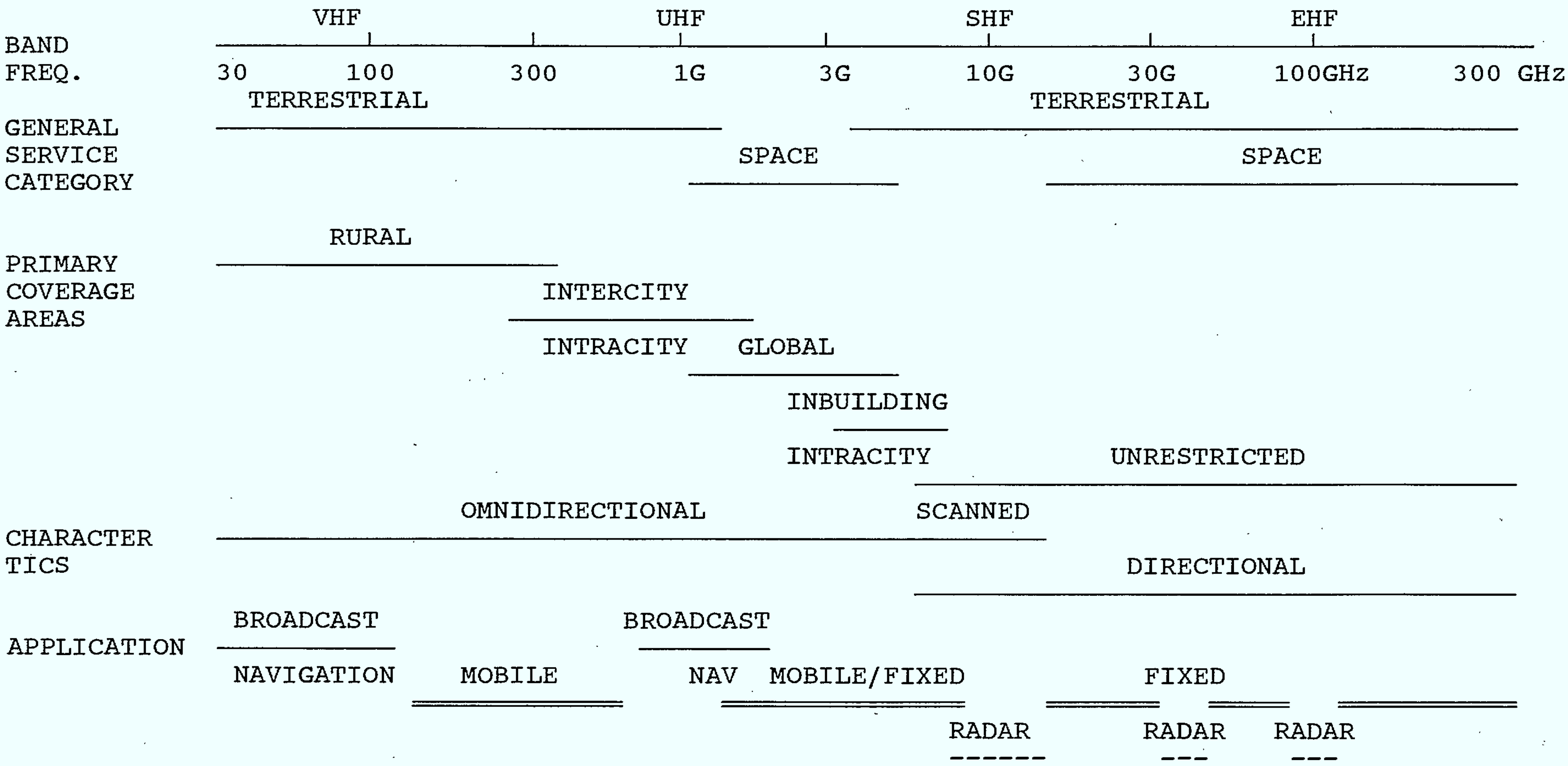


Figure 3 Generic Frequency Allocation Plan

c) allocations below about 400 MHz should be used for low density systems requiring wider areas of coverage.

d) To the extent possible adjacent allocations should be to applications that could exploit common technology eg. satellite broadcast, navigation and satellite mobile could share common antenna and receivers.

e) Existing allocations should be retained where possible particularly where frequencies are assigned on an international basis.

f) The generic plan should be flexible so as to permit some adjustments between adjacent allocations on the basis of demand.

g) Any new services would be accommodated within one of the three service applications shown in a).

7.3 Areas of Operation

The areas of operation have been subdivided into the following:

Inbuilding
Intracity
Intercity
Rural
Global

The operational area (s) of each of the service offerings identified in 7.2.3 is shown in pictorial form in Fig 4. This allows the overlap of the services covering more than one area to be easily identified.

Where the service is continuous across an area boundary without the use of any intermediate devices eg. broadcast, it is shown by a solid line. Where the same service is required independently in two or more areas it is shown by discontinuous lines. Where the same service is required to provide connectivity over two or more areas by means of an intermediate gateway eg. a cellular intra structure it is shown by a G (Gateway) between the connected areas.

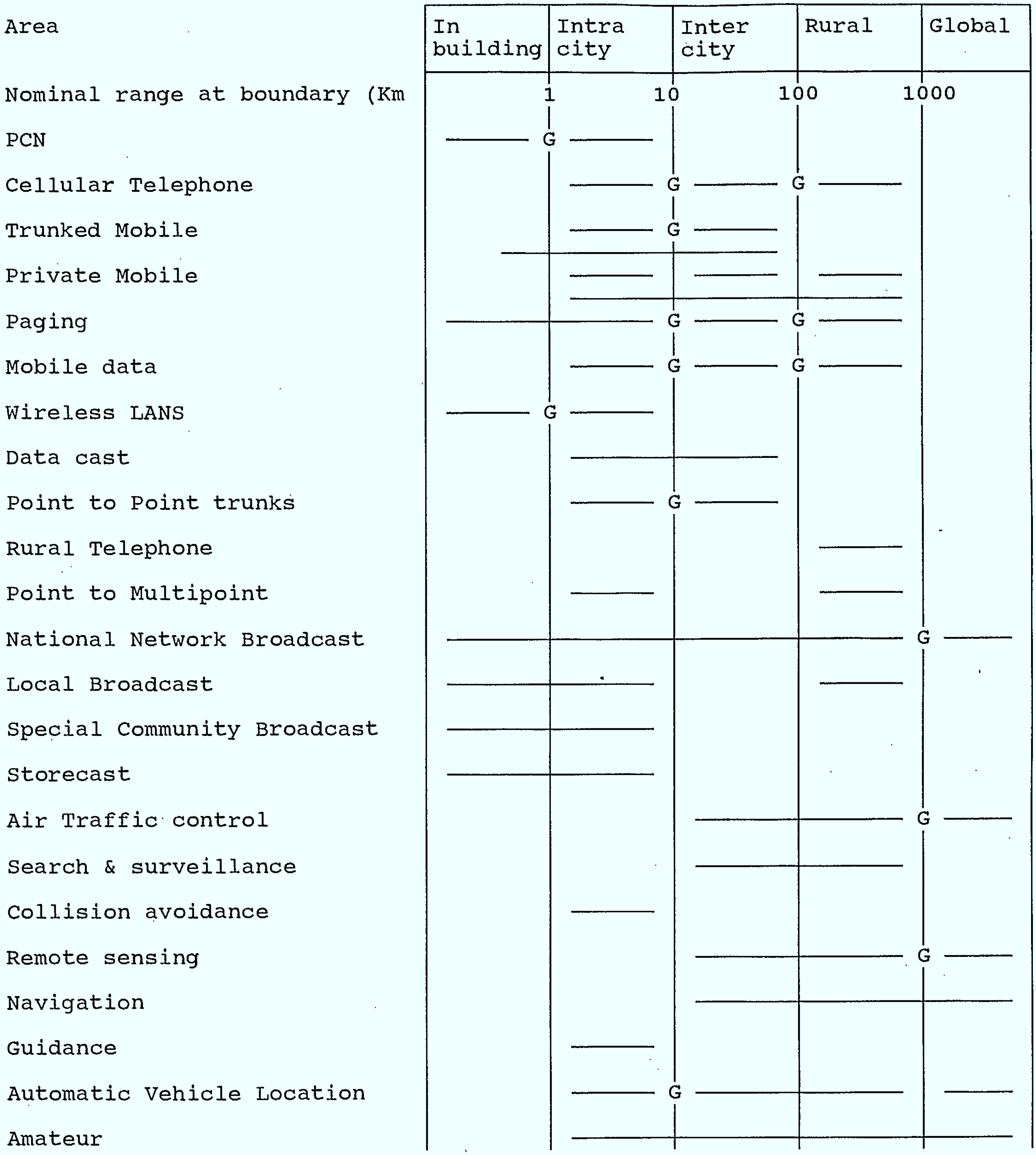

Area
In building
Intra city
Inter city
Rural
Global
Nominal range at boundary (Km
1
10
100
1000
PCN
Cellular Telephone
Trunked Mobile
Private Mobile
Paging
Mobile data
Wireless LANS
Data cast
Point to Point trunks
Rural Telephone
Point to Multipoint
National Network Broadcast
Local Broadcast
Special Community Broadcast
Storecast
Air Traffic control
Search & surveillance
Collision avoidance
Remote sensing
Navigation
Guidance
Automatic Vehicle Location
Amateur
G

Figure 4

8 SUMMARY AND RECOMMENDATIONS

8.1 Phase 1 Summary

Task 1 of the study indicate that evolving technology will bring about performance enhancements, cost and size reductions which will support an increasing demand for radio based services.

Furthermore these services could be provided more economically, and in some cases more conveniently, if the spectrum allocation is based upon propagation characteristics matched to the operating environment and nature of the service. For example, personal communications require omnidirectional antennas small enough to be easily fitted to pocket size radios but large enough to minimize propagation loss. The frequency band chosen should be capable of penetrating building through windows, doors or even walls and yet be reflected from conducting surfaces so as to provide "fill in" in otherwise shielded areas. The band 1 to 4 GHz is considered optimum by most experts in the field.

Despite the rapid evolution of technology few fundamentally new services can be predicted. Instead a number of existing services will be merged thereby enabling subscribers a range of service attributes using a common RF device. Cordless telephone, cellular radio and MSAT (or SHARP) will likely converge to form a universal mobile telecommunication service offering voice, data, facs, low definition video and possibly high quality audio (broadcast) reception.

Services will greatly expand in the fields of application and in the areas of coverage. For example radar technology, in conjunction with mobile radio and leaky feeder could well form the basis for a vehicle guidance system facilitating collision avoidance, lane way guidance and route selection.

Initial coverage along urban freeways would slowly expand to major intercity routes, secondary urban routes and around any areas of frequent traffic congestion or accidents.

A number of technology evolutions will have implications upon spectrum efficiency. Perhaps the most significant are low rate digital speech codecs, error correction coding and mobile trunking.

- The low rate speech codes not only reduce the bandwidth (with respect to FM) required for speech but they allow modes of operation not readily accomplished by other means. In particular time division duplex allows full duplex operation or repeater operation using a single RF frequency. Also it allows efficient time division multiplexing of many speech or data, channels onto a single RF carrier in both point to multipoint as well as point to point services.

- Error correction coding is significant as it allows the use of smaller fade margins. The consequent reduction in transmitter power reduces the interference environment particularly due to intermodulation.

- Mobile trunking provides an effective manner of allowing small user communities access to radio facilities that could not be economically justified on a stand alone basis. Although trunking provides a much better utilization of the radio channel, approaching one Erlang per channel compared with 0.1 Erlang for non trunking systems with an equivalent grade of service, the extra capacity is likely to be taken up by the small user communities.

8.2 Recommendations

The concept of allocating the most suitable, rather than the next available, band could have a huge impact upon many existing users of the spectrum with long term advantages to all.

In the short term many services may be unwilling to relocate to other parts of the frequency spectrum. Further study is required to enumerate the consequences of a change of frequency assignment upon each of the user groups and the suppliers. The factor to be considered in such a study are:

- operational consequences, long term and during transition
- transition cost
- transition time frame
- long term operational and cost benefits
- equipment availability
- commonality with like services in Canada and internationally

From a study of these factors constraints may be imposed with respect to the spectrum allocation plan developed in phase of the study and reported in section 7. The plan should therefore be revised to reflect these constraints as they become known. The above activities are recommended to replace the previously defined task 3 activity of phase 2.

