Chapter 3

Role of Satellite Access

With manufacturers and customers choosing the air interface specifications their terminals work with and with satellites promising such low bit rates and link robustness, the role for satellite access in future mobile networks has to be clearly identified. This chapter clarifies the exact role of satellites in a mass market and suggests some more facilities required in all FPLMTS to support this role for satellite access.

3.1. Coverage of Rural Areas

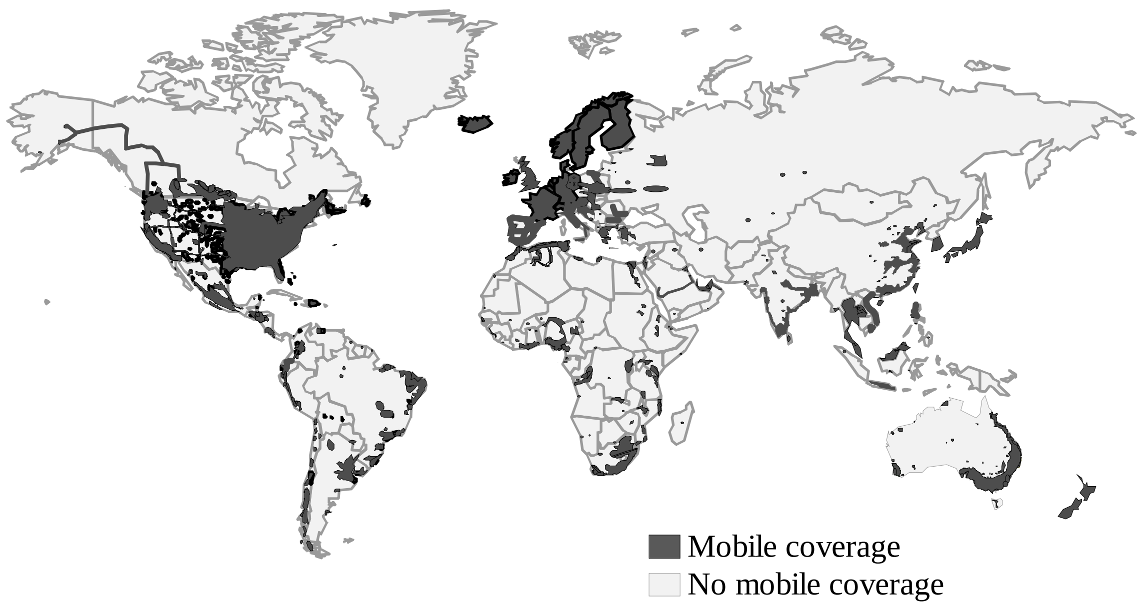

Figure 10 Estimate of cellular network coverage by 2000

Already second generation cellular offers seamless coverage and very advanced services in key markets such as the UK. Here, it is hard to envisage a great deal of use being made of the satellite component of fully developed FPLMTS and it is tempting to imagine it being an optional extra for use whilst abroad. However, in large countries such as Canada and Australia extending the coverage to vast rural areas is very important. In Australia the first and second generation cellular systems will only cover 3% of the country’s area, though this equates to 84% of the population. Integral coverage of the remaining 97% of the country is seen as an important feature of FPLMTS. For third generation systems to be truly global, bringing the mass-market benefits of scale, the needs of largely rural countries must be satisfied. Figure 10 shows just how much of the globe is still waiting for any type of affordable mobile communications[1].

3.2. Guaranteeing Roll-out FPLMTS Coverage

Even in densely populated countries, such as the UK, an integral satellite component could be used to provide complete geographical coverage from the very first day of FPLMTS operation. This would ensure that even the first users of the system would be welcomed to a service with uninterrupted coverage superior to that offered by the second generation systems, rather than inferior as would be the case if satellite facilities were not available. By 2005, a target date for third generation systems becoming operational, second generation systems will be well established across Europe and embryonic FPLMTS would benefit greatly from being at a competitive advantage with coverage rather than being at a disadvantage. Thus even in western Europe, the satellite component would be an invaluable feature for encouraging uptake of the new service. The terrestrial networks will develop and spread as the market grows to handle the bulk of the traffic more efficiently, concentrating terrestrial high capacity cells where the market demands. Satellite coverage will depend on frequency spectrum for the satellite component being available at the same time as spectrum for the terrestrial parts of FPLMTS and on licensing agreements being in place in each country. This has been recognized and WRC '95 brought forward the allocation of satellite FPLMTS spectrum from 2005 to 2000, the same date as the rest of FPLMTS' spectrum becomes available.

