Chapter 2

What are FPLMTS?

FPLMTS will be networks operating in a frequency band near 2GHz, aimed at providing mobile telecommunications at anytime, anywhere [FPLMTS]. It is intended that these systems could begin to be used around the year 2000. Realistically, commercial service is expected to be widespread around 2005.

FPLMTS, a collective term for a number of different systems, have been studied in the ITU-R (International Telecommunications Union radio communications sector) by TG8/1 (task group 8/1) since 1990. In Europe there will be a FPLMTS entitled UMTS (universal mobile telecommunications system) which is being developed in ETSI (the European Telecommunications Standardisation Institute) under the co-ordination of SMG5 (special mobile group 5). UMTS has aligned itself with the objective of FPLMTS and feeds information into ITU-R TG8/1. UMTS is intended to be the European standard for FPLMTS and will be the successor to GSM (the Global System for Mobile communications) throughout the European Union. FPLMTS have become collectively known as third generation mobile systems to distinguish them from second generation systems (digital systems such as GSM, IS-54, IS-95 and PDC) and first generation (analogue) systems. To further confuse terminology, ITU-R has considered renaming FPLMTS as IMT-2000 (International Mobile Telecommunications 2000) to reflect more accurately what a third generation system is hoped to be. Still, FPLMTS is the term that is most internationally recognized at this time and is the name the ITU International Frequency Regulatory Board used when allocating frequency bands to these systems. It is therefore the term used throughout this thesis.

At this time, SMG5 has defined network management principles [ETR05-01], network inter-working principles [ETR03-01] and a framework for satellite integration [ETR12-01]. In these network aspects SMG5 is ahead of work in TG8/1 which has concentrated on establishing the basis for evaluating radio air interfaces, ready for choosing air interfaces in the next few years.

The aggressive schedule for completion of FPLMTS recommendations and standards is:

• Fully specified all network protocols	1997
• Completed ITU-R recommendations and European standards	1998
• First services	2000
• Market acceptance	2005.

During the past 10 years, customers have been strongly attracted to the new freedom that mobile communication provides. This trend is expected to continue, accelerated by a reduction in the cost of providing mobile communications and an improvement in the overall quality of mobile communications service. FPLMTS will be designed to handle and encourage the much larger mobile traffic intensity that is anticipated in the early part of the 21st century. By this time it is expected that over half of all calls will terminate at one or both ends on a mobile terminal. New applications will also be developed to join voice telephony as customers' main requirements. To give network operators the flexibility to provide network capacity where customers demand, one of the new concepts embraced by FPLMTS is the integration of the communications facilities offered by current cordless, cellular and mobile satellite systems. In the past, each of these has been designed to satisfy a particular communication need in an efficient manner, with no facility for the customer to roam between the different types of system and little attempt to provide a consistent platform able to interface with applications other than voice telephony. Customers must carry different equipment to use telephone facilities under different conditions. Operators have had to support applications in different ways on different systems, complicating the porting of new applications such as facsimile and video between communications platforms.

2.1. Cordless, Cellular and Mobile Satellite Systems

The distinction between cordless, cellular and mobile satellite services came about for very good reasons of economy. Cordless technology is inexpensive because it is designed for a friendly radio environment in which it needs only limited facilities. Cellular telephones are more expensive because of the extra technology required to offer telecommunications service in more hostile radio environments, such as to motorists moving at speed. This includes a supporting network capable of in-call handovers. Mobile satellite systems have been more expensive still, because their low capacities mean that a small number of customers bear the cost of supporting an expensive specialist network, compared to terrestrial mobile systems.

There is a need to offer a telephone capable of offering all three types of service, matching network infrastructure to customers' needs rather than to the restrictions of the particular technology chosen. Very small cells, traditionally the domains of cordless telephones, are well suited to home or office where most telephones reside for most of the time. Once the telephone is moving with its owner, larger cell systems supporting automatic handover between cells of varying size are essential to maintain acceptable service whilst moving in urban areas or along major traffic routes. However, terrestrial cellular radio is not economic in rural areas where the telecommunications traffic is too low to justify the expense of a cell-site that can only serve an area of radius 35km at most. There low capacity, wide coverage mobile satellite systems can ensure that telecommunications services are always available, albeit at a premium price.

2.2. FPLMTS

For customers, it will be the application of a terminal (voice telephony, facsimile, Internet data, remote control, video conferencing, etc...) that is the important feature. The communications channel is merely a utility, provided by the service provider, that the terminal uses. FPLMTS terminal equipment will often be embedded in the application's equipment in the same way that a power supply is included as an integral part of an electrical appliance. The capabilities of the terminals will vary, not only because of the different communications requirements of different applications but also because manufacturers will want to limit the number and complexity of air interface specifications they implement in their products.

In developing FPLMTS one aim is to enable a single terminal to have the flexibility to access networks combining the cordless, cellular and mobile satellite range of services. Across the globe there are likely to be numerous air interface specifications designed to FPLMTS recommendations. In any market, service providers will favour a subset of the possible alternatives and FPLMTS terminals will be designed to match customers' needs more closely by supporting just those communications environments that the customer wants to use. The most inexpensive terminals will implement a FPLMTS air interface to allow communications through a base station of the customer's choice in the home or office - a very limited range and unable to handover to other base stations. Such terminals will be ideally suited to replace extension telephones in people's houses or for bulky terminals that are unlikely to be moved whilst in operation. At the other extreme, highly mobile FPLMTS terminals will provide service with pico-cell base stations in their home and office and enable people on the move by public transport to use micro-cell base stations on trains, aircraft and buses, macro-cell base stations in urban areas and satellite base stations in rural areas. Terminals offering service in the full range of environments and to a multitude of different air interface specifications will be more expensive to produce than a cordless only terminal.

FPLMTS' most important feature will be a uniform core network architecture that allows all of these terminals to offer the same services consistently in all the radio environments for which they are capable. The result of effective integration of all these radio environments will be to make FPLMTS flexible, supporting all manner of applications. In many ways FPLMTS will be analogous to the mains power supply - all manner of appliances, from cookers through to video and audio equipment to computers and games, can share the same supply. Because one supply of electricity serves all applications the cost of supplying electricity is much less than it would be if each appliance needed its own unique variety.

2.3. UPT and the IN

INs (intelligent networks) [HUBER, SHARP] offering UPT (universal personal telecommunications) [F.850] services will be a familiar feature of telephony around 2005 and will include mobility features as part of the core network's signalling system. Personal mobility services will then be available to all varieties of access technology, through fixed PSTN (public switched telephone network) telephones to second generation cellular systems and FPLMTS.