ANNEX A
ABBREVIATIONS AND MNEMONICS

ANNEX A

Abbreviations and Mnemonics

The definitions of the abbreviations and mnemonics used in this report are listed below:

ACSSB	Amplitude companded Single Sideband
AM	Amplitude Modulation
AMPS	Automatic Mobile Phone System (North American Cellular)
APCO	Associated Communications Officers Public Safety
BPSK	Binary Phase Shift Paging
CDMA	Code Division Multiple Access
CC	Common carrier
CELP	Code Excited Linear Prediction
CT-2, CT-3,	Cordless Telephone Standard 2 (CT-2) and 3 (CT-3)
CVSD	Continuously Variable Slope Delta Modulation
DECT	Digital European Cordless Telephone
DME	Distance Measuring Equipment
DOC	Department of Communications
FDMA	Frequency Division Multiple Access
FM	Frequency Modulation
FPLMTS	Future Public Land Mobile Telephone Service
GHz	Gigahertz
GPS	Global Positioning System
GSM	(PAN European Cellular)
HF	High Frequency
ID	Identification
ILS	Instrument Landing System

INMARSAT	International Maritime Satellite
ISM	Industrial, Scientific, Medical
ISDN	Integrated Service Data Network
ITU	International Telecommunications Union
MCS	Multipoint Communication Services
MF	Medium Frequency
MHz	Megahertz
MLS	Microwave Landing System
MVDS	Multipoint Video Distribution Service
NTIA	National Telecommunication and Information Administration
OQPSK	Offset Quadrature Phase Shift Keying
PBX	Private Branch Exchange
PCN	Personal Communication Networks
PMR	Private Mobile Radio
PSTN	Public Switched Telephone Network
QAM	Quadrature Amplitude Modulation
RDSS	Radio Determination Satellite Service
RF	Radio Frequency
SBSS	Sound broadcast Satellite Services
SHARP	Stationary High Altitude Relay Platform
SHF	Super High Frequencies
TACAN	Tactical Air Navigation

TACS	Total Access Communication System (UK Cellular)
TDMA	Time Division Multiple Access
UHF	Ultra High Frequency
UMTS	Universal Mobile Telephone Services
VHF	Very High Frequencies
VORS	VHF Omnidirectional Ranging System

ANNEX B

BASE TECHNOLOGIES USED IN RADIO SERVICES

Annex B

Base Technologies used in Radio Services

2.2.1 A/D and D/A Convertors for Speech digitization:

Digital Filtering (Baseband)
Demodulation
Frequency synthesis
Direct digital modulation

2.2.2 Use of digital signal processing for:

speech digitization
speech compression
speech recognition
encryption
error correction and detection
modulation
demodulation
digital filtering
adaptive equalization
diversity combiners
adaptive antennas
code division multiplex (CDM)
time division duplex (TDD)
time division multiplex (TDM)
signal transforms
noise cancellation

2.2.3 Use of linear ICs for:

Voltage Controlled Oscillators (VCOs)
RF amplifiers
Direct frequency conversion
Temperature Compensated Crystal Oscillators (TCXOs)

2.2.4 Use of microprocessors for:

Channel allocation (trunking)
Channel allocation (wide area coverage)
Vehicle location
Navigation
Signalling protocols and protocol conversions in real time
Equipment control & displays
Messaging
Packet switching
Message routing, network management

2.2.5 Software

Message Traffic Management
Switching and Routing
Call data recording
Roaming algorithms
Hand-off algorithms

2.2.6 Bulk effect devices

Filters
Signal Transforms
Signal Delays, Correlations, Convolvers, etc.

2.2.7 Optical devices for:

Data storage/replay
Transmission
Imagery and displays

2.2.8 Antennas

Beam steering
Interference cancellation
Direction finding
Spectrum efficiency improvements for cellular base stations

ANNEX C

APPLIED TECHNOLOGIES USED IN RADIO SERVICES

ANNEX C

Applied Technologies Used in Radio Services

	Today's Standard	Emerging Standards	Future Standards
Modulation			
Speech	25/30KHz FM	12.5KHz FM	4.8KB/S CELP (NSA) ref MSAT
			6.25KHz FM
		12Kbps CVSD	9.6Kbps CELP,
		ACSSB	16Kbps ISDN
Data	FSK BPSK	QPSK	QAM OQPSK
Channelization			
	FDM	FDM/TDM, TDM	CDM PRMA
Channel Access			
	Manual Selection, Channel Scan, Voting	Central Trunking Digital Voting	Wide Area Trunking

Operating Mode

Simplex	FD Duplex	TD Duplex
Half Duplex		

Extended Coverage

Repeater	Simulcast	Single Freq. Repeater,
Multisite		Mobile Satellite, SHARP
Today's **Standard**	Emerging **Standards**	Future **Standards**

Mobile Telephone

AMPS (Cellular)	GSM	PCN
TACS	Digital Cellular	Iridium
ETACS	Telepoint	MSAT

User Features

User ID	Encryption,	Over the air keying,
SEL CALL, Interconnect, Privacy,	Stored Program, Emergency Breakin,	ISDN, Navigation, Location
Digital Modem	4.8/9.6Kbps Data FACS	

Spectrum Management Techniques

Freq. Co-ord. Directional antenna, Power limits Cellular	Cell Division, Narrowband Modulations, Trunking,	Pico cells, Adaptive Antenna, Dynamic Power Control, Linear Amplifier, High Protection Margin, Error Correction

Multipath Reduction Techniques

Low data rates	Auto Scan (HF), Antenna Diversity	Adaptive Equalization Feed Forward, Signal Regeneration

ANNEX D
FUTURE RADIO SERVICES

Annex D

Future Radio Services

Radio dispatch:	private systems
	private carrier systems
	public carrier systems
Radio telephone:	analogue/digital cellular
	GSM
	PCN
	Public cordless
	Aeronautical Public correspondence
	Marine
	Rural Distribution correspondence
Radio data:	Telemetry
	Medical telemetry
	Messaging
	Data base access
	Remote/mobile data collection
	Data casting
	LANS
	WANS
Radio imagery:	FACS
	Slow scan video
	Full motion video
Radio determination:	Vehicle location
	Navigation
	Collision avoidance
Non-Commercial Broadcast:	
	Traffic Information
	Information services
	Advertising

Radio Paging:	One way messaging
Radio Extensions:	Radio microphones
Fixed Links:	Interbuilding Interbase station Intercall trunks Common carrier trunks
Industrial, Scientific Medical (ISM):	
	Ionospheric sounding Weather radar Industrial processing Surveillance systems

ANNEX E

TRANSMISSION METHODS USED IN RADIO SERVICES

Annex E

Transmission Methods Used in Radio Services

Transmission Method	Application
Surface wave	- Marine, - Radio navigation, - Long range broadcast
Ionospheric (limited use above 30MHz)	- Marine, Remote areas, Emergency measures
Meteor scatter (40 to 110MHz)	- Wide area data collection
Troposcatter	- Offshore, fixed point to point
Atmospheric (Terrestrial)	- mobile/personal, - point to point, - broadcast, - point to multi-point, - radio relay - radio location
Space/SHARP	- point to point, - point to multipoint, - broadcast, - mobile/personal, - radio determination - radio navigation

Leaky Feeder	-	Mines,
	-	Tunnels,
	-	Buildings
Optical	-	RF coupling between buildings

ANNEX F

PROPAGATION CHARACTERISTICS AS A FUNCTION OF FREQUENCY AND THE IMPACT UPON RADIO COMMUNICATION SERVICES

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1 INTRODUCTION

It has been suggested that a reallocation of the frequency spectrum, based upon consideration of the propagation characteristics best suited to the different categories of service, would result in improved spectrum efficiency. In order to provide a basis for the evaluation of the above premise, this annex presents the basic transmission loss (B.T.L.) due to signal propagation through the medium, and the delay spread due to the time-dispersive medium. The basic transmission loss is defined as the transmission loss that would occur if the antennas were replaced by isotropic antennas with the same polarization as the real antennas, the propagation being retained, but the effects of obstacles close to the antennas being disregarded *(CCIR, 1986, Rep. 341)*. Throughout the report, the transmission loss will refer to the basic transmission loss unless noted otherwise.

The delay spread Δ is an indication of the magnitude of the time-dispersion. The delay spread depends mainly on the type of terrain, and is therefore empirical. This data exists delay spread will be presented against each of the different propagation evnironments eg. suburban areas, hilly regions etc.

Many service employs different propagation mode. The predominant modes for various service categories are given in table 1.1.

Service category	Predominant propagation
Terrestrial Mobile	Plane earth
Satellite Mobile	Free space
Terrestrial Portable	Plane earth/In building
Terrestrial Satellite	Free space/In building
Personal Communication Network	Free space/In building
Aeronautical	Free space/Plane earth

Maritime	Smooth earth
Fixed (point-to-point)	Free space with Fresnel zone interference
Fixed (point-to-multipoint)	Free space/Plane earth
Fixed satellite	Free space
Navigation	Surface wave
Satellite Navigation	Free space
Radar	Free space

Table 1.1 Service categories and corresponding predominant propagation modes.

To assist in the assessment of the suitability of a frequency to a particular service category, the raw data has been combined in a series of B.T.L. plots. These show the potential communications range as a function of frequency, when the basic transmission loss is varied over a range of 140 to 220 dB. A B.T.L. of 140 dB has been chosen to represent the path loss of a typical personal communication network (PCN) whereas 220 dB is more typical of a long range fixed service employing high gain antennas. Since the reliability requirements are service dependant the BTL curves do not include any fade margin.
The representative system parameters are:

PCN:

Rx sensitivity	-118 dBm
Tx power	+ 20 dBm
Antenna gain	+ 2 dB
B.T.L.	140 dB

Fixed service:

Rx sensitivity	-110 dBm
Tx power	+ 40 dBm
Antennas gain	+ 70 dB
B.T.L.	220 dB

The basic transmission loss is the accumulation of losses due to a variety of causes within the operating area of the service under consideration. For example PCN services are affected by body absorption and losses due to building materials. Fixed services are more likely to be affected by atmospheric and water (rain) absorption , and mobile services can be greatly affected by vegetation. The range/frequency graphs have therefore been developed for the propagation conditions expected to be associated with each of the various service categories.

Finally the empirical values of delay spread, which impacts the coherent bandwidth of simple communication systems, are shown for a number of the expected environments.

This annex attempts to include ,as many as possible, of the effects of major impairments to the communication links in the services listed in table 1.1.

The values used to construct the B.T.L. plots in this annex are either obtained directly from published graphs or by calculation based on formulas given by the reference sources. The error due to graph reading is less than 10%. For graphs with smaller scale, the reading error is within 5%.

The analytical approach, if simple, is employed wherever possible to enhance the accuracy of the system loss prediction. The methods employed to obtain the desired results will be either outlined briefly or shown in detail where appropriate. In both cases, the reference source(s), where additional information can be found, are given.

For most curves, several assumptions are made in the original sources. These assumptions will be stated as much as possible when they are seen to be important for the reader's decision about the system evaluation, comparison, etc.

2 GLOBAL PARAMETERS AND ASSUMPTIONS

The B.T.L. curves for each service are to be presented based on the propagation mode shown in table I. Thereafter, additional losses due to other effects such as the effect of climate, local environment, vegetation, etc. are added to obtain the cumulative attenuation. The impairment factors which are considered in this report are:

1) Rain
2) Gas
3) Building penetration
4) Vegetation
5) Body effect
6) Type of environment

The additional attenuation due to any of the impairment factor above depends on a large number of parameters. For example, the attenuation due to rain is a function of the rainfall rate, the raindrop size distribution, the elevation angle etc.. The loss due to building penetration depends mainly on the type of building, the materials used in the building construction, the floor where the receiver is located etc. In order to simplify the presentation, only a typical set of parameter for each impairment factor is chosen to arrive at the B.T.L. curves representing its effect.

The parameters presented in the following subsections will be used for other propagation mode based curves in section 3. The assumptions, sample calculations, and the approach to obtain the losses for constructing the B.T.L curves are given as follows:

2.1 Calculation of attenuation due to rain and gas

Attenuation due to rain is of practical importance for frequencies above several gigahertz and for percentages of time for which there is precipitation. The attenuation due to gaseous absorption is significant only around the 50 - 70 GHz frequency band. The parameters used to arrive at the losses due to rain and gases are:

Elevation angle	=	90° (vertical path)
Rainfall rate	=	25 mm/h
Pressure	=	1 atm
Temperature	=	20°C
Water vapour	=	7.5 g/m^3

It is also assumed that the measurement is made at the ground level.

The effective path length as a function of elevation angle and rainfall rate is reproduced from [2] in Fig. 2.1. When the elevation angle is 90° and the rainfall rate is 25 mm/h, the *effective path length* is approximated from the 25 mm/h curve in Fig. 2.1 to be 3.2 km. The specific attenuation γ_R due to rain is shown in Fig. 2.2 reproduced from [3]. The attenuation due to gaseous absorption is obtained graphically from Fig. 2.3 and Fig. 2.4 reproduced from [4]. The transmission loss including the effect of rain and gas absorption therefore can be expressed by the following formula:

$$L = 32.5 + 20 \log f + 20 \log d + 3.2\ \gamma_R + L_g \qquad \text{(A-2.1)}$$

where

L_g: the attenuation due to gas (dB),

γ_R: the specific attenuation due to rain (dB/km).

With the aid of Fig. 2.2, Fig. 2.3 and Fig. 2.4, the range d can be determined at different frequencies for values of transmission losses from 140 dB to 200 dB. The plot of communication range versus frequency for propagation in free space and influenced by rain and gaseous absorption is given in Fig. 2.5.

