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Integration between Terrestrial-Based and Satellite-Based Land Mobile Communications Systems

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1. INTRODUCTION

The growing interest in Mobile Satellite Systems (MSS) worldwide has underlined the need for a definition of the possible role of MSS in the more complex panorama of land mobile services. Entrepreneurs stand ready to develop regional mobile satellite systems. Nevertheless potential MSSs would only serve a niche segment of the overall mobile telecommunications market (see Fig. 1), with a potential market share strongly depending on the relative penetration of MSS with respect to terrestrial-based mobile telecommunications services.

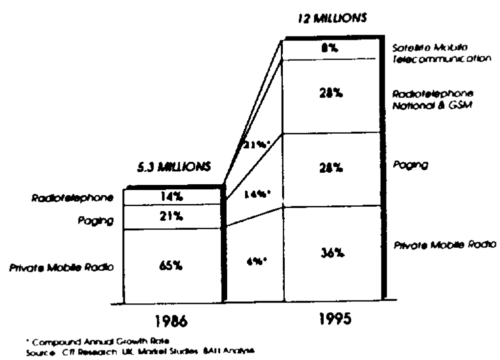

Fig.1. Growth projections for mobile communicating in Europe

On the basis of technical and economical factors, several promising solutions have been analyzed to establish the relative market penetration of MSS. One of those resides in the integration between terrestrial-based and satellite-based MSSs. Another resides in the research of a possible synergy among fixed, transportable and mobile satellite voice/data services/technologies.

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The market segment to be addressed has been clearly identified in the low traffic density areas (see fig. 2). The complementarity with existing and future mobile services is then evident whilst at the same time a possible synergy between mobile and fixed (or transportable) satellite services could be demonstrated. In the long run mobile and Personal-VSAT stations will only differ because of the different frequency allocation and the different market segment addressed while at network level the same tele-services and bearer services are likely to be provided. Several studies have recently been performed on these topics in Europe and this paper is intended to summarize some results which have been obtained. In particular there are two main areas in which the interest has been focused.

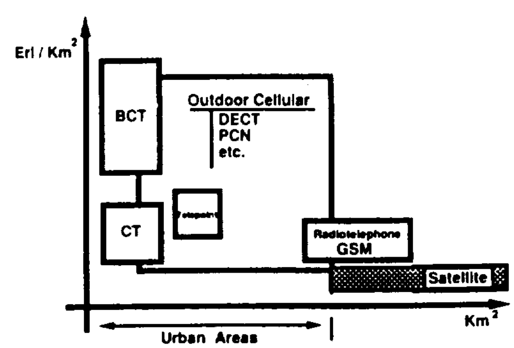

Fig 2. Traffic density vs. mobile market segmentation

The first one is the possible "network" integration between the first European generation of the Digital Cellular Mobile System (GSM) and a Land Mobile Satellite System (LMSS) for the provision of public LMSS services.

The GSM (and in the long run the UMTS: Universal Mobile Telecommunications System) will ultimately provide one common cellular system for the whole of Europe. However, while the implementation of GSM starts in 1991, it may take quite a few years until the coverage is more or less complete, and it is unlikely that this service will be available outside the CEPT countries: Hence, there is a market for a mobile telephone system which complements the GSM system and

- provides complete coverage of Europe, land and maritime neighbouring areas;
- requires little installed equipment so that a service can be provided in a short time;
- has the flexibility to adjust to a changing geographical distribution of the users to keep up with a build-up of the GSM system, and reduces the early and overall investment for the GSM implementation.

These requirements can be optimally satisfied by a satellite-based land mobile radio system: the entire area of interest can be covered from one location in space, hence all the above features are provided automatically. The usefulness of such a system can be enhanced by making the two systems as compatible as possible in terms of services, protocols, etc. This can lead to a system which requires very little hardware in addition to the GSM terminal and which selects the best link automatically and autonomously, hence the user, in theory, needs not even be aware of the fact that the connection is completed through a satellite link.

Lastly, this system will provide a satellite extension of the public cellular mobile system at the expense, for customers interested in a full satellite coverage, of the use of a dual mode satellite/GSM terminal.

On the other hand, if we look at non-public mobile communication services, the same philosophy can be applied even if due to the reduced communication quality and availability requirements, a different system architecture can be optimized. Due to the power and bandwidth constraints in the LMSS environment, the optimized access scheme for satellite closed user network applications has been found to be a system using a synchronized CDMA accessing scheme.