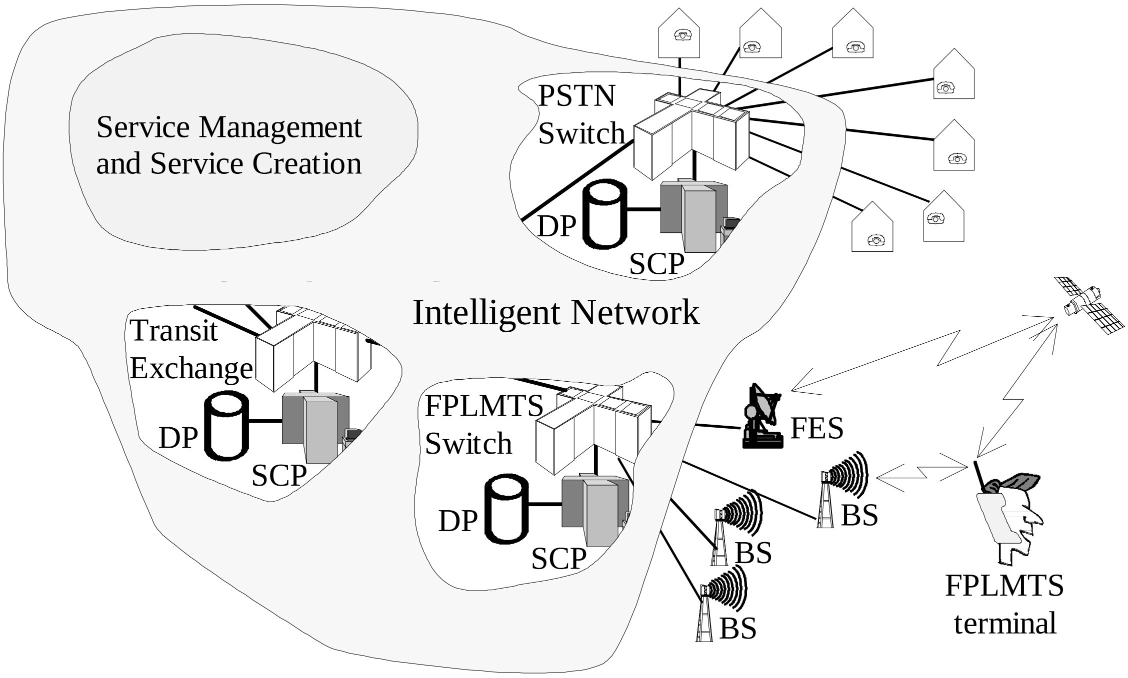

Figure 2 The scope of the IN and its relationship with FPLMTS

The specification of the IN's CS2 (capability set 2) and CS3 are combining the facilities of CS1 and the functionality of mobility management such as GSM's MAP or IS-41. It is possible, therefore, that in-call handover will become an IN service feature rather than a mobile network feature [BROEK, MASON], enabling FPLMTS to be a pure access technology and perhaps endowing the fixed PSTN and first and second generation cordless access technologies with the facility to manually "hand over" calls between network access points. Figure 2 illustrates the IN as the physical and logical connections between switches such that the FPLMTS switches need no interconnections except those provided by the IN. Since FPLMTS terminals and base station (BS) equipment would functionally interface with the SCPs (service control points), these can also be considered to be intrinsically part of the IN.

Note that there is another scenario that foresees FPLMTS being available before intelligent core networks have developed in many markets. In this scenario, each FPLMTS would contain the intelligence for mobility and the core networks would act as dumb transit networks without flexible mobility functions. This is how today's GSM networks, themselves each an intelligent network, work with older PSTN networks. Problems such as tromboning are suffered as a result. Tromboning is the extension of the communications link through the home network of the customer, even if the customer is roaming in coverage of another network thousands of kilometres away from their home network. This has to be done in current systems because the core transport networks are often built on networks without the SS7 (signalling system 7) facilities necessary to ask home network databases for the location of the roaming customer without setting up a call to them. A call to a mobile terminal has a number that any PSTN can recognize and route as a call to the mobile's home network. The home network then sets up another call to the customer's terminal on the network it is roaming in and connects the two calls together, as in figure 3. This often results in the traffic channel being routed through two international links even when the calling party is in the same country as the roaming customer.

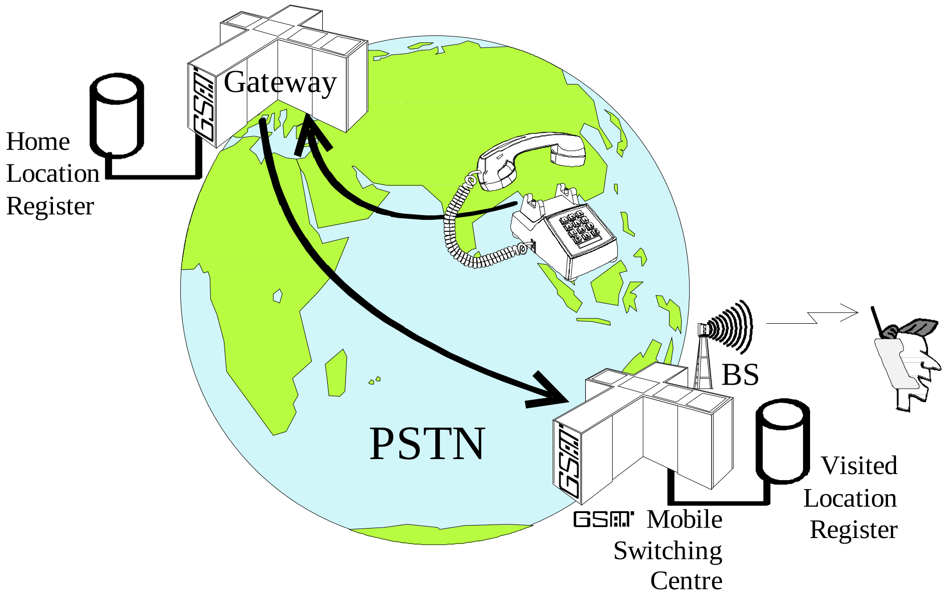

Figure 3 Tromboned call routing in GSM

A more efficient call routing would be that shown in figure 4, where the call is routed by an IN SCP near to the originating terminal and the SCP queries the appropriate databases before connecting the call by the most efficient route. Data on a customer's location and service profile is available through any SCP from the distributed database, with the SCP making appropriate connections to find the information at a service level rather than the call switching level having to search for it. Second generation networks, such as GSM, are evolving to solve such problems. GSM Phase 2+ may overcome these problems with Camel (customized application for mobile enhanced logic) [SMITH] and optimized routing by the time FPLMTS networks are launched.