3.3. In-fill for Low Density Population Areas

A permanent role for satellite service will be to fill in the gaps in terrestrial coverage that cause customers to complain. Rural cell sites are sometimes built simply to fill in gaps of an otherwise completely covered region to ensure that customers' calls are not dropped as they drive away from major roads. The increased coverage is beneficial to the perceived quality of the operator's service but the call revenue generated through these cell sites may not be enough to justify their expense on its own. Expanding terrestrial networks to cater for calls in rural areas can be uneconomic in that the revenue generated by the small number of calls does not offset the estimated US$½ million cost of equipment for each cell site[2]. In rural areas the revenue generated is low because there are so few customers there. Despite the lack of return, their provision has normally been necessary in first and second generation systems to ensure that customers are not faced with blocked calls too often. Anything above a 3% probability of a call being blocked is regarded as endangering customers' perceptions of the service being reliable.

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[1]Figure 10 shows regions where cellular networks are expected to be operational by the year 2000. Source: ICO Global Communications.

[2]The US$½ million figure is a very rough estimate of the average cost of the physical infrastructure for a GSM base station [MOBEURO]. It excludes planning costs and the cost of renting the antenna site which vary from site to site but often nearly double the whole-life cost of the base station. Note that with the move to remote transceivers in second generation systems the cost is becoming much less than this but then there are also transmission capacity costs to be included.

Satellites' most obvious role is blanket rural coverage, so FPLMTS' integration of satellite facilities is potentially an opportunity to dispense with uneconomic terrestrial cells and support the "overflow" of traffic using satellite links that, in many cases, will be a more economic use of resources. In the knowledge that the FPLMTS space segment is providing this, it will be possible for terrestrial network planners to avoid building loss-making cells just to ensure seamless coverage. An assumption was introduced in section 2.4.4 that whenever terrestrial channels are available, these will be used leaving the satellite segment free to carry only the low density rural traffic. This makes frugal use of the scarce satellite resource and ensures that customers are always using the most economic channel available to them.

The following sections discuss this theme and aim to determine how large an impact a satellite capability can make and what precautions are required to use this approach effectively.

If most customers choose satellite compatible telephones then uneconomic terrestrial cell sites are not needed because customers would be handed over to the satellite segment whenever leaving terrestrial coverage. In this case, the integration of FPLMTS' satellite segment will have a clear benefit to offer terrestrial network operators by ensuring good continuity of the FPLMTS service and high customer confidence in its use, whilst allowing the terrestrial network planners to concentrate only on serving the profitable, high density traffic areas.

3.3.1. Impact of Cost on Satellite Usage

These benefits depend on the majority of customers being capable of using satellite facilities. This will depend on two things:

- the price of the FPLMTS satellite-compatible mobile terminal (section 3.3.2) and
- the cost of using satellite communications (section 3.3.3).

Both of these will be compared with the FPLMTS terrestrial segment and if they are significantly more expensive then potential satellite customer numbers will dwindle. Figure 11 illustrates how these costs affect the customer base for satellite services.