2.2 Building penetration

The loss due to building penetration highly depends on the material used in the building construction and the type of building. The loss also increases on upper floors. Measurements from [5] and [6] give median losses for office and high rise buildings at VHF, and a steel shell building at UHF. Table 2.1 summarizes the building description and the median building loss as well as the standard deviation.

Frequency Band (MHz)	Building Description	Median Loss (dB)	Standard(dB) Deviation
154-174	Office & High Rise	30	8
450-470	Office & High Rise	24	8
900	Steel Shell Building	28.5	Rayleigh

Table 2.1 Median loss for different types of buildings in the first floor.

Denote d_0 the distance that the signal travels with a loss L incurred in free space, and d_1 the distance the signal travels with the same loss when additionally penetrated by building. Knowing the loss due to building penetration is ΔL, d_0 and d_1 are related by

$$20 \log (d_0/d_1) = \Delta L \qquad \text{(A-2.2)}$$

from which d_1 can be calculated.

Fig. 2.6 shows the maximum distance that a signal could travel versus frequency due to free space and building penetration while keeping the loss not exceeding various values of B.T.L.s.

2.3 Effect of Vegetation

The foliage effect depends on a number of factors such as the vegetation density, the moisture content of the leaves, the shape of the leaves, and the height of the tree etc. The additional attenuation through woodland measured when the trees were in full leaf [7], and the antennas were below the tree tops, is given in Fig. 2.7.

Assuming the attenuation is linearly proportional to the distance, the graph in Fig. 2.8 estimates the distance that radio waves can travel through woodland areas without exceeding a given path loss.

Tamir [8] measured the signal loss due to foliation at a distance of 1 km, with both the transmitting and receiving antennas at the treetop heights. Tamir's study shows that between communication terminals that are spaced more than 1 km apart, the loss is independent of distance. Fig. 2.9 shows loss versus frequency due to foliage effect.

2.4 Body effect

The loss due to the presence of a human body in the radio field depends greatly on the antenna configuration and relative position of the antenna to the body of the person who holds it. [5] and [9] give measurements of the median loss due to body effect with different antenna configurations. Table 2.2 summarizes the median body loss and standard deviation for a particular receiver ("PR" series units)

Frequency Band (MHz)	Antenna Configuration	Median Body Loss (dB)	Standard Deviation (dB)
150-174	Hand-Held Angled Helical	10	2
450-470	Hand-Held Angled Helical	18	5
900	Waist Dipole	4-7	

Table 2.2 Median body loss at VHF and UHF.

In the same manner, relation (A-2.2) is used to calculate the maximum distance that the signal could travels when the effect of the human body is included, i.e.

$$20 \log (d_o/d_l) = \Delta L$$

where

d_o: distance the signal travels in free space to be attenuated by L dB (km),

d_l: distance the signal travels in free space and influenced by the presence of a human body, and attenuated by L dB (km),

ΔL: the loss due to human body.

2.5 Effects of Terrain

2.5.1 Urban areas

An empirical model developed by Egli [10], using data from large U.S. cities, is used to estimate the path-loss on roads within urban areas. Path loss is determined from

$$L = 85.9 + 20 \log f + 40 \log d - 20 \log h_t - 20 \log h_r \text{ if } h_r > 10\text{m}, \quad \text{(A-2.3a)}$$

$$L = 76.3 + 20 \log f + 40 \log d - 20 \log h_t - 10 \log h_r \text{ if } h_r \leq 10 \text{ m}. \quad \text{(A-2.3b)}$$

where

h_t, h_r: the transmitting and receiving antennas heights respectively (m).

The variation of the path loss may be estimated to be

$$\sigma = 5.5 \log f - 3.2 \quad \text{(dB)}$$

Using (A-2.3b), graph of range versus frequency is plotted at different values of path loss for antenna heights of 60m (transmitter antenna) and 1.5m (receiver antenna)

$$h_t = 60 \text{ m}$$
$$h_r = 1.5 \text{ m}.$$

The graph is shown in Fig. 2.10.

2.5.2 Rural areas

Murphy [11] has presented an empirical expression for path loss in rural areas with mountainous terrain

$$L = 21.4 + 39.4 \log f + 40 \log d - 20 \log ht - 5.3 \log(h_r - 2.4)$$

The path loss standard deviation is given as

$$\sigma = 17.3 - 0.019\ h_r + 0.0012\ f \quad \text{(dB)}$$

Plot of range versus frequency is generated from (A-2.4) for transmitting antenna height of 60 m and receiving antenna height of 1.5 m

$$h_t = 60 \text{ m}$$
$$h_r = 1.5 \text{ m}.$$

The plot is shown in Fig. 2.11.

3. BASIC TRANSMISSION LOSS CURVES FOR DIFFERENT PROPAGATION MODES

3.1 Free space propagation

The services which have free space as a predominant mode include aeronautical, mobile satellite, fixed satellite, navigation, and radar.

The B.T.L. for the services in which the predominant mode of propagation is free space is calculated using the free space transmission loss formula

$$L = 32.5 + 20 \log f + 20 \log d \qquad \text{(A-3.1)}$$

where

L: the free space basic transmission loss in dB,

f: the frequency in MHz, and

d: the distance in km.

The range versus frequency curves for these services including the effects of rain and gaseous absorption are given in Fig. 2.5.

3.2 Smooth earth propagation

Maritime mobile is the predominant service in which propagation takes place over a smooth earth although smooth earth propagation can be experienced in some land mobile and fixed service locations.

[12] provides data for signal propagation over a smooth earth. The type of surface used in the measurement, its conductivity and relative permittivity are provided below:

SURFACE	CONDUCTIVITY	PERMITTIVITY
Average land	σ = 0.005 mhos/m	ϵ = 15

The effective antenna heights of both the transmitter and the receiver were taken at 100 m.

$$h_t = h_r = 100 \text{ m}$$

The effects of rainfall and gaseous absorption are included to the path loss over smooth earth and shown in Fig. 3.1.

3.3 Plane earth propagation

The plane earth propagation is the predominant propagation mode in mobile and portable communication. In mobile communication, the signal variation is caused mainly by the type of areas and the kind of terrains the signal travels through. Fig. 2.10 from section 2 is reproduced here but also includes the effect of rain and gaseous absorption (Fig. 3.2).

For a personal outdoor communication, the impairment factors may include: the effect of terrain, body loss (VHF, UHF), rain, and gaseous attenuation (SHF, EHF). Denote L_t and L_b the losses incurred by the effect of terrain, which includes free space loss, and human body respectively. The total loss at VHF and UHF is thus

$$L = L_t + L_b \qquad \text{(A-3.2)}$$

When the area is of urban type, L_t is estimated using (A-2.3b). Values of and L_b are obtained from table 2.2. (A-3.2) therefore becomes

$$L = 76.3 + 20 \log f + 40 \log d - 20 \log h_t - 10 \log h_r + L_b \text{, for } h_r \leq 10 \text{ m.} \qquad \text{(A-3.3)}$$

Fig. 3.3 gives the range versus frequency for h_t = 60 m and h_r = 1.5 m. The effect of rainfall and gaseous absorption are also included in the figure at SHF and EHF.

3.4 In building propagation

There are basically two types of 'in building' communications: the first type is when two antennas are within a building; the second type is between the transmitting antenna outside the building while the receiving antenna is located inside the building. We consider only the second type.

The effects to be considered are in this type of communication are: the type of terrain, building penetration, and body effect. Denote L_t, L_p, and L_b the losses incurred by the effect of terrain, building penetration and human body respectively. The total loss is thus

$$L = L_t + L_p + L_b \qquad \text{(A-3.4)}$$

When the area is of urban type, L_t can again be estimated using (A-2.3b). Values of L_p and L_b are obtained from tables 2.1 and 2.2. (A-3.4) hence becomes

$$L = 76.3 + 20 \log f + 40 \log d - 20 \log h_t - 10 \log h_r + L_p + L_b \, , \quad \text{for } h_r \leq 10 \text{ m} \qquad \text{(A-3.5)}$$

Choose h_t = 60 m and h_r = 1.5 m. The plot of communication range as a function of frequency in an in-building communication, based on (A-3.5), is given in Fig. 3.4. The effect of rainfall and gaseous absorption are also included in the figure.

4 MULTIPATH DELAY SPREAD

This section gives a summary of the multipath delay spread caused by the effects of terrains and man-made structures. Table 4.1 lists the delay spread as an aid to the reader.

The presence of a good direct path often results in smaller value of the delay spread and thus is also included in the table.

In general, the delay spread depends mainly on the local environment of the receiver and the path between the transmitter and the receiver. The type of terrains where the measurements were made, the propagation conditions, and the methods

Type of environment	Line-of-sight	Delay Spread
Open area [1]		< 0.2 μs
Suburban area [1]		0.5 μs
Urban area [1]		3 μs
Hilly region [13]		
- within city	Yes	3 μs
- suburbs, outskirts	Yes	17 μs
- suburb, outskirts	No	23 μs
Building [14] (inside-to-outside path)	Yes	100 - 325 ns
	No	420 ns
Office Building [15] (within)	No	210 - 250 ns
	Yes	< 100 ns
Forest [16] (tree tops)	No	0.2 μs
Ionoscatter [17]		20 μs
Meteorscatter [17]		1 μs

Table 4.1 Multipath delay spread for various types of environments

of measurement are described in the original sources.

For the ionospheric propagation, Millman [18] has plotted the group time delay difference as a function of frequency for different pulse widths (Fig. 4.1).

The time variability of multipath spread in meteorburst propagation is constructed by Grossi et al. [19] (Fig. 4.2).

5 IMPACT UPON RADIO COMMUNICATION SERVICES

5.1 PCN

In the 10 to 20 year time frame it is widely expected that PCN services will become the largest volume user of two way communications. The spectrum selection for PCN should therefore receive a high priority if the service is to be economically provided in terms of spectrum utilization and equipment size and cost.

Although micro or pico sized cells may be necessary to provide capacity in high density areas, larger cells, up to 8 Kms, or even hyper cells provided via satellites are likely to be economically necessary. The selected frequency must therefore be suitable for all three areas of operation.

Path loss and multipath spread are the two propagation factors that will most influence economics whereas path loss variance will be the factor which most influences spectrum utilization.

Based upon Figures 3.3 and 3.4 and in consideration of the work of many other investigators the frequency band 1 to 3 GHz is considered best for PCN.

5.2 Broadcast Services

Although within most urban environments cable (probably fibre optics) is likely to become the dominant mode of broadcast distribution. However an increasingly leisure orientated public will likely demand broadcast news, high quality audio and TV outside of the home. As for PCN, the high volume of users will require that frequency allocations permit both low cost and, possibility to a lesser extent, spectrum efficient allocations.

The one way nature of broadcast allows the use of lower frequencies using efficient but large physical antennas at a central location. Since TV viewing is, and should remain, a non mobile activity multipath signals can be largely minimized by antenna orientation at least for low definition TV standards. For HDTV picture quality impairment due to small multipath spread is likely to be more evident and hence will be a factor in determining optimum frequencies.

Figures 2.10 suggest that the frequency ranges will be best suited to audio and NTSC signets whereas the band may be better suited to HDTV.

5.3 Mobile Services

5.3.1 Business

Business economics is such that almost all vehicles used in a business or transportation application can eventually be expected to employ two way radio. Cost and size will be less important than for PCN and broadcast but high reliability and ease of operation are critical.

In most cases short messages either voice or data will predominate so that the potentially longer call set up time and service charges of PCN will not be acceptable. These mobiles services will likely therefore require an independent network and have frequency band form that of PCN.

Business mobiles are largely constrained to roads, parking lots and loading bays. Except for the latter these areas are not generally subject to building penetration losses from figures 2.10, 2.11 and 2.12 the frequency bands up to 1 GHz are best suited.

5.3.2 Law Enforcement and Emergency Services

Mobile service requirements are equivalent to those discussed in 5.3.1. However an additional requirement is for communications to hand held portable units. These may be in the open or within buildings. Due to the safety of life associated with phase activities a very high coverage reliability is required in all areas.

Since different buildings provide a significantly different penetration loss it is difficult to select a single frequency band which covers all applications. However the 400 to 470 MHz band seems to offer the best overall compromise.

5.4 Aeronautical Mobile

Aeronautical communications can be divided into three categories.

a) Short range (5 Km) ground based communications while at the ramp or while taxing.

b) Medium range (30 Km) for air traffic control in the terminal area.

c) Long range (unlimited) for on route air traffic control and public correspondence.

Aircraft locations are such that free space propagation is possibly given a modest ground based infrastructure or satellite orbital location. Thus a common frequency band could be used for all three categories. Ideally this would be vis satellite in order to facilitate communications over oceanic regions. However, ground based facilities can be anticipated to be required as a back up particularly for terminal approach. This could be provided by a sub band adjacent to a satellite band. Since approach paths to airports on occasion pass close to high power broadcast stations a frequency band well separated from these or other high power installations seems desirable. In view of all of the above considerations the frequency band 0.5 to 3 GHz appears the most suitable.

5.4 Fixed Service

The two categories of fixed services are point to point, which allows the use of highly directional antennas, and point to multipoint which requires at east an omnidirectional central antenna.