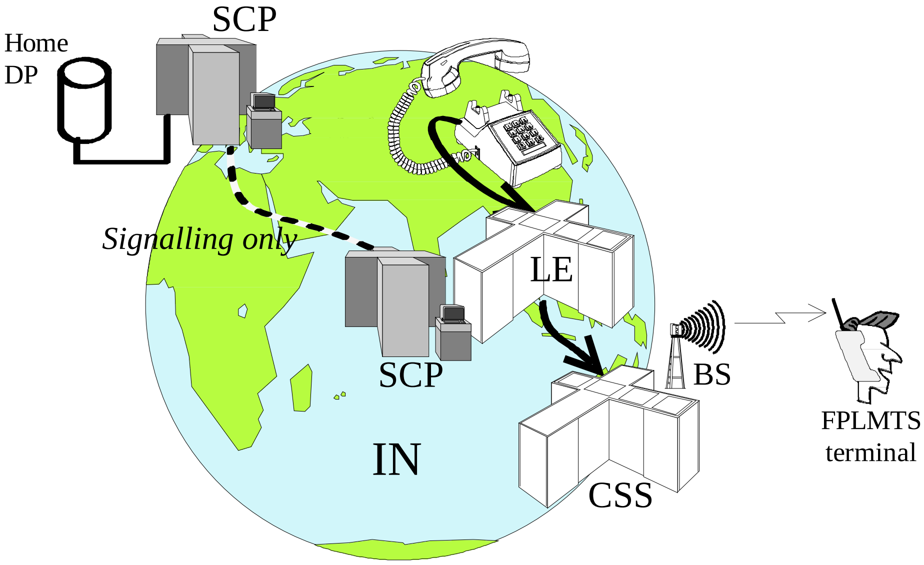

Figure 4 Direct mobile call routing with Intelligent Networks

Assuming that an IN approach is adopted [SG11-Q6/11], a CS3 can be envisaged where a customer or his/her terminal simply requests "log me on to this access point" to the IN core model SCP to direct the customer's services to the new access point and logs the customer out of the previous access point, *transferring any active calls to the new access point*. Not only does this provide customers with common facilities across numerous types of access technology, it brings mobility closer to the fixed network and allows customers to (manually) transfer a live call from any fixed telephone to any other fixed telephone or even to a mobile telephone as they leave their desks for the car-park.

FPLMTS' niche therefore is the access technology that enables the customer to carry the same telephone from his/her desk out to the car without interrupting the telephone call, which is why the integration of mixed-cell technologies is essential to FPLMTS' success. Figure 5 illustrates this distinction.

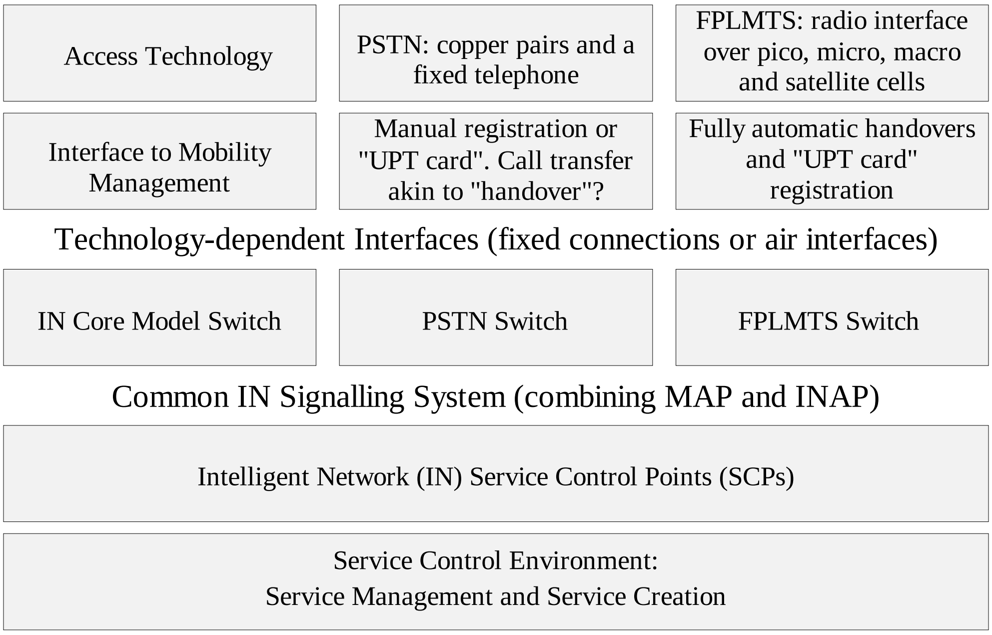

Figure 5 Network layers illustrating the relationship between the IN, FPLMTS and PSTN connections

2.4. Multi-Tier Air Interfaces

Around 2005, the brand new FPLMTS products will have to distinguish themselves from second generation mobile access technologies in the voice telephony market purely on the basis of value for money, voice quality and coverage. There is also considerable scope for improving support for applications across different communications environments and providing higher data rates in pico and micro cells. UPT will tend to obscure other differences such as numbering and customer mobility between systems.

Considering efficiency and coverage, best practice will still be to optimise air interfaces by having cells of varying size and shapes that are tailored to offer capacities matched to the expected traffic from a given area. Second generation practice has been to use different systems for small cells (DECT, CT-2 or PHP) to those used for larger cells (GSM, IS54, IS95 or PDC). FPLMTS will harmonise the services provided in these different environments (see chapter 8) but there is good reason to use a multi-tier system to handle the huge variation in communication capacity demanded in different environments [CHIA2].

2.4.1. Pico-Cells

Pico-cells will be the usual, inexpensive means by which people communicate through FPLMTS, just as most people prefer to use a fixed or cordless telephone in preference to a cellular telephone at present. People strategically place pico-cell base stations where they will conduct most of their telephone conversations, such as at home and at work.

Because of the amount of traffic it is anticipated that pico-cells will carry, it is wise to use the structure of the rooms containing the mobile terminals to limit radio interference to neighbouring pico-cells, allowing maximum re-use of radio resources. These short-range, low power radio links can be isolated by very short distances inside building structures, allowing large amounts of radio resource to be useable in each room and the same radio frequencies can be re-used without interference only a few hundred metres away. In this environment, 2Mbit/s communication links to mobile terminals are economically viable and the radio environment is very friendly with only slow movement and fading from wall reflections. Coverage is very well tailored to the "fixed" communication needs of users.