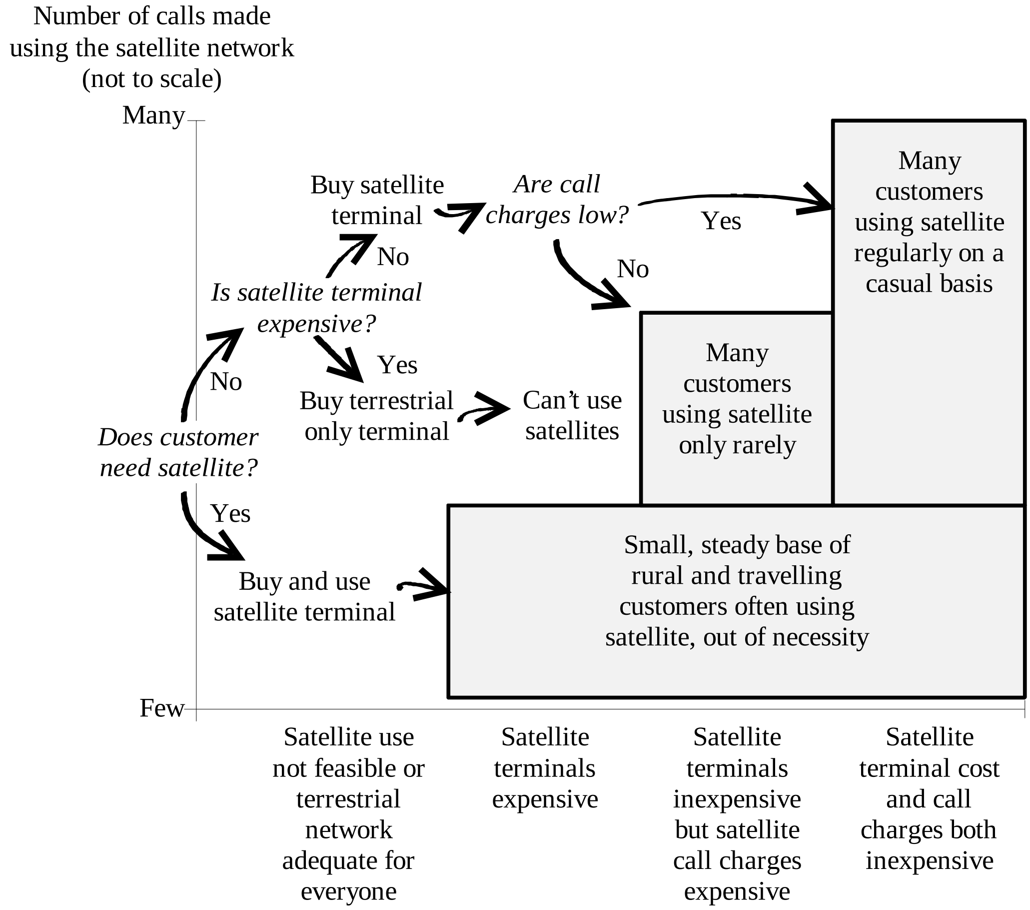

Figure 11 Cost factors affecting the number of satellite calls

3.3.2. Terminal Cost

The most important criterion is the cost of the mobile terminal. When a potential FPLMTS customer goes out to buy a telephone they will be presented with a choice of terminals, some of which are more expensive because of a satellite feature that will not be used that often, if at all, by the vast majority of people. If the cost difference is not very big, for example 10% of the cost of the terminal, then many people will buy satellite compatible terminals "just in case". If the cost difference is larger, for example 50% of the cost of the terminal, then only those with specific need for satellite usage, such as people living in rural areas or frequently travelling in rural areas on business, will buy satellite compatible telephones. Thus the number of satellite compatible terminals may only be 10%, for example, which would mean that most customers could not use satellite facilities even on the odd occasion they were outside terrestrial coverage.

It is worthwhile remembering that in some markets, such as the UK, the cost of the mobile terminal itself is heavily subsidised by the network operators so that the customer is not faced with choosing from a range of expensive terminals. Also relevant are insurance companies and car manufacturers who include mobile telephones in a package of services as added "peace of mind". In these cases it will be the companies buying the terminals from the manufacturers who will decide what networks' air interfaces are implemented. For these companies, the extra peace of mind and coverage flexibility that satellite capabilities add may be well worth the extra cost of providing them.

If terrestrial operators cannot rely on their customers' use of satellites to fill in uneconomic rural areas, they will begin to install terrestrial macro-cells to placate customers who have experienced calls being frequently dropped on the outskirts of their towns and cities or as they drive away from motorway junctions. Then terrestrial coverage becomes adequate for most people's needs and so very few people require satellite telephones, ensuring that they always remain an expensive niche product. However, the network operators then have to support large numbers of unprofitable cell sites and these costs are passed back to customers through higher terrestrial network call charges. The entire FPLMTS system is more expensive to use.

On the other hand, if satellite compatible FPLMTS terminals were inexpensive enough to become ubiquitous then network operators would fully exploit the capacity of satellites to fill in areas with no terrestrial coverage and concentrate on what terrestrial cellular radio does best, which is accommodating high traffic densities. Most customers would find that they use the satellite system infrequently, possibly only for short periods within their calls, but it would be convenient for them to be able to continue their calls even though they are outside terrestrial coverage.

3.3.3. Call Charges

The other criterion influencing satellite use is the cost per minute of calls. Because of the high cost of satellite infrastructure, limited radio resource re-use and its low capacity, call charges on a satellite system will be significantly more expensive than on terrestrial systems. There is nothing that can be done to avoid this because only a small number of callers are sharing the cost of providing an expensive service (see section 2.4.3). Even though they may posses a satellite compatible telephone, many customers will want to avoid using the satellite system, just as many customers avoid making telephone calls at peak rates. But there will also be many customers willing to pay the higher call charges as necessary to conveniently make calls whenever it suits them.

It is likely that there will be four types of customer:
- those who will ban satellite use,
- those wishing to be asked if they want to continue before connecting via a satellite,
- those who would like a warning when a satellite connection is made and
- those who will want to make calls uninterrupted under all circumstances.