Point to point services are often used in a daisy chain multihop systems. Each path must therefore been designed for very high reliability and low interference. For short hops the use of EHF frequencies, which permit very high gain but physically small antennas is advantageous. The low installations cost per site could probably compensate for extra sites.

Long haul point to point in remote areas is best served by SHF frequencies between 3 and 20 GHz. Rain attenuation at frequencies above 10 GHz could today be dynamically compensated by automatic power control.

For point to multipoint systems omnidirectional antennas and multiple paths from a single station require the use of frequencies with low path losses and less susceptibility to fading. The frequency band 2 to 5 GHz is most suitable.

5.5 Radio Navigation

Long range radio navigation must either employ surface wave propagation, requiring very low frequencies, or satellites. The satellite mode requires frequencies in which propagation delays are least perturbed by atmospheric or ground reflection effects.

Receiver antennas should be omnidirectional and even space based transmitters should provide global beams. Therefore propagation losses should also be small. The use of radionavigation in the proximity of broadcast or other high power transmitters requires good frequency separation from these services.

In view of all of the above considerations the frequency band 800 to 3 GHz appears the most suitable.

Short range navigation systems are used where higher accuracy is required than is available by means of the long range systems. Such systems require very wide bandwidths and/or exceptional phase stability for their operation. However propagation losses are not critical therefore any available frequencies in the upper UHF or throughout the SHF band appears feasible.

A characteristic of navigation systems is that only one system of a given accuracy is necessary in each service area. Therefore despite large bandwidth for each systems the overall bandwidth required is less than for many of the other systems discussed herein.

5.6 Radio Location

The characteristics of radiolocation services vary significantly according to their application, many of which are military in nature.

In general they can be summarized into:

- long range surveillance
- medium range surveillance and tracking
- short range targeting and guidance
- short range collision avoidance
- remote sensing

The frequencies required to best satisfy these applications are dependant upon propagation loss, reflectivity of target of interest versus clutter, physical environment of antenna etc.. As a result no single frequency band is ideal and a number of bands throughout the range 1 to 100 GHz are necessary.

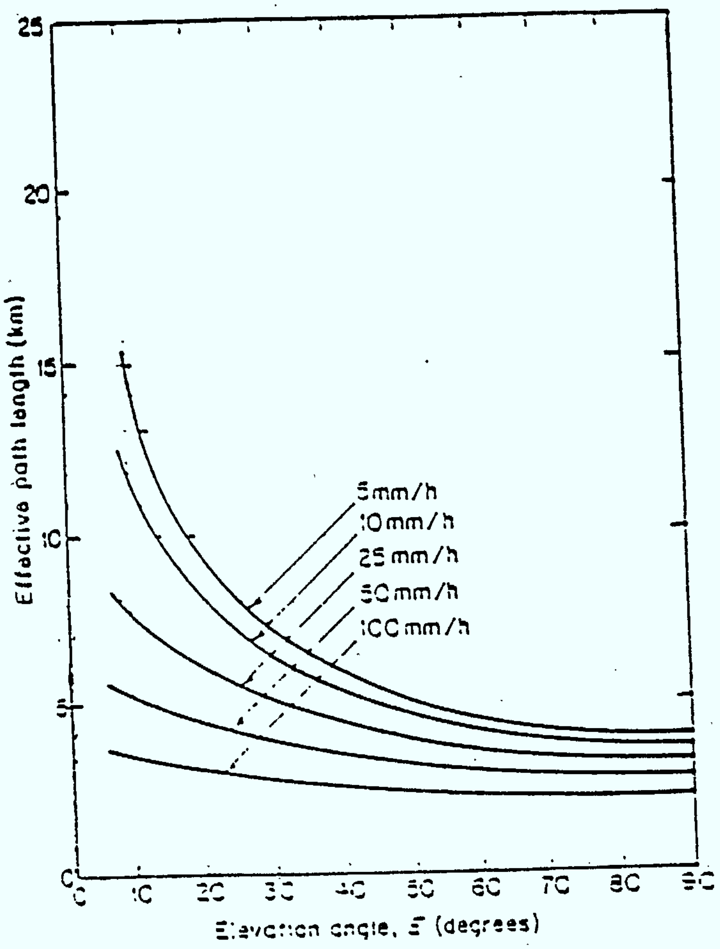

Fig. 2.1 Effective path length as a function of elevation angle and rainfall rate (CCIR, 1978)

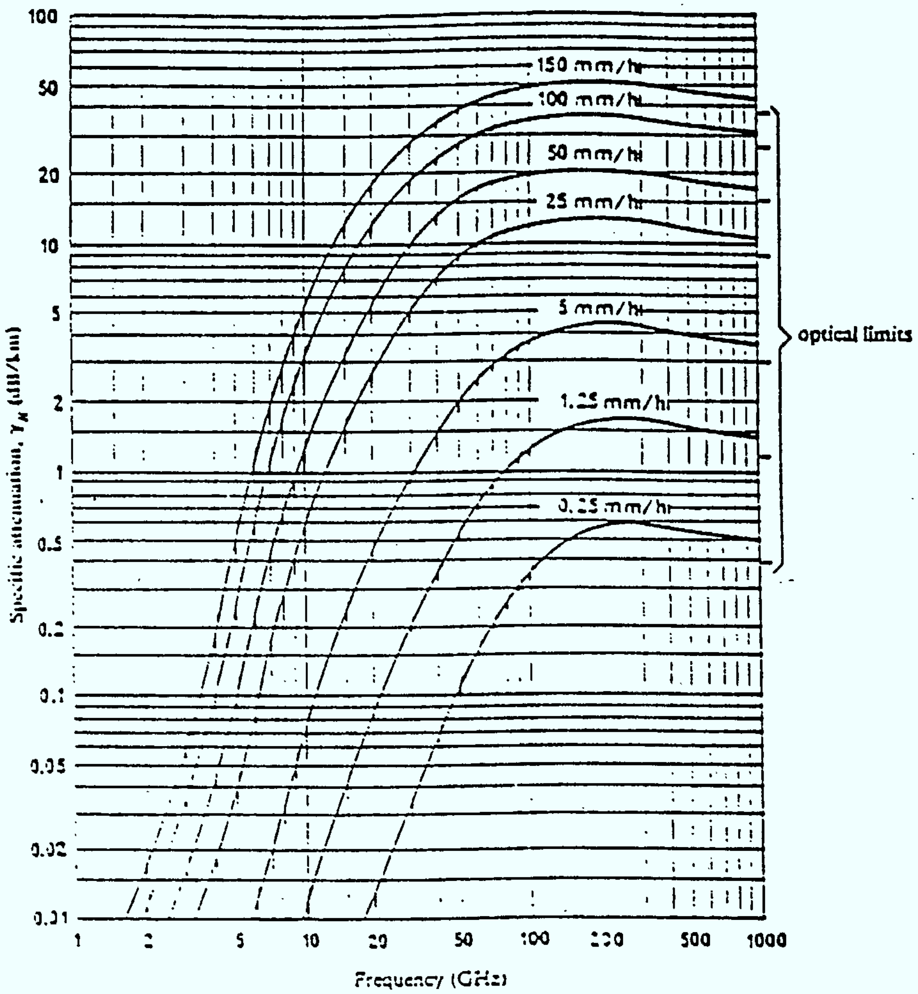

Fig. 2.2 Specific attenuation due to rain (CCIR, 1986)

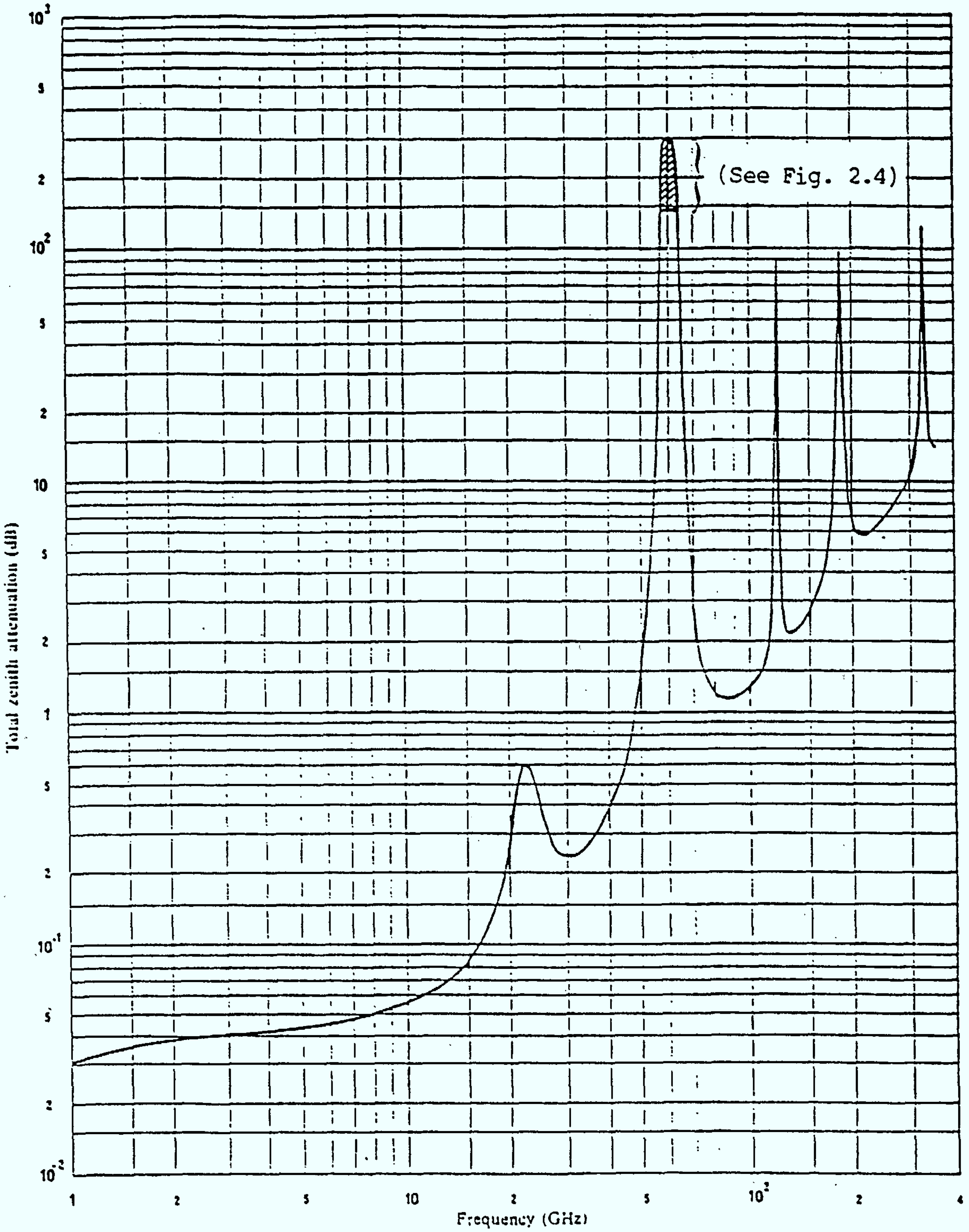

Fig. 2.3 Total zenith attenuation (CCIR, 1986)