2.4.2. Macro and Micro Cellular

Cellular traffic demand should result from the unpredictable movements of users on the move, not of users at home or in their offices. Figure 6 illustrates[1] an example of the density of total satellite + macro + micro-cell offered traffic. It excludes pico-cell traffic because if it were included in figure 6 it would show the density of population living and working in each area, not their mobile communications requirements.

Most of this traffic is concentrated in relatively confined urban areas where it can be best served by terrestrial cellular radio, using the smallest cells where the offered traffic is the most dense. Nearly all of this traffic would be served by a combination of micro and macro cells. Micro cells tend to differ from macro cells by the way that they are shaped using buildings and highly directional antennas to isolate them from neighbouring cells, often requiring very rapid handover at street corners, for example. Macro cells tend to maximise radio coverage, rather than minimise it, to capture the lower density offered traffic outside population centres.

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[1] Figures 6 and 7 show example traffic densities within a satellite spot beam offered to different parts of FPLMTS. The vertical axes show some measure of offered traffic per unit area on a non-linear scale. "Cordless" traffic handled by pico-cells is excluded. The satellite spot beam is circular, of approximately 1700km diameter and centred near to London. It is approximately the same size as Odyssey and Globalstar spot beams (see chapter 4) and the same size as the baseline LEO satellites'. Traffic densities shown are to illustrate this discussion only and are not based on real data - they are the author's illustration based on areas of high population density.

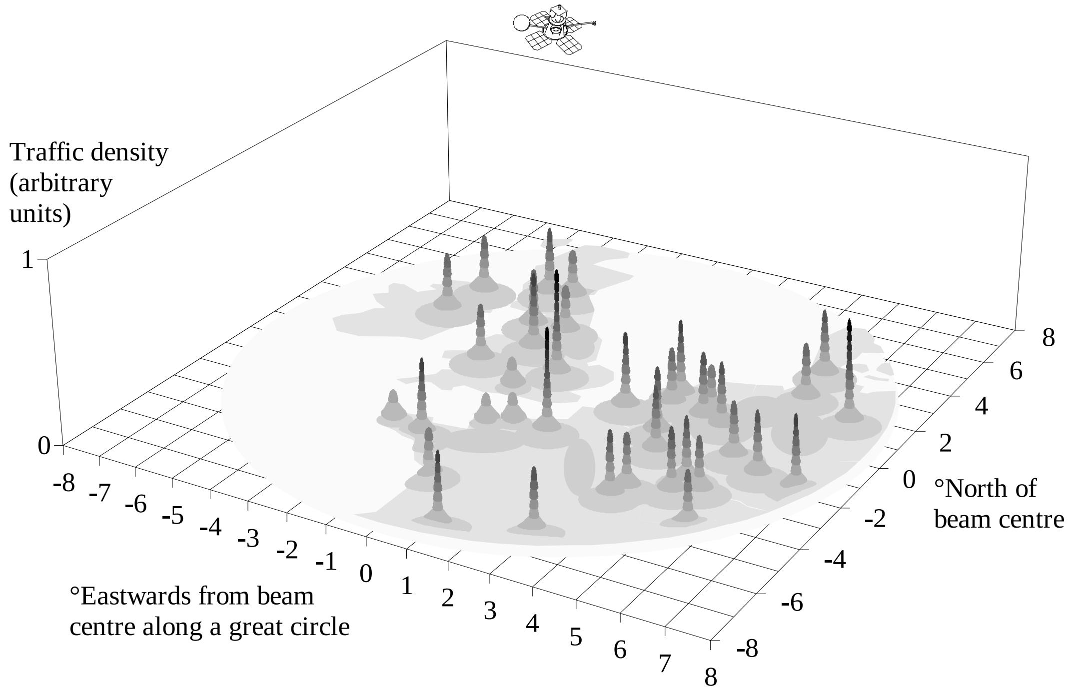

Figure 6 Distribution (not to scale) of UMTS traffic offered to micro, macro and satellite cells within a satellite beam of diameter 1700 km covering part of Europe

2.4.3. Satellite Coverage

Because satellite spot beams cover such huge areas, there is less radio resource reuse in satellite systems than in cellular radio where resources can be reused only a few tens of kilometres away. In a satellite system with spacecraft antenna of manageable proportions, radio resources cannot be reused for hundreds of km around a mobile terminal. This is why the capacity of the satellite system will be so limited and why if the coverage area is so wide, the acceptable offered traffic density must be very low. Terrestrial mobile networks must handle the high density traffic leaving only the terrestrially unserved rural traffic for the satellite to handle, as shown in figure 7. Note that this figure shows almost no traffic demand from urban areas, since ideally the terrestrial network is carrying all the high density traffic. This must be the case, because the peak total traffic densities of figure 6 are many orders of magnitude greater than the traffic densities outside terrestrial coverage in figure 7. The micro-cells' capacity is two million times greater than the satellite beam's traffic capacity, based on the relative areas of 1km diameter micro-cells and the 1700km diameter satellite spot beam and assuming similar power and bandwidth resources are available in each radio environment. Satellite spot beams can be made smaller than this but they will still be larger and less spectrally efficient than their terrestrial counterparts[2].

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[2] Teledesic (see chapter 4) proposes 3,000km^2 spot beams, comparable in area to large macro-cells. Interference is, however, much greater outside of a satellite spot beam than it is outside of a macro-cell because the roll-off of gain in a satellite antenna pattern is r^{-2}, compared to a roll-off of $r^{-3.5}$ in radio propagation along the Earth's surface. The greater interference power levels reduce the opportunity for frequency re-use, reducing system capacity in a given bandwidth.