With FPLMTS' flexibility to offer personalised services, the personal FPLMTS profile could contain a record of whether a particular customer wants transparent use of satellite services, requires warning of their use or wishes to be asked before using them. In this way, customers are in complete control of the extent to which they use premium rate satellite services, so how often they will decide to use them will depend very much on the call charges. However, the fact that a customer has a satellite compatible telephone is the most important thing. For example, if a customer is roaming out of terrestrial coverage and the call has to be handed over to a satellite, very few people would simply drop the call before finishing their conversation to save money. It is large numbers of casual satellite users like this who add to the small number of rural and travelling customers dependant on the service most of the time, to make the FPLMTS satellite traffic density large enough to be profitable. It is also the widespread accessibility of the satellite terminals that allows terrestrial network operators to dismiss coverage of unprofitable rural areas.

3.4. Overflow Traffic from Terrestrial Network "Hot Spots"

There are other places where it is uneconomic to provide sufficient terrestrial capacity - "hot spots", where there are short peaks in traffic demand, which may occur on a random basis, which rise above the network's capacity. Here some customers wishing to place calls are blocked and, in first and second generation systems, have their calls discarded or queued. Where a small density of such requests overflows from a terrestrial network incapable of handling all the traffic being offered within its coverage, it is tempting to think that in a third generation system the satellite segment might be able to support some of this traffic if customers are willing to pay for the more expensive service. More importantly, there will be some customers such as the emergency services who will require very quick connections from FPLMTS. This will be especially important where accidents have occurred, which often cause overloading of mobile networks.

There are at least two causes of "hot spot". The first is where a development has occurred resulting in a permanent increase in traffic demand during some part, or all, of the day and the terrestrial network operators have not foreseen or been able to meet this demand quickly enough. In well-managed terrestrial networks this does not happen very often and when it does the condition is usually very short-lived. In the worst cases, where new micro-cells are required to support very dense traffic, clearly the satellite segment will not be endowed with enough capacity to support all the overflow traffic, although it is feasible that a premium priced service could offer satellite use to a very small proportion of the overflow traffic. The second cause is where completely unpredictable events have occurred, such as road accidents and natural disasters. In these cases the overflow may also be very great, since the terrestrial network would be dimensioned for normal traffic conditions. Terrestrial operators are unlikely to install extra terrestrial capacity to accommodate infrequent accidents. As these hot-spots appear and disappear randomly over very large areas they might appear to be suited to satellite communications.

3.4.1. Priority Access in Areas Unserved by Terrestrial FPLMTS

An apparent problem with allowing mobile terminals within terrestrial coverage access to the satellite network, illustrated by the different traffic densities portrayed in figures 6 and 7. The peak total traffic densities of figure 6 are many orders of magnitude greater than the traffic densities outside terrestrial coverage in figure 7. Based purely on the relative areas of micro cells and satellite spot beams, the micro-cells' capacity is two million times greater than the satellite beam's capacity. Hence even a 3% overflow of "hot spot" traffic from a small number of micro-cells amounts to a large number of calls that may account for an uncomfortably large proportion of a satellite spot beam's capacity. 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 to remove most of the traffic, leaving only a low density of customers scattered outside terrestrial coverage who rely on satellites for service (compare figures 6 and 7). There is a danger that the overflow traffic from just a few square kilometres of a city centre terrestrial network might use all the available channels for the satellite spot beam, leaving calls from rural areas throughout the entire satellite beam blocked. This is undesirable and it would be better for more calls in the "hot spot" to have been blocked rather than wiping out FPLMTS service for people over large areas. The "hot-spot" customer has a better chance of obtaining a connection to the terrestrial service by redialling or queuing than the rural customer has of obtaining a satellite connection because there is likely to be a larger pool of channels and so the turnover of calls is likely to be faster.

If satellites are to handle overflow traffic then we must consider that there is not necessarily any way of determining precisely where within the satellite beam calls are coming from and that there is therefore no way of recognizing when a large proportion is coming from the same place. Unless the mobile terminal provides some information, there is no option but for the satellite base stations to accept call requests until all the satellite capacity is in use and then block all further calls, no matter where they may be coming from.

So, in general overflow traffic from terrestrial "hot spots" should not be taken onto the satellite networks. The mobile terminals must be relied upon not to default to a satellite connection if they are blocked by a terrestrial network because the satellite network will have no way of policing this restriction itself. A small number of customers, such as emergency services, will require this kind of access to satellite services under all circumstances and their terminals will need to be programmed differently by their service providers. Calls to certain numbers, such as the emergency services may also need to be treated specially.