Pressure: 1 atm
Temperature: 20°C
Water vapour: 7.5 g/m³

at ground level

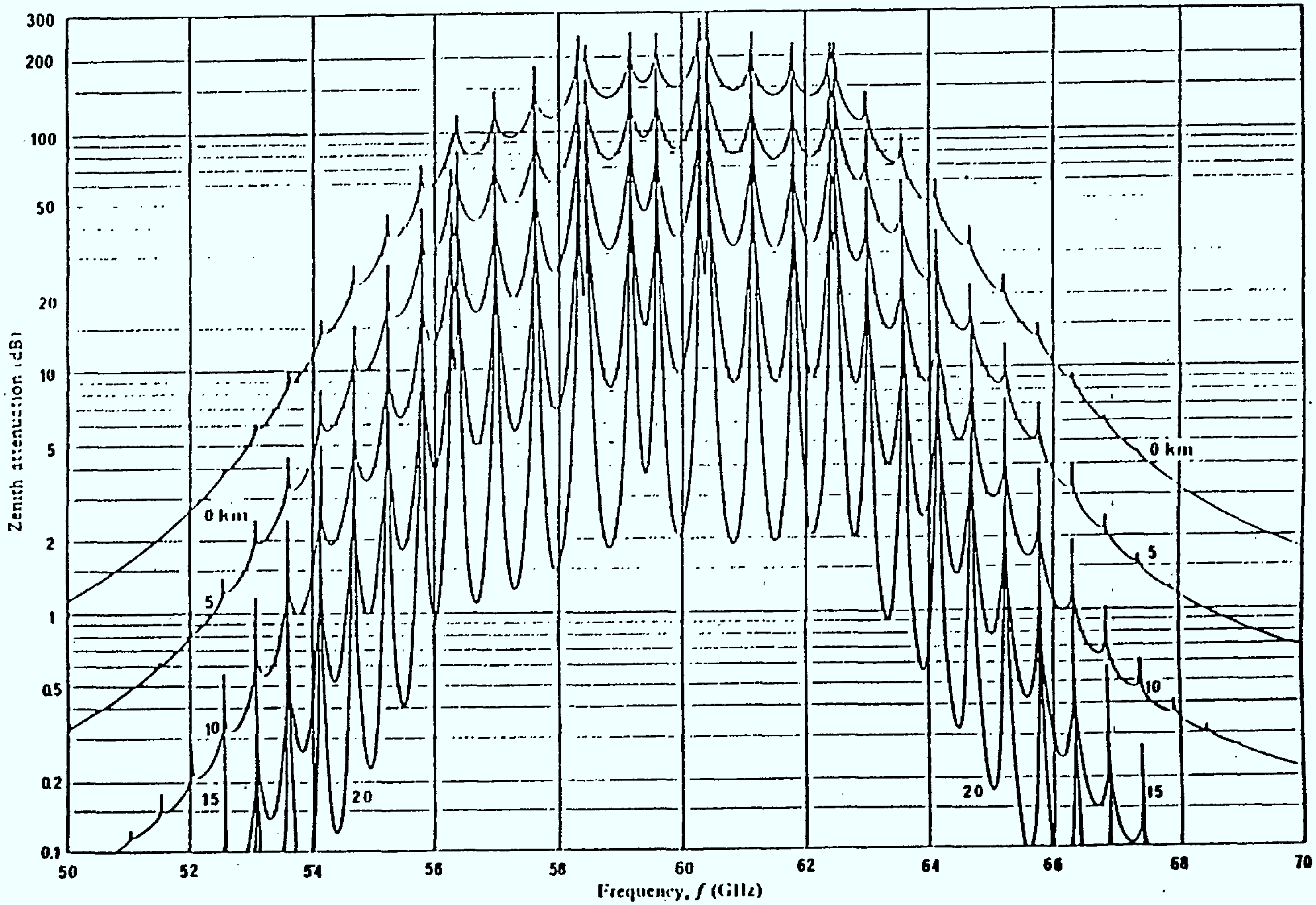

Fig. 2.4 Zenith oxygen absorption for some initial heights (CCIR, 1986)

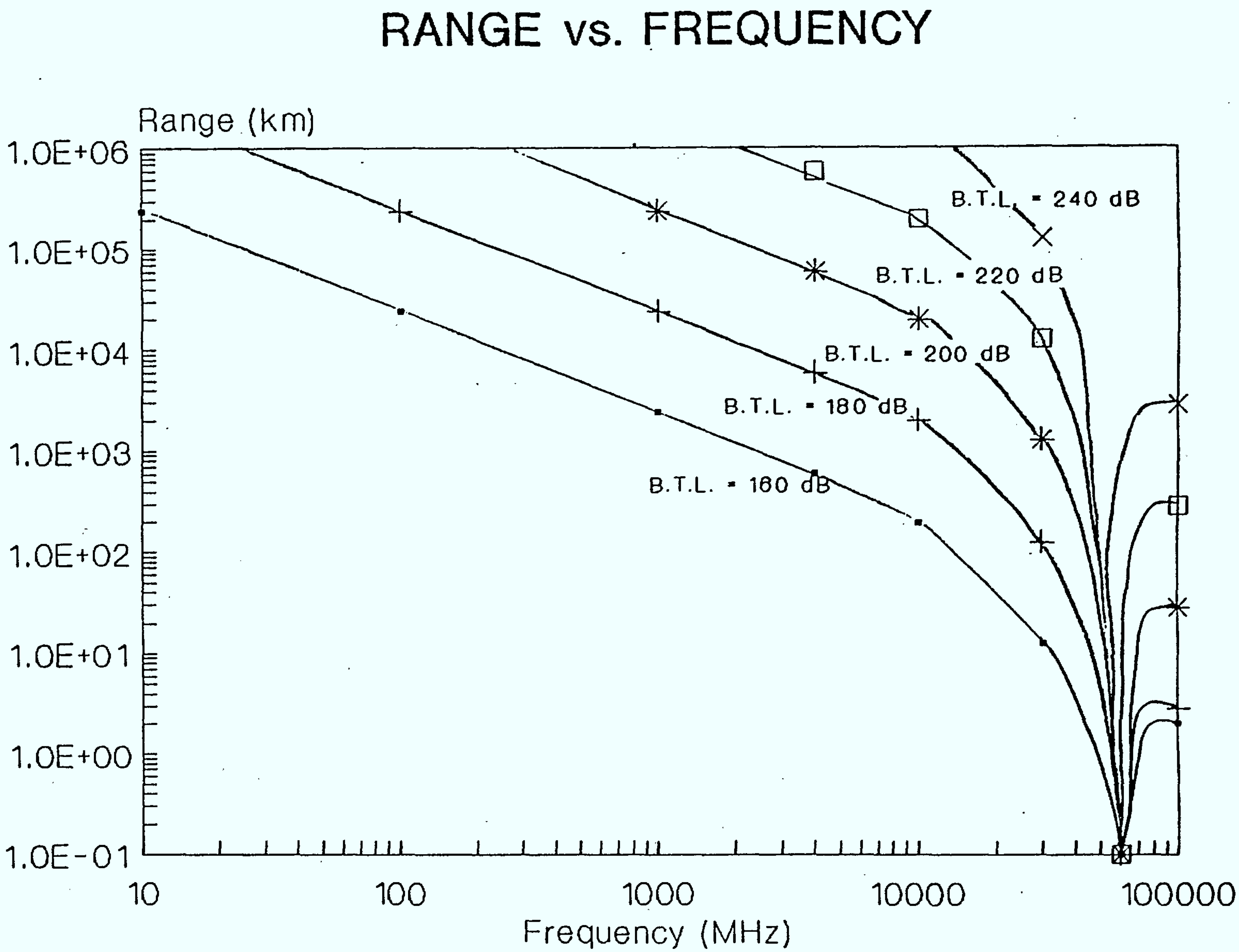

Fig. 2.5 Communication range as a function of frequency for different B.T.L. due to free space, rain, and gaseous absorption.

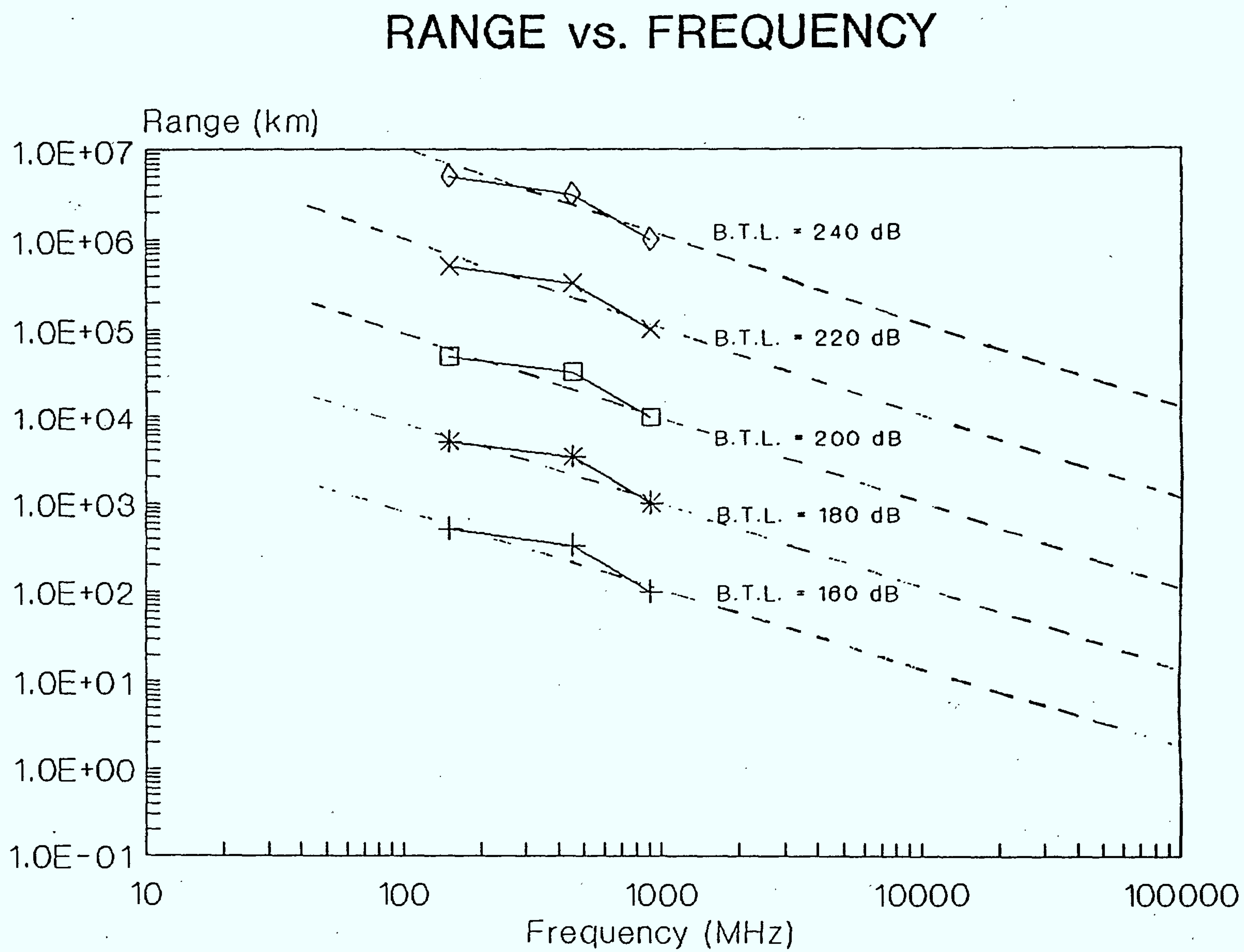

Fig. 2.6 Communication range as a function of frequency for different B.T.L. due to free space and building penetration.