This kind of accessing scheme has the advantage, in terms of frequency reuse, of at least a factor of 2.5 over an FDMA based satellite system. Furthermore, the same accessing technique used in a mobile cellular (or trunked PMR) system has several advantages over the classic TDMA scheme. CDMA requires fewer cells, lower power levels, a simpler frequency planning and an increase in capacity of up to 20 times that of the existing techniques. Finally, in terms of service provision CDMA techniques can provide a complete set of services without any change in the lower network layers. This capability allows a larger flexibility in the provision of different services tailored to the different user requirements. The easy implementation of features like link-activation (voice activation, connectionless data links, etc.), a localisation and a very short call set-up time together with an efficient use of spectrum give to this accessing technique further advantages to become a good candidate for the provision of both terrestrial based and satellite based mobile and fixed telecommunication services.

For all these reasons the possibility of integration of a terrestrial based and satellite based system seems to be of great interest and also in this field several studies and experimental activities have been performed in Europe and all over the world.

2. THE PROVISION OF VOICE/DATA SERVICES IN THE FUTURE REGIONAL EUROPEAN LMSS

More and more interest has recently been given to the need for a European standard compatible with GSM for public services, and for the standardization of PMR satellite services.

The development of these standards is aimed at supporting the growth of a European regional system (covering also Eastern countries, North African countries and, in general, all countries in the Mediterranean basin) in order to complement the future public and private terrestrial based systems.

An initiative has been taken by ESA to fund the development of an L-band payload (with Ku-band feeder links) called EMS, to be launched in 1993. This payload is intended, as the first choice by ESA, to be operated by Eutelsat to provide digital MSS voice/data communications. A possibility for the embarkation of this payload is the Italsat I-F2 Satellite (1993). The spare to the EMS payload could be provided through the ESA-Artemis-LLM payload (1994) which will also be provided to experiment L-band spot beam technology in Europe.

It has also been considered in the future to provide a better coverage (elevation angles > 45°), of the countries in Northern Europe, utilising satellites in highly-inclined elliptical orbits (Archimedes (ESA), Loopus (D), Sycomores (F), Elmsat (I), etc.) For those systems the possibility of utilising the Ku-band (or even mmwave) frequencies is under study.

2.1 Public service

It is recognized that the GSM system will ultimately provide a common system for the whole of Western Europe.

As outlined in the introduction, several requirements can be optimally satisfied by a satellite-based land mobile radio system (LMSS): the entire area of interest can be covered from one location in space. The usefulness of such a compatible system could be enhanced by making the two systems compatible in terms of services and eventually protocols. This can lead to a system which requires some hardware in addition to the GSM terminal and which selects the best link automatically and autonomously, hence the user needs not even be aware of the fact that the connection is completed through a satellite link. The proposed integration can be obtained by designing the LMSS/GSM integrated system without any impact on the already existing GSM specifications.

It can be assumed that the most important use of the space segment is when a user in a zone not covered by the GSM cellular system is considered. The possibility of a mobile terminal able to select which of the two link characteristics, i.e. GSM or satellite, is better at a fixed moment, could be envisaged, thus comparing, for example, the two levels of the signal received from the base station. This is possible for a standard GSM terminal since the central station periodically forwards managing hand-over and location information. However, some additional modifications should be considered in this case as in other cases. For example, in the terrestrial system each base station broadcasts some data on its neighbours. This information is used in the handover procedure. Since handover from the satellite can be to any one of a very large number of terrestrial cells, the satellite cannot provide this information.

A more realistic approach could be to allow handovers between the terrestrial and the satellite system but not vice-versa. Furthermore, considering the significant cost involved in defining and designing a new telecommunications system both at terminal and network levels, research on the maximum commonality between the protocols of the two systems is fundamental.

For this reason, the mobile terminal could be conceived with a view to minimizing the impact in terms of cost/complexity on the design of a re-usable GSM/LMSS terminal. Similarly, the maximum commonality at protocol level (at least for signalling) could permit the use of the same switching network developed for the GSM system.