3.4.2. Emergency "Hot Spot" Connections

Satellites can provide an overlay of "spare channels" across a large area for resale to those who need FPLMTS connection desperately quickly. Their service provider could program the customer's FPLMTS card to allow connection to a satellite network even after blocking by a terrestrial network, informing the user *and the satellite network* that a premium rate will apply to this urgent connection. The associated software in the network would have to recognise that priority must still be given to satellite traffic in locations where no terrestrial FPLMTS service is available but if there is still spare capacity in the satellite network then the call could be connected.

This provides the facility for satellites to handle terrestrial "hot-spot" traffic overflow whenever individual customers have an urgent need but priority is always given to traffic coming from areas where no terrestrial base stations are operating. Calls from areas with terrestrial coverage would always be blocked before calls from rural areas. The result may be that once traffic demand outstrips a terrestrial system's capacity then the satellite system would quickly become congested, resulting in a similar probability of call blocking for callers from the terrestrial network to that which would have existed without the satellite overlay. This may also happen when there are simultaneously many "hot spots" within the coverage of a satellite spot beam, even if the overflow traffic from each "hot spot" is acceptably low.

3.4.3. How Much Could Overflow Traffic Handling by Satellite Systems Help?

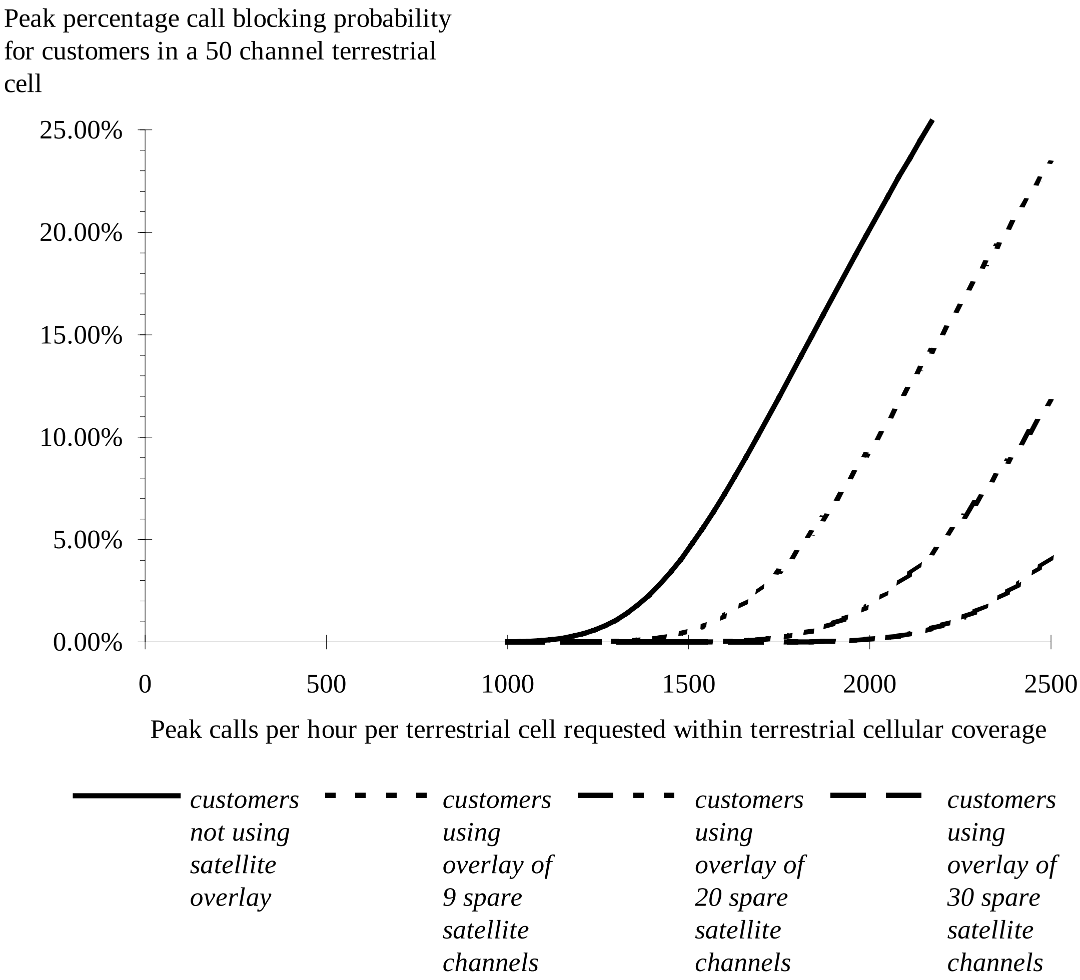

Figure 12 Reduction of call blocking probability by satellite handling of overflow traffic from an inadequately sized terrestrial network