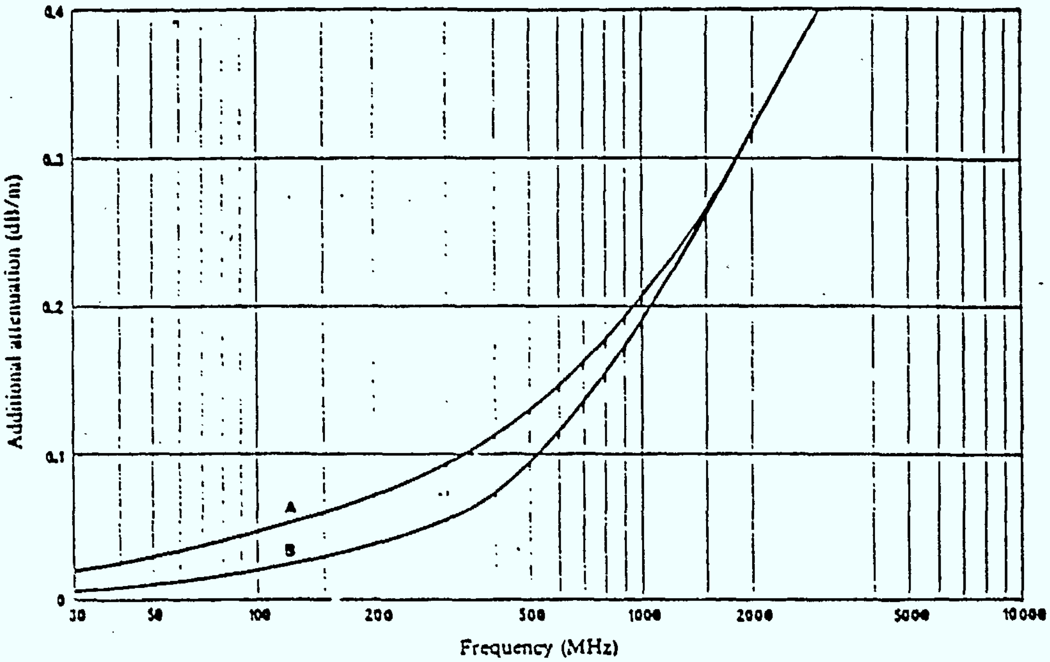

Fig. 2.7 Additional attenuation through woodland

A: vertical polarization
B: horizontal polarization

RANGE vs. FREQUENCY

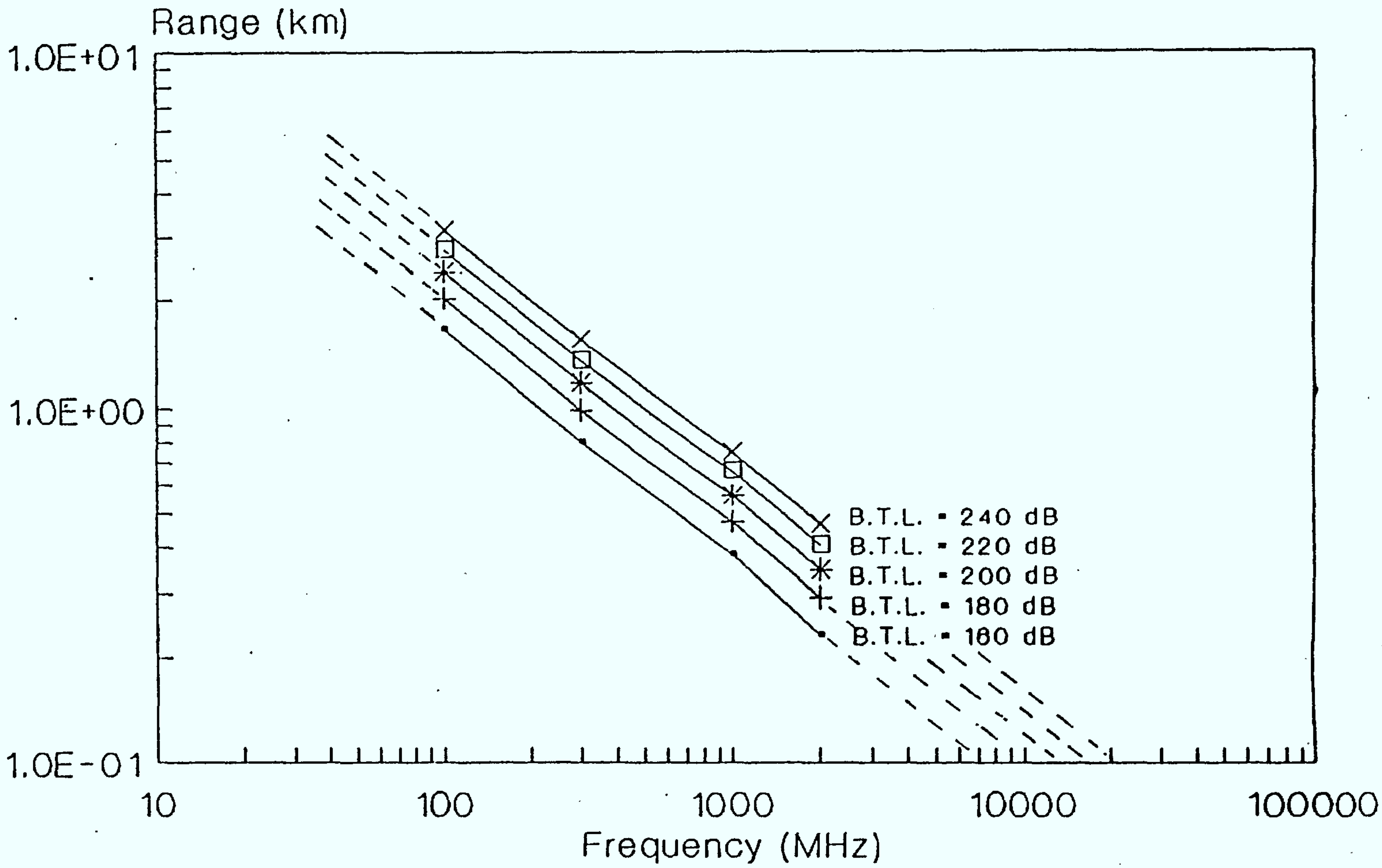

Fig. 2.8 Communication range as a function of frequency for different B.T.L. due to free space and woodland (points within forest).

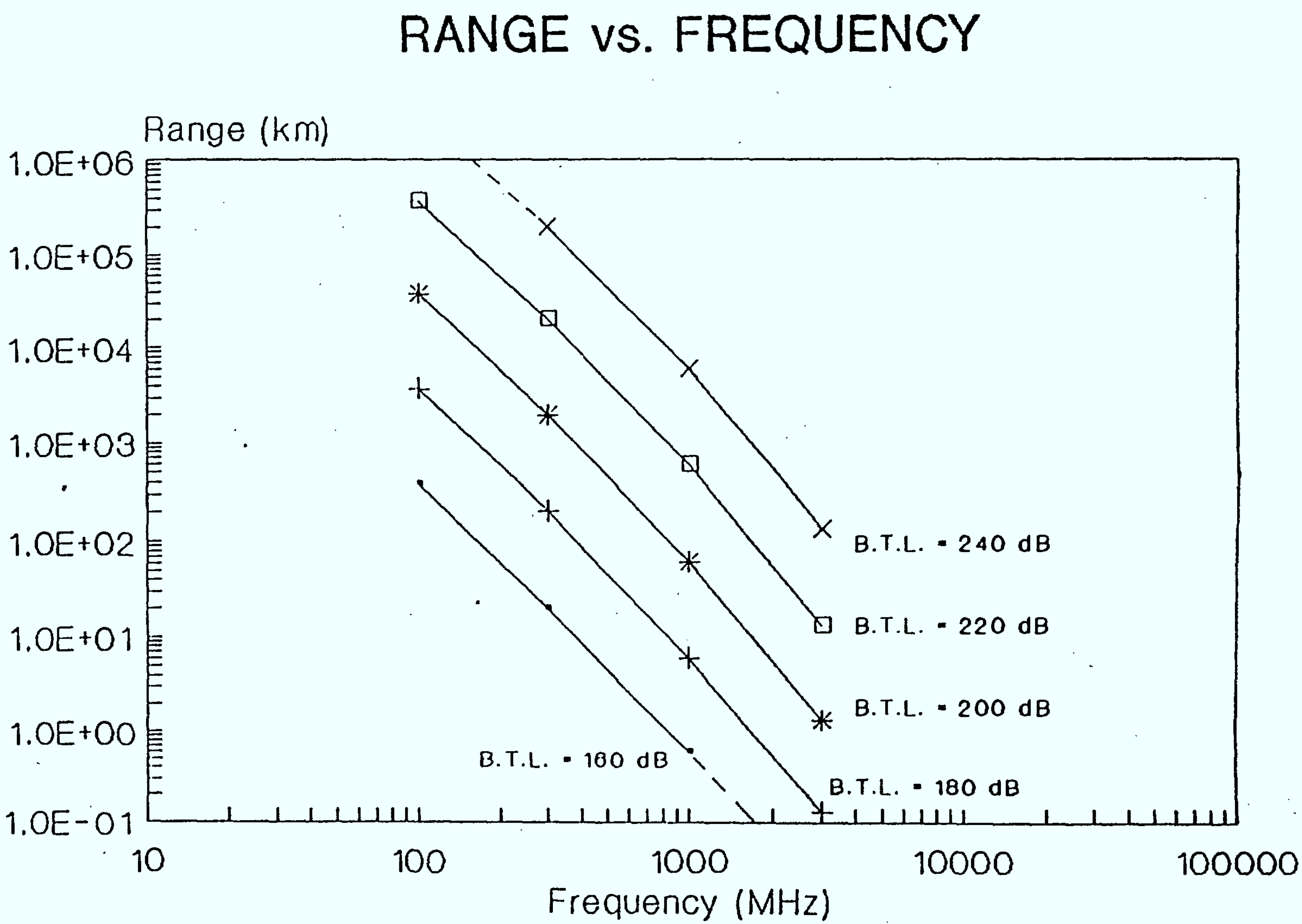

Fig. 2.9 Communication range as a function of frequency for different B.T.L. due to free space and foliage (points located at treetops).

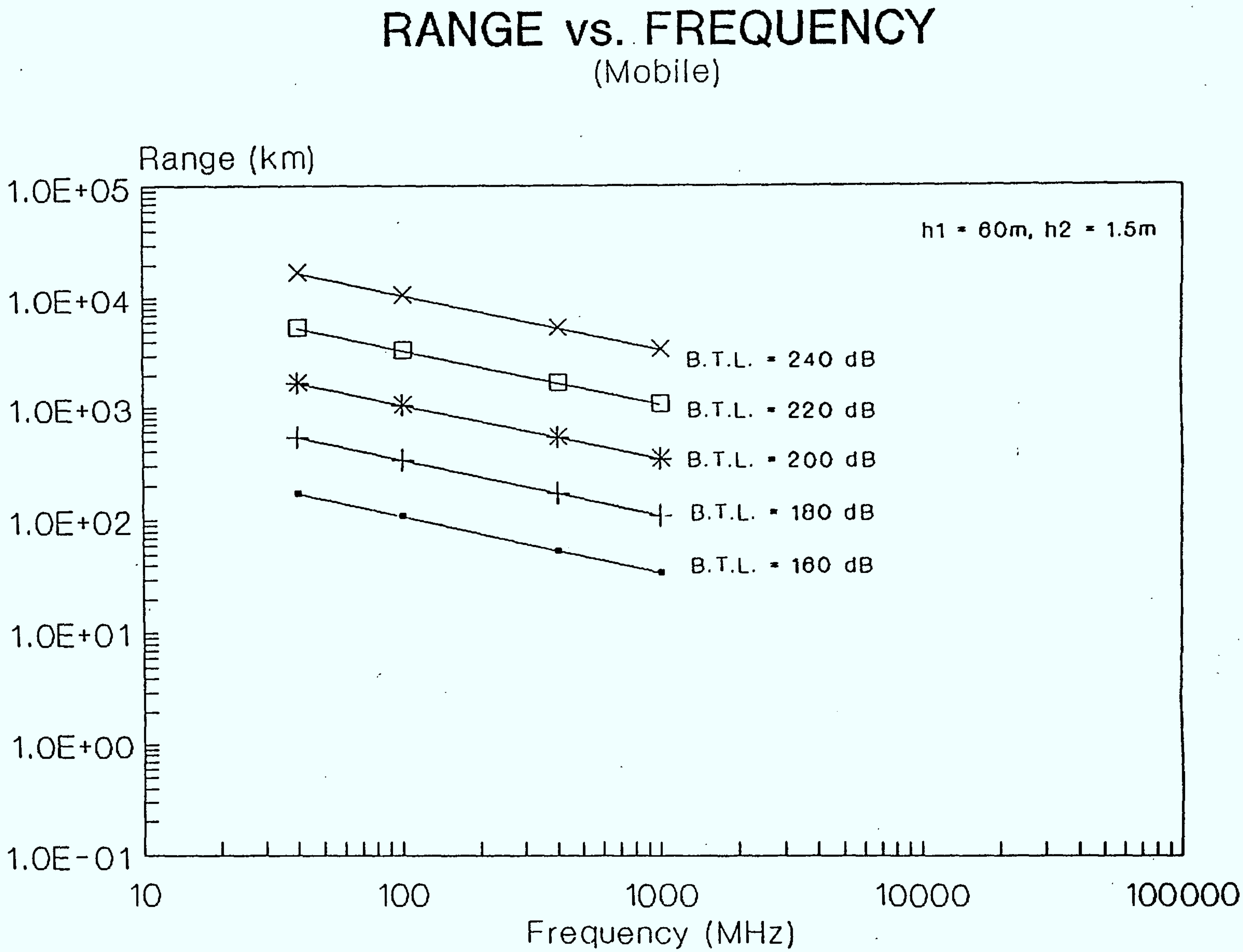

Fig. 2.10 Communication range as a function of frequency for different B.T.L. in urban areas (including free space loss).

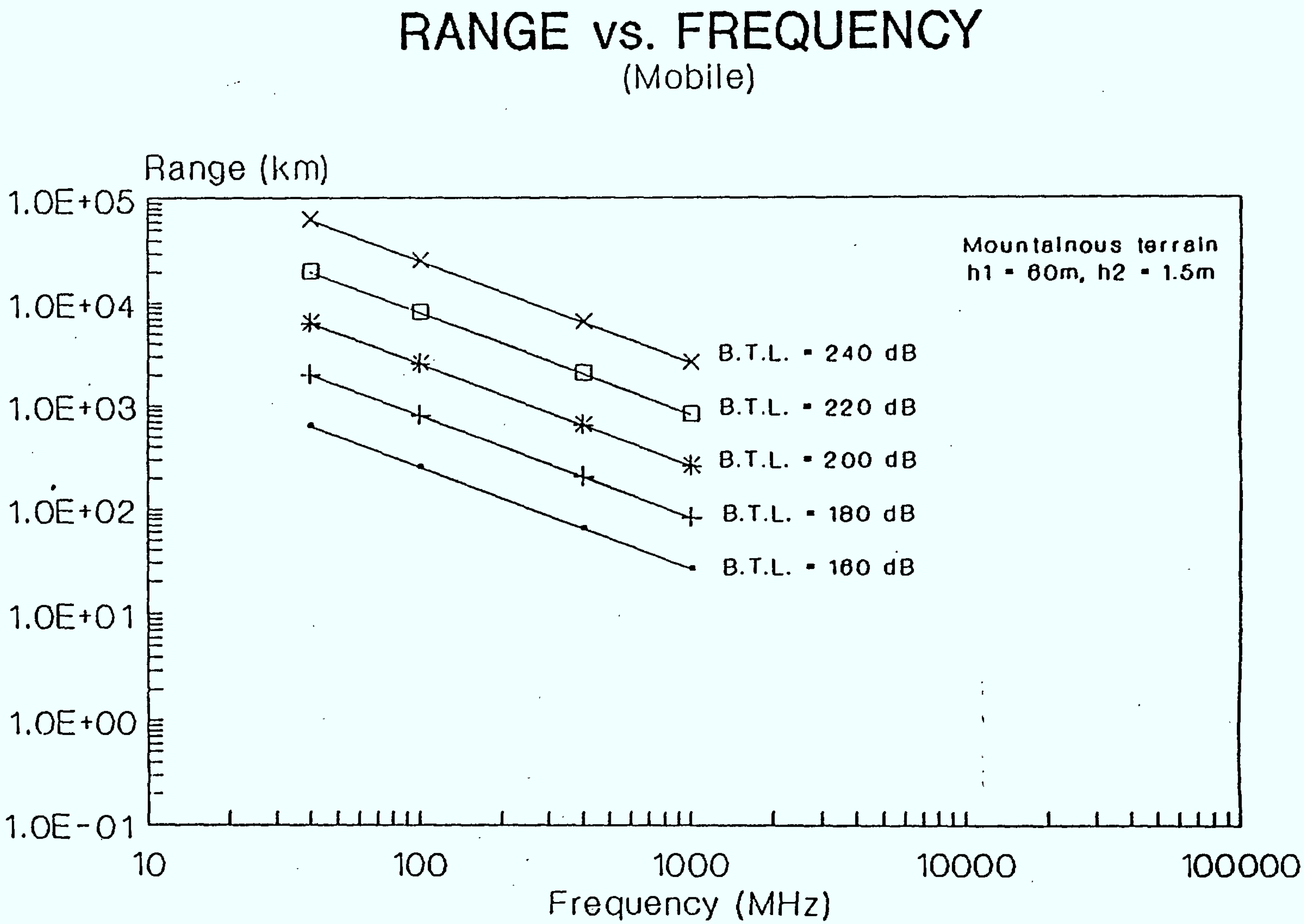

Fig. 2.11 Communication range as a function of frequency for different B.T.L. due to free space and rural areas (mountainous terrain).