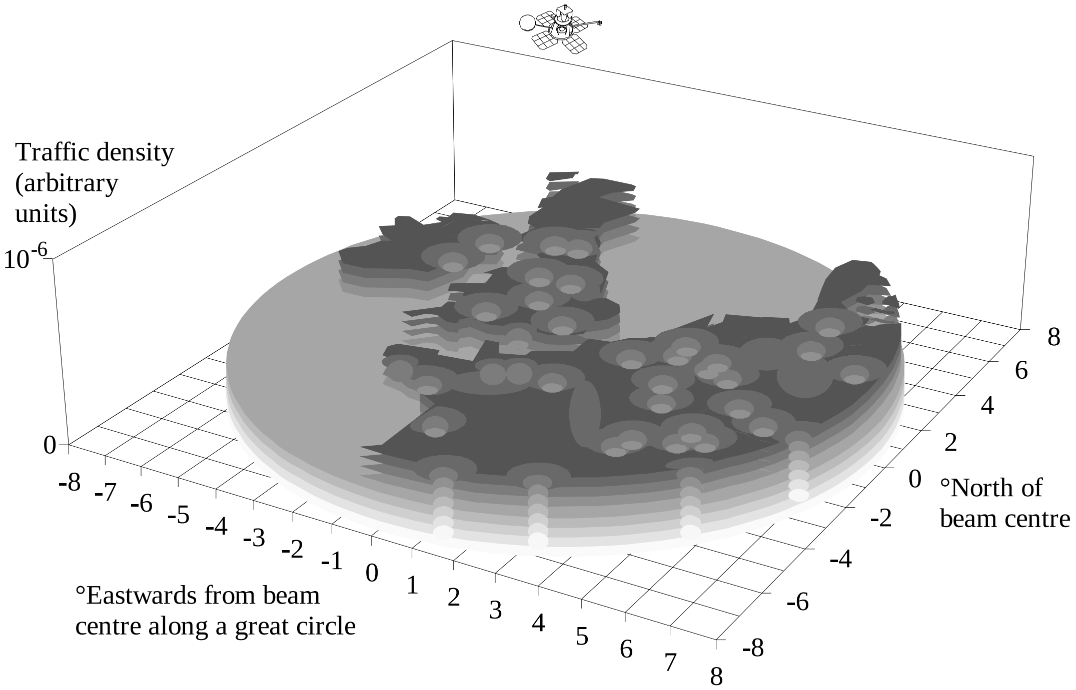

Figure 7 Distribution (not to scale) of traffic offered to a FPLMTS satellite within a spot-beam of diameter 1700 km in Europe, assuming effective terrestrial coverage of all high density traffic

The satellite spot beam is intended to cover a very wide area, often spanning several countries, with a relatively small number of channels. Its ability to do this depends on the terrestrial network's ability to remove most of the traffic, leaving only a low density of users scattered outside terrestrial coverage who rely on satellites for service (compare figures 6 and 7).

2.4.4. Selection of Network and Air Interface

In order for a multi-tier air interface system to function effectively as a whole, each terminal should normally use the smallest cell with which it has radio contact. The mobile terminal determines this for itself. Whilst it is idle it scans for the broadcast paging channels of terrestrial cells and satellites. These channels allow the mobile to rapidly identify the various terrestrial cells and satellites from which it can receive service. In general, the terminal will have to select base stations in the following order of preference:

1. pico-cells,
2. micro-cells,
3. macro-cells,
4. satellite coverage.

It could be that the terminal can receive the broadcast channels of more than one network of the same cell type, in which case the customer's service profile, programmed into the terminal by the service provider and customer, may help to choose the preferred network to work with.

Once the terminal decides which network to use it transmits a request to the base station to register itself and its users on that network (see section 6.1) so that incoming calls can be routed to it and it monitors the paging channel to listen for them. If the terminal subsequently moves and loses the paging channel it will scan for new broadcast channels, select a new base station and register with that. The new base station automatically cancels the mobile's registration from its old base station. Terminals capable of communicating by more than one air interface specification will be capable of monitoring the registered paging channel whilst scanning for other base stations at the same time. This will enable them to find more suitable base stations as they move into coverage and register even though reception of the old paging channel is still adequate. The customer then benefits fully from the terminal's multiple air interfaces by always being registered with the cell providing the best service at the lowest cost.

If a call is started, it is set up with the network to which the terminal is registered at the time. If, during the call, the mobile terminal moves out of range of the base station it is communicating with it needs to hand over to another one. In FPLMTS the terminal will again be able to scan for broadcast channels of other base stations whilst communicating the application's information with its current base station. Using the same criteria as above it will select the best link and if it is not the same as the current one it will initiate handover even if the current link is satisfactory. Handovers are always "forward handovers" in that the mobile terminal transmits the handover request to the new base station and the new connection is usually made before the old one is broken.

The automatic selection of the most efficient cell type is very important to achieve the very high capacities that FPLMTS are designed for. There will be exceptions to the small-is-best rule, described in greater detail in section 3.4:

- Fast moving terminals in vehicles moving at high speed should avoid small cells with which their connection will only last for a short time. If there is a pico-cell moving with the vehicle (on a public train or aircraft, for example) then that should be used. Also if the vehicle is stationary then a pico-cell or macro-cell from outside could be an efficient choice.
- Customers with special needs for rapid connection and channel robustness, such as the emergency services, may have a preferred type of connection under all circumstances.

2.5. Satellite Service Bandwidths

Is 2Mbit/s going to be available in all UMTS environments? It is evident from the wide area covered by an individual spot beam that geographic reuse of spectrum in a satellite system is much less than that achievable in terrestrial cellular, which is in turn much less than that achievable in indoor pico-cell environments. This, combined with the link power requirements for longer radio paths, means those data rates available through satellite access need to be scaled down appropriately. The conditions in which service will be available will also vary depending on the mobile terminal's environment.

To better understand the restrictions, power budgets for a LEO (low Earth orbit) and a GEO (geostationary Earth orbit) satellite system (see sections 4.2, 4.3 and 4.4 for more details) are presented and compared with a terrestrial macro-cell. In determining the important parameters for the link budget, only the mobile terminal to satellite part of the link is detailed. For the backhaul link, from the fixed Earth station to the satellite, there is the opportunity to use much larger antennas on the ground. These are used to ensure that the backhaul link parameters are non-critical. The link budget figures are indicative of the technology available in 1995 that could be applied to satellites in FPLMTS and illustrate the limiting factors in satellite communications:

- large path losses
- high satellite antenna gain
- limited satellite power for downlinks
- limited mobile terminal power for uplinks
- tight link margin requiring line-of-sight or near-line-of-sight communication with the satellite.

2.5.1. Path Loss

Maximum free-space path losses for satellite communications are orders of magnitude greater than those for terrestrial cellular radio. Table 1 compares such losses.

	Path length		**Path loss** (at 2GHz)	
Cell type	**minimum**	**maximum**	**minimum**	**maximum**
Terrestrial macro cell (32km diameter) †	0km	16km	0dB	123dB
769km altitude LEO satellite	769km	3,225km *	156dB	169dB *
GEO satellite	35,786km	41,679km *	190dB	191dB *

* to 0° elevation

† all path losses, including terrestrial, are calculated using the theoretical 2nd order power law

Table 1 Path losses for some types of FPLMTS cell

Actual path loss in a terrestrial cell is greater, somewhere between a 3rd or 4th order power law. Taking the free-space comparisons at face value, transmissions for GEO satellite links would have to be 68dB more powerful than those for terrestrial links. To reduce this dissipation, large antenna gains are sought at the satellite.