Figure 12 compares the probability of calls being blocked in an overloaded cell for customers not using satellites (solid line) and for customers using satellites to make emergency calls (dotted lines). The emergency call blocking probability is shown for three cases where the satellite overlay is under varying loads from rural customers and can therefore offer varying numbers of spare channels to the hot spot emergency services. The graph is drawn assuming that whenever the terrestrial cell cannot connect a requested call and there is spare capacity on the satellite network then the call is connected using that satellite capacity. It assumes that no customers refuse to be connected by the satellite segment and that all customers' mobile terminals have satellite communications capabilities. Furthermore, it is assumed that this cell is the only "hot spot" within the coverage of the satellite spot beam. Other, less debatable, assumptions are that call requests occur randomly during peak times, with the mean number of calls per hour requested at peak times within the "hot spot" cell indicated on the *x*-axis. The duration of calls that are not blocked is exponentially distributed with a mean of 1 minute 45.6 seconds[3]. Customers in areas where a terrestrial network is not available are always connected by satellite in preference to customers who have been blocked by the terrestrial network.

The real effect on blocking probability would be much better for emergency callers than the graph shows, as long as emergency calls are only a small proportion of the total traffic demand in the hot-spot. With fewer calls competing for the "spare" satellite overlay channels, the result would be much lower blocking probabilities for these calls than figure 12 indicates. The number of callers using this emergency service should be kept low either by service providers only offering the service to emergency services or through very high tariffs. More than one "hot spot" could be tolerated in a satellite spot beam, as long as the combined overflow traffic does not become excessive at any time. For example, peaks in traffic demand might be very short and occur at different times in different "hot spots", making large satellite spot beams a suitable way to statistically multiplex this traffic.

Alternatives to using satellites would be to reserve a number of traffic channels on terrestrial cells for emergency use only or to randomly drop calls that are in progress through a cell in favour of connecting an emergency call.

3.5. Satellite Paging for Terrestrial Networks

An uncomfortably high proportion of terrestrial cellular network signalling traffic is for network control, specifically updating location databases for mobile terminals on the move so that calls made to the mobile can be connected. When a call is made to the mobile the network obtains the terminal's location from a database. The database knows the terminal is within the broadcast area of the base station that the terminal is registered with. The base station broadcasts a paging message to all idle terminals within radio coverage containing the identities of all the mobile terminals it wants to contact. When the called terminal hears its identity in the paging message it transmits a paging response message to the base station and call set-up begins. The network may try to page the mobile a number of times and use a number of base stations before it gives up and reports that the terminal is unavailable to the calling party. This paging traffic uses a significant proportion of the available radio resource that could be otherwise used for revenue-earning traffic, though the use of a detach procedure to cancel the registration of a mobile with a base station (see section 6.3) could prevent this from happening.

A balance can be struck between wide-area paging of mobile terminals whose location is only known to the nearest macro cell or groups of macro cells and local paging of stationary or slow-moving terminals whose position is maintained to the nearest micro-cell. Studies have been made of the trade-off between location updating to micro cell resolution versus paging throughout macro cells within mixed cell architectures

[3]One minute 45.6 seconds was the mean duration of a call on the first generation NTT DoCoMo mobile network in 1994.

[CHIA1] These indicate that the best compromise is dependent on the mobile terminal's speed. For relatively immobile telepoint terminals, location registration to the nearest micro-cell would be infrequent and more efficient than paging the terminal through multiple micro-cells or a large macro-cell every time a call is incoming. For vehicular cellular applications location registration to micro-cells would occur too frequently to be feasible and so registration to macro cells or even groups of macro cells makes more economic use of network resources, since incoming calls, and the overhead of paging over a wide area, occur relatively infrequently. Even using macro-cell registration and grouping macro cells along main roads to reduce location updating, the control traffic generated can be considerable and, as it is customary not to charge for the service, it is all overhead cost to the terrestrial network operators. In addition, this signalling traffic places a heavy load on the processing performance of network switches and databases, reducing the number of customers that they can support.