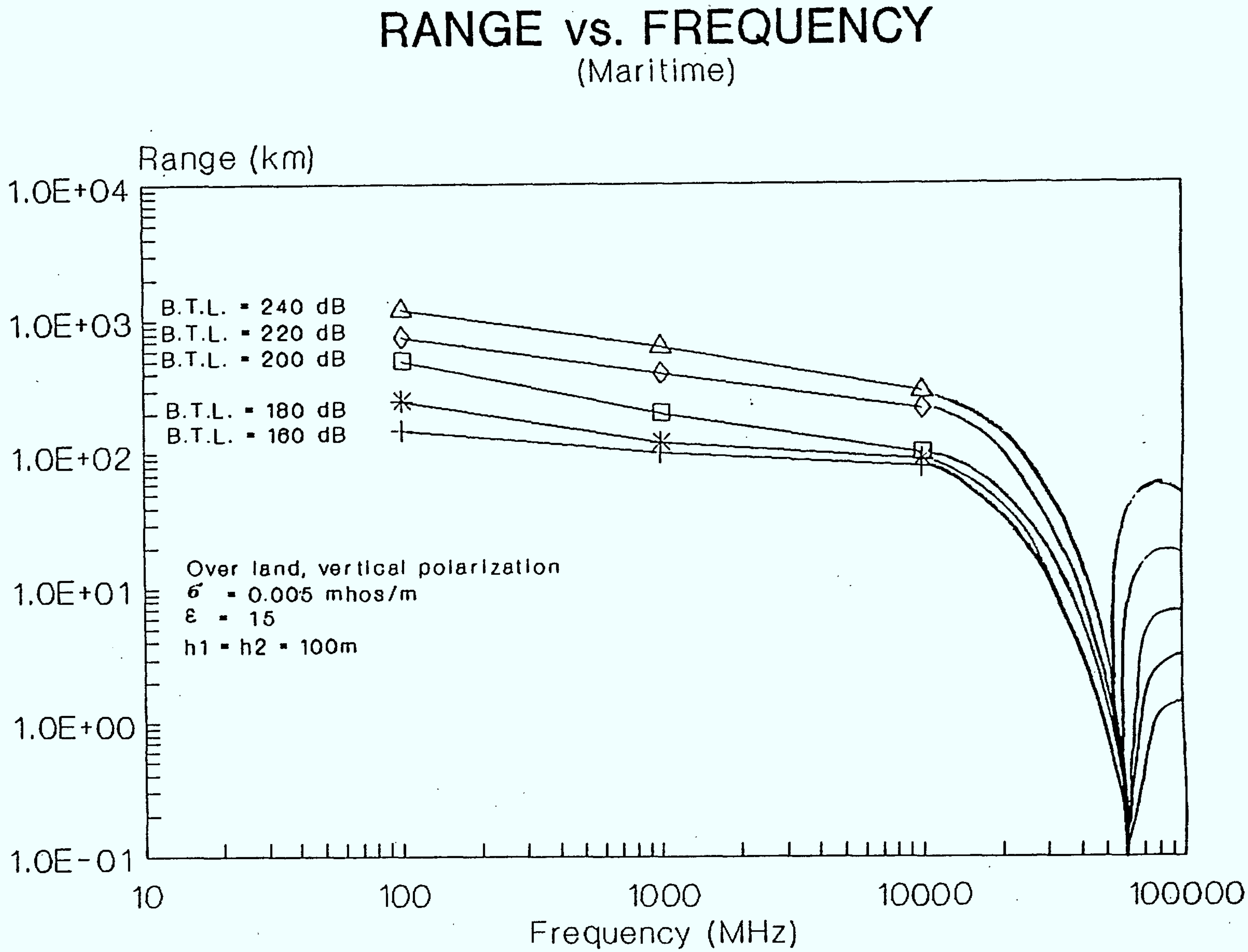

Fig. 3.1 Communication range as a function of frequency for different B.T.L. in propagation over smooth earth.

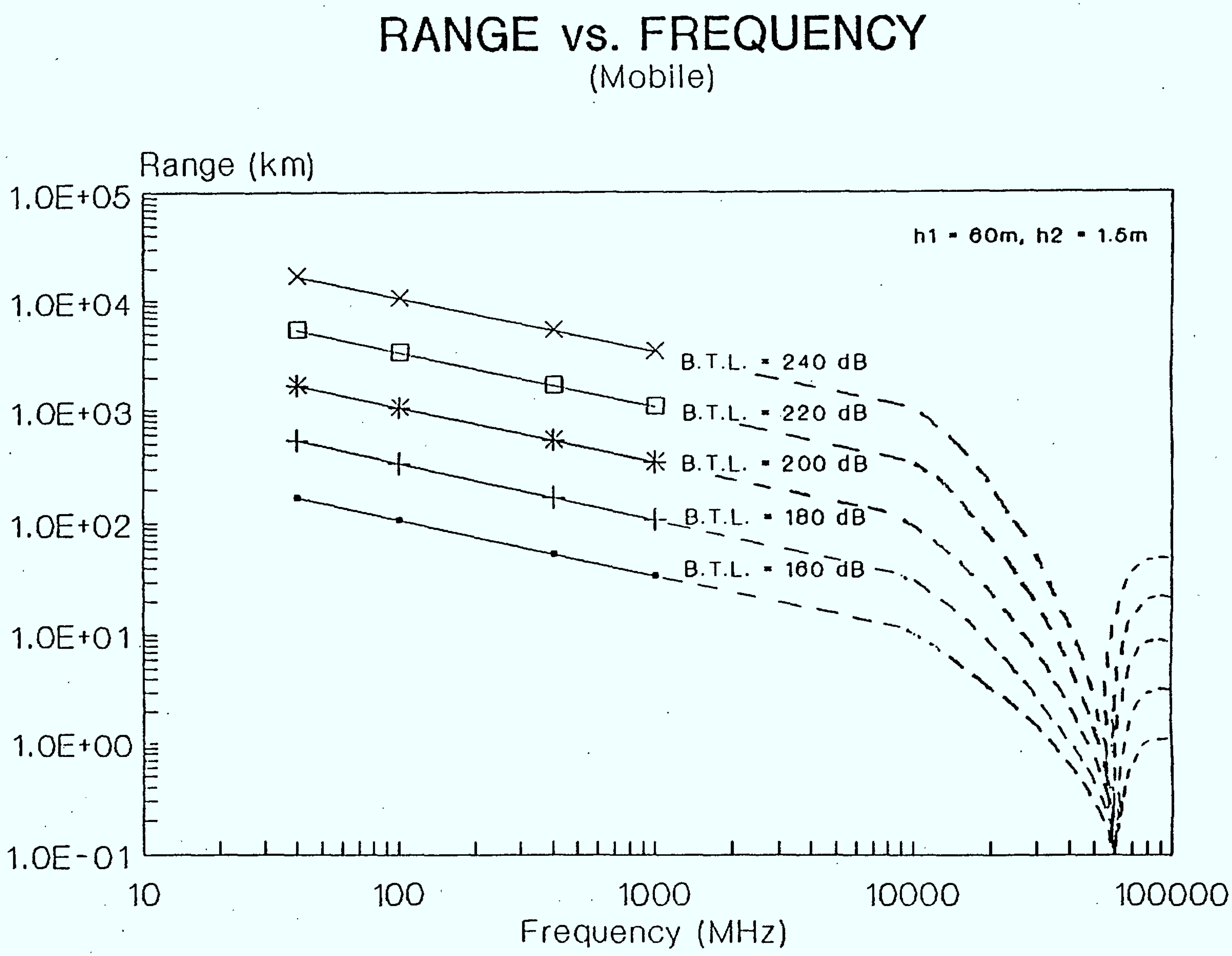

Fig. 3.2 Communication range as a function of frequency for different B.T.L. due to free space, urban areas, rain, and gas absorption.

RANGE vs. FREQUENCY
(Outdoor Personal Communication)

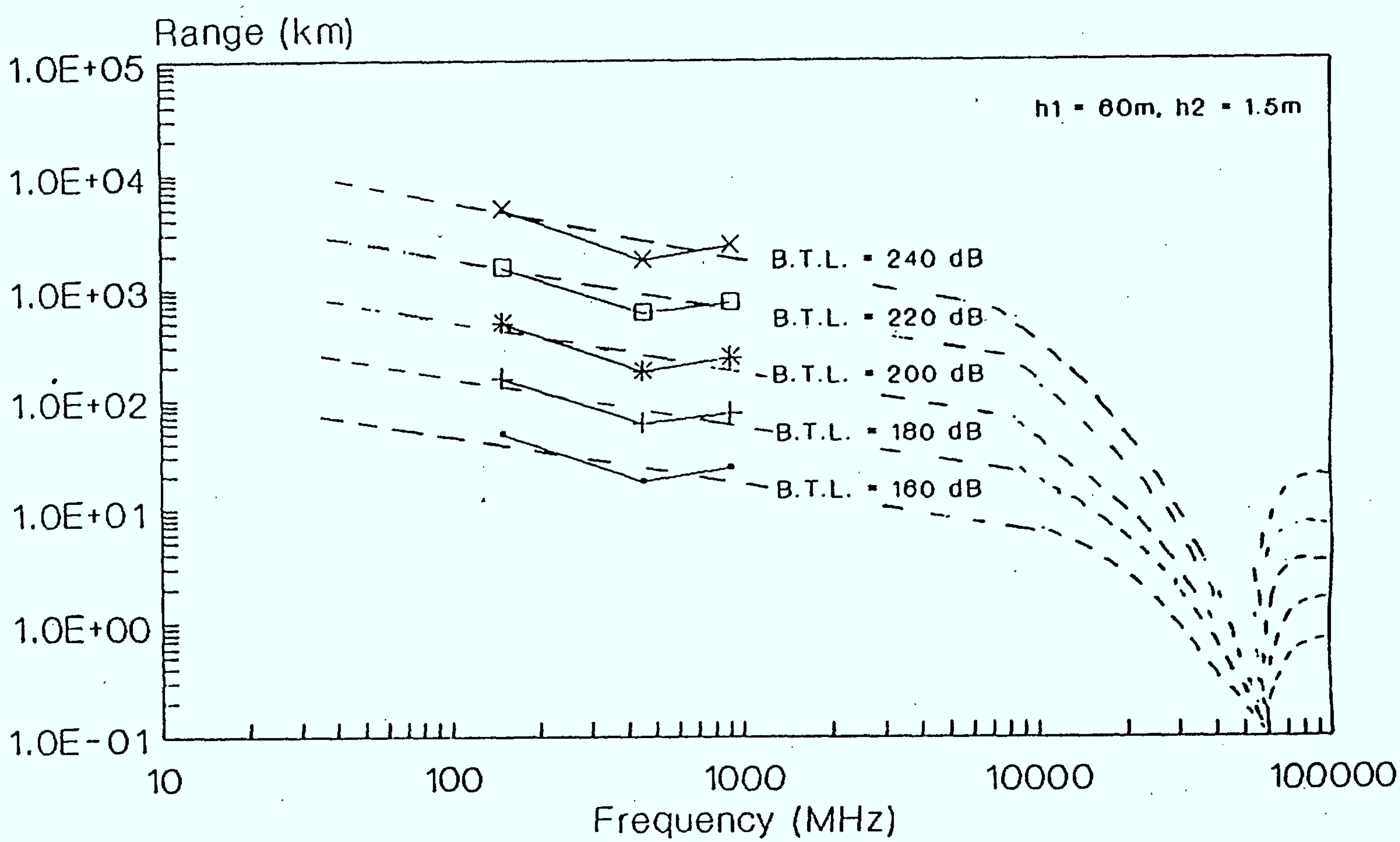

Fig. 3.3 Communication range as a function of frequency for different B.T.L. due to free space, urban area, body effect, rain, and gas absorption.