To summarize, it is in principle possible to obtain the maximum commonality both in terms of protocols and eventually in terms of terminal hardware between the LMSS and the GSM. However, should the re-usable terminal architecture be simplified, if a different protocol or hardware were assumed for the LMSS system, the requirement of the maximum commonality would be abandoned in favor of the reduced cost/complexity of the dual mode terminal. This is due to the fact that a different distribution of the overall business opportunity has to be considered in the terrestrial-based and in the satellite-based systems. In the terrestrial GSM, only 30% of the overall system cost can be allocated to the terminals' cost and the remaining 70% is dedicated to the base stations (50%) and switching centres (20%). On the other hand, in a satellite-based system the largest share of the overall system investment cost corresponds to the terminals' cost amounting to more than 50% of the overall LMSS cost.

The integration of terrestrial and satellite-based mobile systems will be further taken into account in the evolution towards UMTS (Universal Mobile Telecommunication Services). During this work the particular characteristics of satellite-based mobile systems will be taken into account to ensure effective interwork- ing. A base for these investigations can be found in the work of CCIR 8/14, CCIR 8/13, COST 227 and ESA.

2.1.1 Identification of critical areas for the implementation of integrated GSM/LMSS systems

The terrestrial and satellite land mobile systems have been considered separately up until now and, therefore, their specifications have not been harmonized. The difficulty in the harmonization of specifications of the two systems seem, at first glance, to depend on the physical macroscopic differences between the terrestrial-based and satellite-based mobile systems. In particular, these physical limitations can be found in the signal attenuation, propagation delay, multipath channel characteristic, etc.

Moreover, difficulties in the harmonization between the two systems depend on the delay in the frequency allocations of LMSS as compared with cellular systems.

A fully integrated approach based upon the harmonization of all the technical solutions adopted in the two systems hardly seems feasible. In an attempt to rationalize the integration possibilities a scale of possible levels of harmonization between the two systems has been proposed to CCIR IWP 8/14.

This classification follows a "Russian doll" structure where each possible level of integration includes the basic concepts of the previous one. We could have, in the following order: Geographical, Services, Network and finally System Integration (see fig. 3).

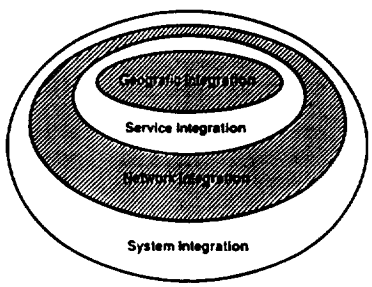

Fig.3. GSM/LMSS Integration levels

In the first case (Geographical Integration), the GSM and LMSS systems are independently conceived and based on different techniques and do not provide the same or compatible services as they could at the second level of integration. In this second case (Service Integration), the LMSS will only be capable of supporting a subset of the services available with a degraded service. Nevertheless, from the user point of view already at this level of integration a unique interface can be provided which has an appropriate protocol conversion.

However, even more interesting is the possible integration at the third level and, in a next generation, possibly at the fourth level (UMTS).

In the case of network integration, the fundamental requirement is to enable the fixed user (connected with the PSTN or ISDN) to call the mobile without having to select the call routing (satellite or terrestrial). A single calling number identifies the mobile. As already explained, this solution results in economies with regard to infrastructure due to the common utilisation of network functions.

At the same time, the maximum integration at network level should have an impact on communication and signalling protocols which should be as similar as possible to those of GSM. Finally, the last level of integration will envisage the system integration in a single network where the coverage areas provided by the LMSS are regarded as one (or more) cells of the original GSM system. This solution should include all the advanced system features such as rerouting of live calls between either satellite cells or terrestrial cells.

2.1.2 Space segment scenarios

As far as the space segment is concerned, two different satellite P/Ls are at present under development:

- satellite P/L with single beam (Eurobeam)
- satellite P/L with spot beams

The two listed alternatives have different operational capabilities and not all the GSM functions can be implemented in each of them.

Option 1.

In the first case, we assume a transparent satellite with a single beam covering Europe. The link with mobiles is in L-band and the link with fixed earth stations is in Ku-band. This kind of space segment corresponds to the European Mobile System (EMS) payload (see fig. 4) which should fly in 1993 [1]. In this case only three kinds of services have been considered:

- low data rate LMSS services
- voice/data PMR services (up to 9.6 kbit/sec)
- voice/data public LMSS services

The possibility of integrating a subset of GSM network services with these kinds of EMS services seems reasonable but only at the first or, at most, second level of integration (geographical or service integration, see sect. 2.1.1)

The main characteristics of the referenced EMS L-band payload are:

<u>Forward Link</u>
Total EIRP 42dBW (45dBW on Italsat-F2)
3 channels: 4+4+3 Mhz
<u>Return Link</u>
G/T - 2.0 dBK (-1.2dBK on Italsat-F2)
11 channels: 11x1 Mhz

Option 2.