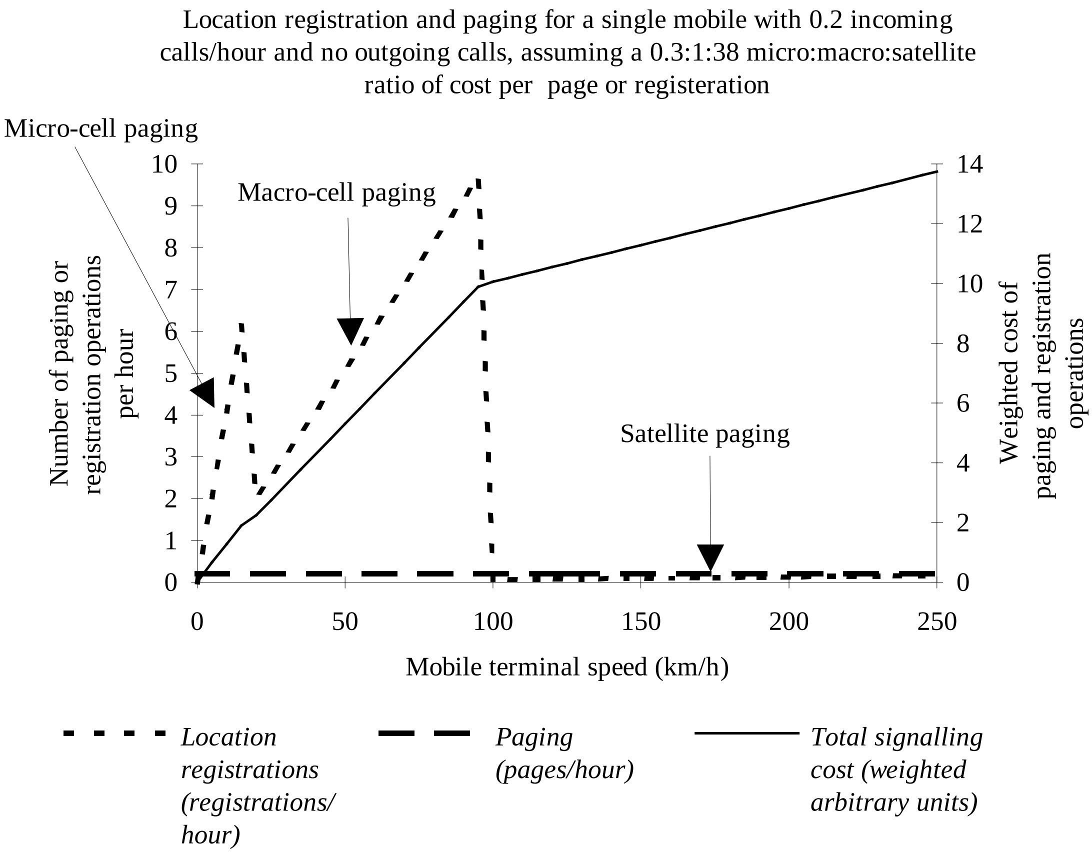

Figure 13 Satellite paging and location registration reducing overall mobility management cost (an ideal outcome)

Satellite facilities suggest the possibility of reducing this non revenue generating signalling traffic on the terrestrial network by allowing paging over still wider areas, as illustrated by figure 13. The paging of mobile terminals using satellites would not rely on all (or even the majority) of terminals being equipped with satellite capability. The network need not even know in advance if the mobile terminal has satellite capabilities: it would be up to the mobile terminal to recognize that it is roaming too much and instead of requesting location updating to a terrestrial base station's location area, it should request location updating to a satellite FES's location area. This location registration signalling could still be carried on a terrestrial radio link to avoid use of more expensive satellite links. The benefit would be less frequent location updating because the areas over which a satellite would page for incoming calls would be larger than terrestrial base stations' coverage areas. The network would page a mobile on the satellite downlink but a mobile terminal could respond to the nearest terrestrial base station so only the satellite downlink is occupied by the signalling.

The threshold at which roaming becomes "too much" to location update needs determining since, whilst the cost of location registration can be established from first and second generation cellular networks experience, the cost of satellite paging is not yet clear. Figure 13 shows what is ideally hoped for, with the threshold set at 100km/h, an incoming call rate of 1 call every 5 hours and a 38:1 satellite:macro cell paging cost ratio. The location areas used in figure 13 are single cells: 1km radius micro-cells, 16km radius macro-cells and 850km radius satellite spot beams. The trade-off is very strongly influenced by both the incoming call rate and the relative cost of satellite and terrestrial paging operations, so these are investigated further.

3.5.1. Incoming Call Rate

The satellite paging area is so great that location registrations should be necessary only very infrequently. Location registration operations would cost the same as location registrations to terrestrial base station coverage areas because they would be carried on the usual terrestrial cellular signalling links. It is therefore the number of pages for incoming calls that dominates the cost: the higher the incoming call rate, the greater the number of pages and the higher the cost. In contrast, for smaller macro cells and fast moving mobile terminals the location registration function is dominant over the relatively infrequent incoming call pages. Therefore for small cells there is less pronounced correlation between the incoming call rate and the overall cost of locating and paging the called terminal.