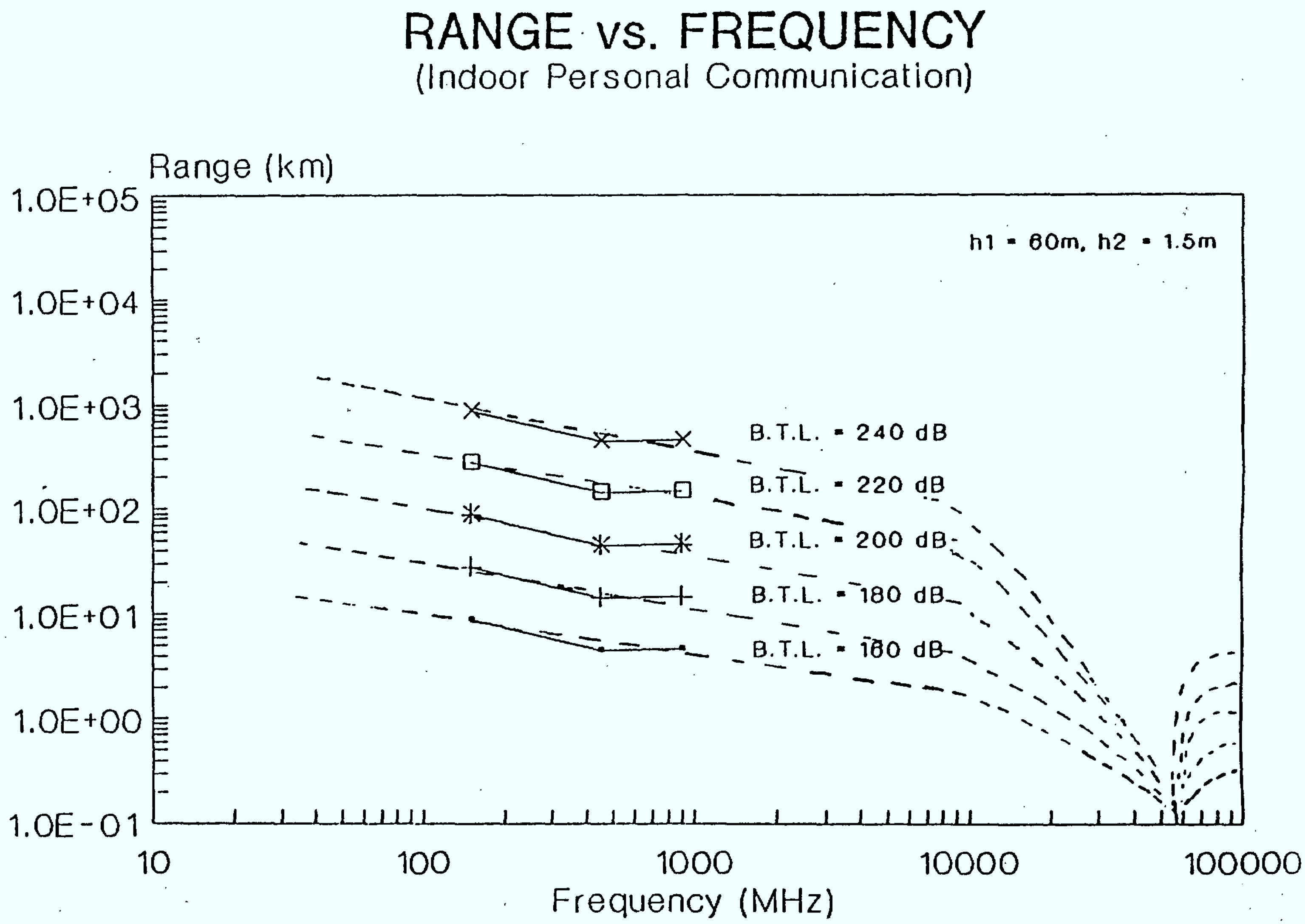

Fig. 3.4 Communication range as a function of frequency for different B.T.L. due to urban areas, building penetration, body effect, rain, and gas absorption.

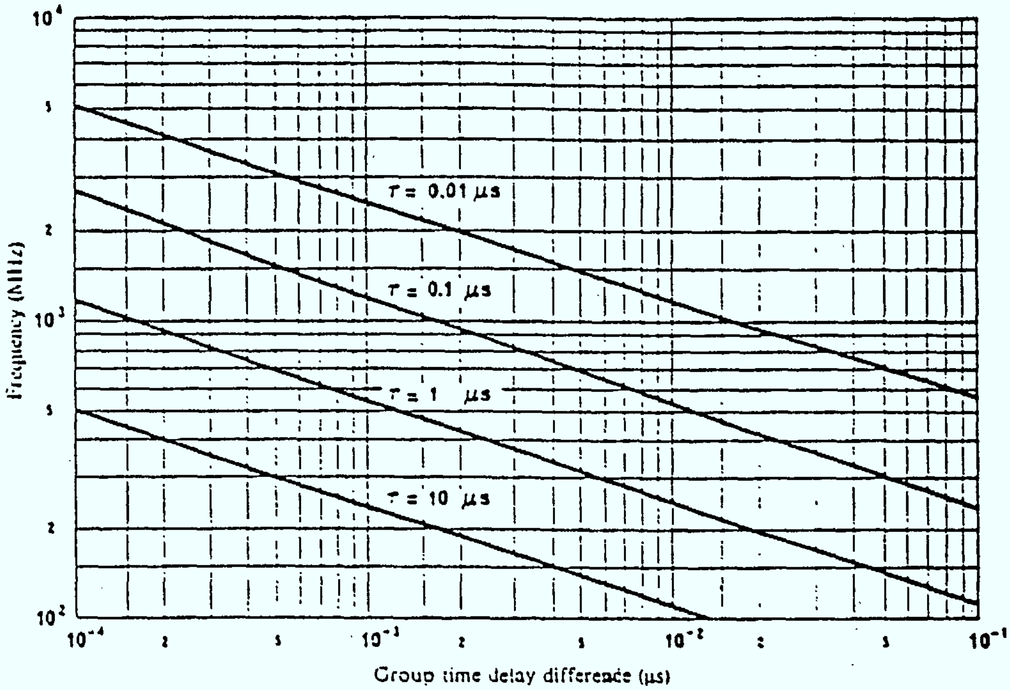

Fig. 4.1 Difference in the time delay between the lower and upper frequencies of the spectrum of a pulse of width transmitted through the ionosphere, one-way transmission path [Millman, 1967]

$\int n_e ds = 5\times10^{17} \text{electrons/m}^2$

τ : pulse length

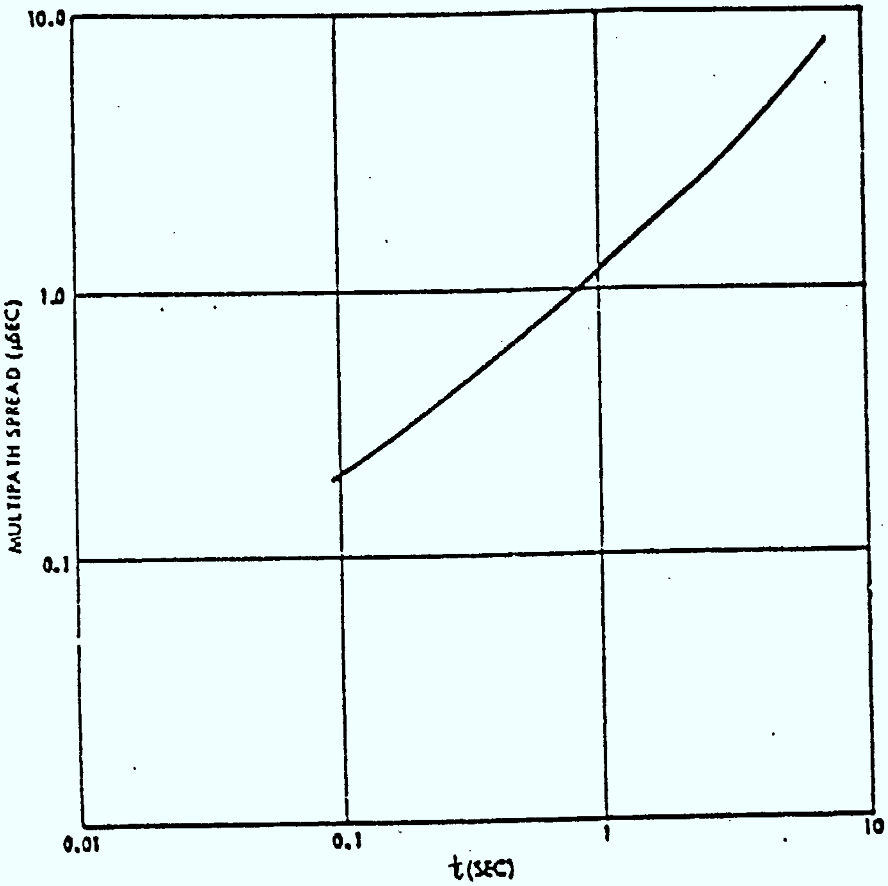

Fig. 4.2 Time dependence of multipath spread at VHF frequencies.

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ANNEX G

CHARACTERISTICS OF THE PROPOSED CELLULAR FOR NORTH AMERICA

ANNEX G

Characteristics of the proposed digital Cellular Standard for North America

A.1 Introduction

This annex provides a short summary of the main features of the proposed digital cellular standards in respect to technical requirements for spectrum observation centres. The proposed standard is based upon sub-division of the existing 30Khz analogue channels using the time division multiplexing. Channelization scheme at the 30Khz level is identical to that of existing analogue cellular systems. The mobile elements of the system may be operable in a dual mode, providing both analogue capability or working into conventional analogue sites, and a TDMA digital capability working in city areas, partially or fully transmitted to digital operation.

A.1.1 TDMA structure

In the TDMA mode, the 30KHz channel is divided into 25 frames per second in which each frame is subdivided into 6 slots. Within a frame, 2 slots may be allocated to a user for the full rate service, and 1 slot for a half rate service. The full rate service will provide an effective 13Kbits gross data rate which after error correction will provide 9.6Kbits of data or 9.6Kbits code excited linear predicted digital voice. A half rate service will provide a 4.8Kbit data, and eventually a 4.8Kbit digital voice technique.

In the forward direction from the base station, time slots are contiguous. Each comprises 162 symbols which, through the use of offset QPSK modulation, provides 324 databits. In the reverse direction from mobile to base station, each mobile transmits 1 slot at the time with a guard time interval of 3 symbols, approximately 75 micro seconds, and a ramp time of 3 symbols, at so of 75 microseconds, is allowed at the beginning of each slot.

The guard time of 75 microseconds is sufficient that timing adjustment is unnecessary in a range of approximately 20 miles.

A.1.2 System Features

The system is centrally controlled from the base station. Mobile frequency and timing is derived from the forward transmission from the base station. The transmitter power of each mobile is controlled in 4dB steps over a range of 7 steps. The power used by the mobile is under direct control of the base station.

A.1.3 Protocols and Procedures

Signalling protocols, synchronization words, etc. are fully defined in telecommunications industry association standard TR45-3 [ref. 1.3c].

A.2 Digital Cellular Standard proposed for Europe

A.2.1 Introduction

The standards proposed for the Pan European GSM system are structurally similar to the proposed North American Standard (see Annex B1) but are substantially different in the actual parameters used. The differences are summarized below:

	North America	GSM
Frequency band (base)	869-894MHz	935-960MHz
Frequency band (mobile)	824-849MHz	890-915MHz
Duplex separation	45MHz	45MHz
RF carrier spacing	30KHz	200KHz
# Duplex RF channels	4832	124
Peak ERP (base)	300W	300W
Average ERP/ch	100W	37.5W
Nominal mobile station power, pk	1.8-9W	2-20W
Nominal mobile station power, avge.	0.6-3W	0.25-2.5W
Assess Method	TDMA	TDMA
Traffic channels/carrier full rate	3	8

Traffic channels/carrier half rate	6	16
Transmission rate	48.6Kbps	270.833Kbps
Full rate speech codec	8Kbps CELP	9.8Kbps RPE.LTD
Adjacent channel rejection	TBD	18dB
2nd adjacent channel rejection	TBD	50dB
Modulation	OQPSK	GMSK
Delay spread equalization	60Msecs	20Msecs

A.3 **Digital Cellular Standard proposed for Japan**

A.3.1 Introduction

Whilst closely similar to the North American standard, many parameters have still to be defined. The significant known differences are:

	North American	Japan
Frequency band (base)	869-894	810-830Mz (1.5GHz tbd)
Frequency band (mobile)	824-849	940-960 (1.5Ghz tbd)
Duplex separation	45Mhz	130Mhz (48 at 1.5Ghz
Transmission rate	48.6Kbps	37 to 42Kbps
RF Carrier Spacing	30KHz	25 interleaved 50KHz