2.5.2. Satellite Antenna Gain

Satellite antenna gain depends on the effective area of the antenna which also directly determines the size of spot beams formed by the satellite. A realistic approach is therefore to determine the maximum spot beam area expected in third generation mobile satellite systems and deduce the required antenna gain from this.

The 769km altitude LEO satellite, chosen as the LEO baseline for this thesis in chapter 4, has 6 spot beams across its footprint's diameter. This satellite has antenna beams with -3dB beam widths of 20° in at least one diameter. The maximum -3dB semi-major axis can be the entire width of the satellite cell, which is 123°. The area of this spot beam on the ground will be a 4,200km×700km ellipse of approximately 2,300,000km^2. The circular spot beam shown in figures 6 and 7 is the same area, to give an impression of scale. To allow for a good overlap between beams the area within the -3dB contour is increased to 2,500,000km^2. Assuming efficiency comparable to a reflector antenna, a circular beam of this area around the sub-satellite point can be created with a very small, lightweight antenna of gain as low as 6dBi.

A satellite in GEO would have to use 2.7° beam width circular beams produced by a 4m diameter reflector antenna to provide beams of the same area on the ground. The antenna's gain would be about 36dBi. Note that the 30dB increase in gain over the LEO does not quite compensate for the 34dB difference in path loss experienced in the link. Since (gain × path loss) is a critical figure in the link budget, this is plotted as a function of orbital altitude in figure 8. (Gain × path loss) turns out to be almost constant, as would be expected, except for the LEOs and MEOs (medium Earth orbits) where the range of path lengths causes (gain × path loss) to deviate more from the mean.

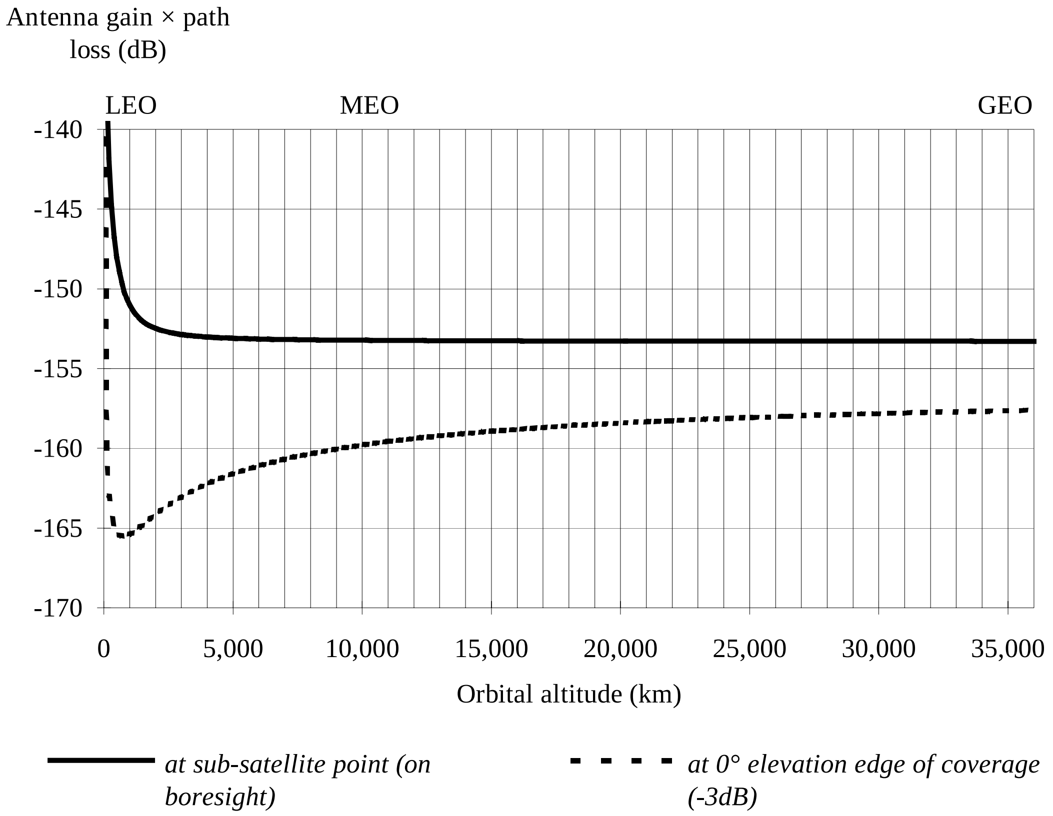

Figure 8 (Satellite antenna gain × path loss), in dB, as a function of orbital altitude for circular 2,500,000km^2 beams at 2GHz

The minimum and maximum (antenna gain × path loss) values both correspond to the 769km altitude LEO and are -166dB and -150dB respectively. By comparison, when a terrestrial cell is divided into six 60° sectors the cell site antenna gain is around 17dBi, resulting in (antenna gain × path loss) = -106dB at 16km from the cell site. This figure is therefore up to 60dB better than for satellite links.

2.5.3. Satellite Power for Downlinks

The other key parameter in the downlink power budget is the power available from the satellite transponder. The limitation is the power that can be generated from the solar array and the power that can be stored in batteries whilst the satellite is eclipsed from the Sun. Available DC power is therefore a function of the size of the solar arrays but it is also a function of the orbital altitude since the lower the orbit, the faster the eclipse cycle will occur. The faster cycling of the battery charge shortens the life-span of the batteries and lowers their charge capacity. Hence the higher the satellite orbit, the more power that is likely to be available from a given satellite bus mass. Furthermore, higher altitude constellations would contain fewer satellites than low altitude constellations and therefore more investment can be made in each of the fewer satellites. Hence larger satellites are feasible and larger batteries and solar arrays can be used, further increasing the available DC power.

The above arguments indicate that the 769km LEO will have the lowest power generating capability. Using 1995 technology GaAs solar arrays, nearly 1.5kW of power can be provided on such a satellite whilst the arrays are illuminated [IRIDIUM]. Using NiH_2 batteries to even out the supply and subtracting the power used by other satellite sub-systems, the communications payload is left with approximately 250W for its power amplification. If 50W is used for the backhaul to the base station and 200W is used for the mobile terminal downlink then about 33W is available for each of six spot beams. With a 50% efficient TWTA (travelling wave tube amplifier) the average saturated transmit power will be 16.7W, about 12dBW.