Customers expecting large numbers of incoming calls would therefore be better served by continuing to register their location to terrestrial base stations rather than to a satellite base station. Only customers with exceptionally low incoming call rates would have any chance of deriving benefit from having the satellite page them rather than a terrestrial base station. The incoming call rate at which the break-even occurs cannot be identified without knowledge of the relative costs of signalling on the satellite and terrestrial networks. However, as an average of 80% of calls from terminals on the move originate at the mobile terminal and only 20% are incoming and require paging, the break-even call rate may be high enough to include sufficiently large numbers of customers to make this scheme worthwhile.

Note that this requirement to keep the number of location registrations very low will be returned to in chapter 6. Non-GEO satellites' spot beams move around the earth and a LEO satellite system may need to update the current beam of a mobile terminal nearly once a minute: clearly this should not be done by using location registration analogous to terrestrial systems' location registration mechanisms. The FES should predict the spot beam movements and make adjustments accordingly. This may require paging over more than one satellite beam, should the mobile terminal's location be in any doubt (see chapter 6).

3.5.2. Cost of Satellite Pages

Although incoming calls to mobile terminals are infrequent and the paging message is short, satellite bandwidth is expensive even for low fade-margin voice and data communications traffic channels. Furthermore, in order for satellite paging to be reliable, the fade margins in the satellite link budget must be restored to the levels of a terrestrial cellular radio link budget, perhaps requiring an extra 30 to 40dB of gain (see section 2.5.5). This gain is conveniently achieved by lowering the bit rate of the paging data by 30 to 40dB compared to the voice and data traffic channels. The satellite channel is fundamentally power limited and bandwidth usage is already excessive for voice and data communications because the large coverage areas limit frequency re-use. Thus increasing transmit power or bandwidth for traffic channels is undesirable. However, the paging message is discrete and therefore time is not such a scarce resource, so reducing the bit-rate is a practical possibility. The energy per bit is thus raised to a level acceptable for reception via multipath reflections and even within vehicles and buildings. Unfortunately the cost of conveying the paging message has also increased by up to 10,000 times (40dB) and, since it now takes several seconds to transmit a paging message, queuing will need to be implemented, resulting in delays of perhaps several minutes to page the mobile terminal. It would perhaps be more economic to use less gain and page the mobile terminal several times if it does not respond to the first page because of poor propagation conditions. Figure 13 assumed the cost of a satellite page to be only 38 times that of a macro-cell page but in view of the above, this is a very conservative estimate. Even just comparing the areas being paged, this figure is a factor of 600 too small.

Although the maximum call rate below which satellite paging can reduce signalling costs cannot be identified until FPLMTS' specifications are more detailed, considering all the above it looks likely that it would be so low that few mobile terminals would be able to benefit. If the numbers of roaming terminals participating in this scheme were to be too low, then the additional network and terminal software complexity required for use of the satellite segment of FPLMTS to page terminals roaming within terrestrial coverage would not be justified.

3.6. Summary of Satellite Roles

The benefit of satellite communications' large coverage area has long been seen and enjoyed using Inmarsat and other services. FPLMTS promises to extend this benefit to many more customers by using inexpensive satellite compatible mobile terminals. FPLMTS' efficient integration of satellite services with terrestrial will allow closer geographic mapping of system capacity to customer demand because there will be a whole range of cell sizes offering a complete range of traffic density support from sparsely populated rural areas and oceans to densely populated city centres and mass transport systems. Thus satellite's integrated debut in FPLMTS will enable the concentration of resources into expanding the terrestrial network vertically rather than horizontally, that is increasing capacity where the demand exists rather than increasing coverage over areas where demand is almost vanishingly small. Satellites will not increase the capacity of FPLMTS but allow capacity to be *reduced* to the level of customer demand in areas where demand is insufficient to pay for terrestrial infrastructure. This will benefit all concerned as there is a certain traffic density below which satellites' huge spot beams enable more efficient and cost-effective communications than large numbers of under-utilized terrestrial macro-cells would.

This guarantee of coverage will prove to be most useful during the roll-out of FPLMTS when terrestrial networks are incomplete. An international satellite system can provide local service providers with the means to guarantee basic coverage and quality of service to their customers and build revenue whilst local terrestrial networks are being built to match the traffic demand.

It has been shown that using satellites to carry traffic overflowing from terrestrial cells incapable of handling it is detrimental to the quality of service offered by FPLMTS as a whole. However, for customers with special needs such as the emergency services, a facility should be available for service providers to allow access to FPLMTS by whatever means will be quickest.

It has also been shown that satellite networks are not suitable for carrying terrestrial networks' paging traffic.