A TWTA can only be driven to saturation if all the frequencies that it is transmitting have been derived from a single coherent frequency source, otherwise the non-linear transfer characteristic causes intermodulation to occur between different frequency components. Thus a single TDMA (time division multiple access) carrier will not suffer from intermodulation but a number of FDMA (frequency division multiple access) carriers sharing the same TWTA would. CDMA (code division multiple access) carriers also suffer from intermodulation effects but these manifest themselves as a noise level increase so the de-spreading process overcomes the interference with a small cost to channel capacity. Where intermodulation would be a problem the signal input to the TWTA is backed off the non-linear saturation point. Fortunately the resultant loss in output power from the TWTA is not really significant at only 1 to 2dB. Other measures such as pre-distorting the TWTA input to compensate for the non-linearity or using constant-envelope modulation schemes that are tolerant to intermodulation effects can successfully be used to maintain full power output [AGHVAMI]. It can therefore be safely assumed that the full saturation output power, 12dBW per spot beam, will be available.

Finally, combining the transmit power, satellite antenna gain and path loss, we can compare the power budgets for example terrestrial, LEO and GEO cases, as shown in table 2. The same power output per spot beam is used for GEO and LEO satellites because although a GEO satellite may be able to generate more DC power, it will be using the additional power to handle more spot beams in its wider coverage footprint. A comparison of the powers available at the mobile terminal reveals a difference of nearly

50dB between LEO and 32km diameter terrestrial cells. Note that C/N_0 is for the combined carrier powers in the whole spot beam.

	Terrestrial	**LEO Sat**	**GEO Sat**	
Cell Site				
Carrier power per spot beam	3 *	12	12	dBW
Transmit antenna gain	17	6.1	36.3	dBi
Pointing loss	-3	-3	-3	dB
Radio Paths				
Free space attenuation	-123	-168.6	-190.9	dB
Atmospheric attenuation	-0.6	-0.6	-0.6	dB
Fading margin	-40 †	-40 †	-40 †	dB
Hand Held Terminals				
Pointing loss	-2	-2	-2	dB
Received power at mobile	-148.6	-196.1	-188.2	dBW
Hand held terminal G/T	-32.6 ‡	-32.6 ‡	-32.6 ‡	dB/K
Downlink C/T	-181.2	-228.7	-220.8	dBW/K
1/Boltzmann's constant	228.6	228.6	228.6	dBHzK/W
Downlink C/N_0	47.4	-0.1	7.8	dBHz

Note - this C/N_0 is the combined carrier powers for the whole cell sector or spot beam.

* Terrestrial cell-sites are not power limited, so this could be much greater. However, best practice is to limit effetive radiated power to 100W for the largest cells and to much less than 100W for smaller cells to limit cell diameters and avoid interference with other cells.

† This 40dB includes margin for log-normal fading, required to alleviate shadowing with multipath [LEE].

‡ Comprises whip antennae gain of 2dBi, noise temperature of 290K and 10dB noise from receiver front-end.

Table 2 Comparative downlink power budgets for terrestrial, LEO and GEO cell sites to mobile terminals at the edge of cell coverage with no interference

2.5.4. Mobile Terminal Power for Uplinks

The uplink transmit power is very restricted for hand held terminals, directly affecting the size, weight and time for which the terminal can operate between recharges. Lower power terminals will therefore be much more convenient for the customer to carry and to use than higher power terminals. We will assume 200mW average power output for a hand held terminal as a maximum that can reasonably be achieved using current technology aimed at a mass market. Combined with a whip antenna of 2dBi gain, the effective radiated power will be -5dBW. Table 3 compares the uplink power budgets to terrestrial macro-cell sites, LEO satellites and GEO satellites. The difference between C/N_0 for LEO and terrestrial macro-cell sites is again high, this time nearly 60dB. The C/N_0 values here are for single carriers.

	Terrestrial	**LEO Sat**	**GEO Sat**	
Hand Held Terminal				
Individual carrier power	-7	-7	-7	dBW
Transmit antenna gain	2	2	2	dBi
Pointing loss	-2	-2	-2	dB
Radio Path				
Free space attenuation	-123	-168.6	-190.9	dB
Atmospheric attenuation	-0.6	-0.6	-0.6	dB
Fading margin	-40 †	-40 †	-40 †	dB
Cell Site				
Pointing loss	-3	-3	-3	dB
Received power at cell site	-173.6	-219.2	-241.5	dBW
Cell site G/T	-17.6 ‡	-28.5 ‡	1.7 ‡	dB/K
Uplink C/T	-191.2	-247.7	-239.8	dBW/K
1/Boltzmann's constant	228.6	228.6	228.6	dBHzK/W
Uplink C/N_0	37.4	-19.1	-11.2	dBHz

† This 40dB includes margin for log-normal fading, required to alleviate shadowing with multipath, and margin for Rayleigh fading [LEE].

‡ Comprise antennae gains as for downlinks, noise temperature of 290K and 10dB noise from receiver front-end.

Table 3 Comparative uplink power budgets to terrestrial, LEO and GEO cell sites from hand held mobile terminals at the edge of cell coverage with no interference

2.5.5. Link Margins

Tables 2 and 3 show link budgets for line of sight, free-space propagation links and no interference other than thermal noise. A cellular radio system is interference limited and so a margin is also required to ensure that signal detection remains possible in the midst of interference from other channels during fades and shadows. The worst-case fade margin is equally applicable to satellite and terrestrial communications if the same ranges of blockages and fading environments are to be accommodated.

For digital cellular applications, best practice is to not add any fixed margins. Instead power control is relied on to overcome propagation difficulties as and when they arise. There is no reason why this technique should not be used for FPLMTS' space segment as well. Allowance must be made for the slower speed of response of the control loop on the satellite link compared to a terrestrial link due to longer propagation delay.

It will not be possible to follow the multipath fading pattern from non-GEO satellite orbits as a terrestrial base station could. A terrestrial power control loop's range includes some 40dB to fill in fast fades. The satellite loop's range would also have to include the same 40dB of margin but instead of always using minimum power just sufficient to overcome the instantaneous fade depth, a satellite power control loop would use the minimum power necessary to overcome the worst fade depth expected in the period of the closed loop time constant. This means that there is an increase in mean transmit power from the mean fade depth to the maximum fade depth, a difference of approximately 30dB [LEE].

Terrestrial cellular systems have enough power range to ensure that they are capable of providing sufficient power to overcome propagation difficulties for good in-building coverage. In bridging the 60dB gap between terrestrial and satellite paths the margin available to overcome such propagation difficulties is likely to be reduced to the bare minimum. This is unfortunate, as it means that satellite coverage is not as complete as terrestrial coverage would be in built-up or mountainous regions since gaps are found behind objects obstructing a direct line of sight to the satellite. Satellite propagation studies show the need for a minimum of 7dB margin even for just direct line-of-sight communications with a satellite, primarily due to multipath fading from the ground reflection from a satellite at low elevation [FITCH]. If the line-of-sight radio path cannot be guaranteed then the margin must be increased to about 16dB [IRIDIUM] to stand a good chance of acceptable communications through multipath reflections. Even at these levels of margin, the probability of successful communications would not be as high as that with terrestrial cellular networks employing margins of 40dB or more.

Two approaches, which may be used together, can improve depth of coverage and service availability. The first is to include a permanent fade margin, the second is to rely on satellite diversity to evade radio shadows. Satellite diversity, where signals through two satellites are combined, is very similar to terrestrial macro-diversity and satellite constellations can be designed to maximise the chances of having multiple satellites visible to mobile terminals (see sections 4.2.2 and 6.5.5). Inevitably the penalty of reducing link margins to the level where the satellite link is feasible will be to require the customer to participate in setting up and maintaining a call connection by positioning the mobile terminal antenna in a satisfactory position.

Note that the link budgets above have assumed the worst case path losses for 0° elevation. In practice, 10° elevation figures would be adequate, since satellite constellation designs tend to ensure that one or more satellites will always be above a minimum elevation such as this. The difference in path loss between 0° and 10° elevations for the 769km LEO is a useful 3.3dB margin.

2.5.6. Effect on Service of the Satellite Power Budget

Without a detailed satellite design, the figures derived here are only for indication of the order of magnitude of differences between satellite and terrestrial radio links and what compromises will be required to realise satellite links to hand-held mobile terminals. The observations are:

- Power received at the mobile terminal from a LEO satellite could be up to 50dB lower than from a terrestrial cell. If a satellite is supporting about the same number of mobile terminals per spot beam as a terrestrial cell, then each terminal's signal will be 50dB lower from a satellite than from a terrestrial cell site.
- Power received at a LEO satellite will be up to 60dB lower than that received at a terrestrial cell site from the same mobile terminal.

There is scope to build future satellites with greater power generation capacity to increase downlink power. Also, a mobile terminal could claim more of the satellite's power resource for its radio link to allow a better radio link at the expense of other mobile terminals sharing the satellite resources. In these ways the downlink bit rates could be increased for applications requiring asymmetric bearers with greater capacity to the mobile terminal than from it. The uplink power can also be increased but only at the expense of terminal portability.

The effect of this tight power budget on satellite access will be:

- Service into buildings and heavily shadowed areas will be very restricted. It is likely that a high margin will be reserved for paging channels and customers will need to move to a clearer radio environment (outside or close to a window, for example) to connect their call.
- Bit rates will have to be much less than terrestrial cellular bit rates to raise E_b/N_0 above the Shannon limit.

These unfortunate effects will restrict the quality of service available from satellite systems. FPLMTS needs to be designed to cope with these limitations - no amount of marketing hype can improve the link budget. Figure 9 compares the data rates expected to be available to a hand-portable terminal in pico-cell, micro and macro-cell and satellite radio environments[3]. It shows clearly how service bandwidth scales with environment, assuming similar power and bandwidth resources are available in each environment. The same frequency spectrum shared over a larger area and number of customers means that each customer gets fewer kbit/s.

Figure 9 reflects bandwidths achievable in 1995. The UMTS Task Force recognizes that available bandwidth will vary with the terminal's environment. It aims to use technology advances to push the bandwidth/cell radius line up, increasing micro-cellular bandwidths to 2Mbit/s and increasing cellular and satellite bandwidths tenfold by the launch of UMTS in 2005 [UTF].

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[3] Figure 9 is based on capabilities of services in development for launch in the next five years, including 2Mbit/s radio LANs, 28.8kbit/s on GSM, 9.6kbit/s on Iridium, 2.4kbit/s on Ellipso-II, amongst others. These all fall on a line close to the expected proportion, that $\mathit{Throughput}^2 \propto \frac{1}{\mathit{Cell\ radius}}$.

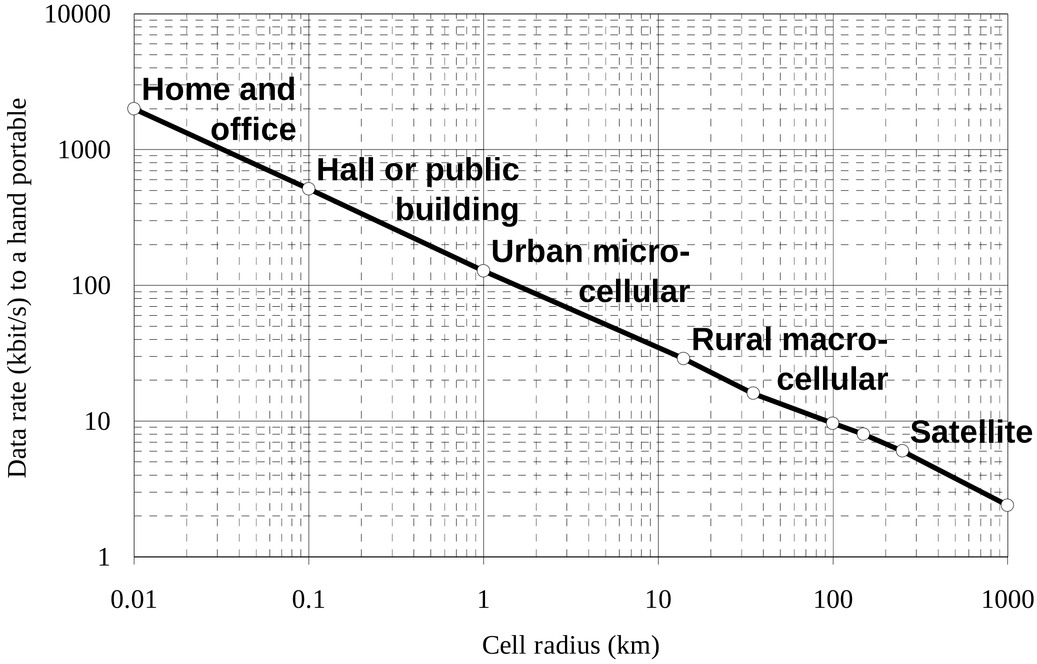

Figure 9 Anticipated data rates available to a hand-portable FPLMTS terminal in different radio environments

Given the large range of data rates shown in figure 9, for FPLMTS to support applications in all environments applications will either need to assume a lowest common denominator of FPLMTS service facilities or adapt to the varying service conditions. This may mean that the application in a terminal will have to vary its bit-rate depending on which FPLMTS environment it is using for communications. This will be discussed in detail in chapter 8.