In this case, we assume a transparent satellite with multi-spot beams to and from the mobiles (see fig.5) and a global beam to and from the fixed earth stations.

This solution corresponds to one of the experimental payloads which will be embarked on the ESA-Artemis satellite to be flown in 1994.

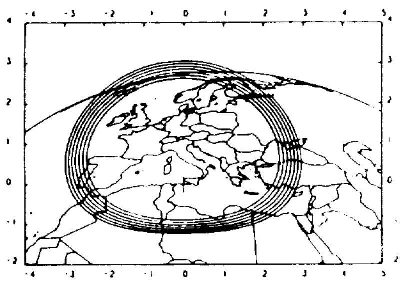

Fig.4. EMS coverage (L-band)

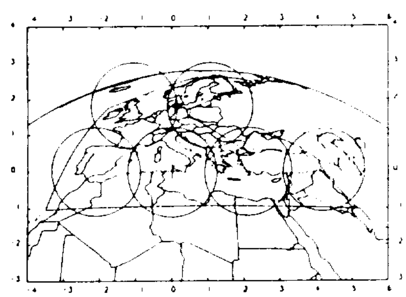

Fig.5. Artemis coverage (L-band)

In the case of the provision of a public service, we can consider for this space segment two possible system architectures: a central earth station for the system communicating with all mobiles or multiple earth stations in the Eurobeam (as many as the number of beams).

In the first case the use of a single fixed earth station has the disadvantage of creating long terrestrial tails. In the second case those ground tails can be reduced. However, if the mobiles are generally far from their base stations the tails may actually be longer than with a single earth station.

The main characteristics of the referenced ESA-Artemis L-band payload [1] are:

Forward Link
Total EIRP 51dBW (to be shared across the 6 beams)
7x1 Mhz channels*
Return Link
G/T - 4.6 dBK
7x1 Mhz channels
*over the MSS allocated frequencies

2.2 LMSS for Digital Trunked PMR services

In addition to a public system providing voice/data services, the need for a business voice/data service has been identified as a natural improvement and follow-on of the already existing low data rate LMSS service (e.g. Euteltracs).

Several study activities are in progress in order to define an optimized network architecture for the provision of a satellite digital trunked PMR service. The possibility of accepting a reduced speech quality (2.4 : 4.8 Kbit/sec. voice coding) together with the maximization of the spectrum utilisation (synchronized CDMA techniques, etc.) should provide an economically viable service. Two other main functional features for the proposed system are the provision of a VSAT receiving station at customer premises together with the reduction in the call set-up time (bypassing any PSTN connection).

2.2.1 CDMA techniques for a terrestrial/ satellite system.

Historically CDMA was mainly considered for applications requiring low susceptibility to interference and/or information privacy. For other applications (civil applications) the utilisation was considered to be limited due to the performance degradation arising from "self-noise", caused by the hardware complexity for the implementation of CDMA receivers (mainly due to the code acquisition and tracking procedures), and to the complexity of the compensation of near-far problems and finally to the poor spectrum efficiency when compared with conventional accessing techniques.

At European level an attempt to introduce CDMA techniques for land mobile communications was made by Philips (NL) and SEL (D) which presented to the GSM committee ("Groupe Spécial Mobile" which selected the first generation of a European Digital Mobile System) two proposals based on a CDMA concept. Finally, partly due to the mentioned criticalities, neither of those two proposals was retained and the final decision was taken for a TDMA/TDM system.

Only recently in Europe [2] and in the United States [3] a new interest has been shown to the implementation of CDMA based land mobile communication systems. This new interest is fundamentally due to the introduction of a new CDMA implementation concept which can be called synchronised CDMA.

In Europe this interest has mainly been

originated by ESA which has been working for several years on CDMA techniques and which recently has devoted a strong interest in the development of the synchronized CDMA system concept. Moreover ESA is also supporting the European industry in a technological effort aimed at the development of a series of systems, with a common technological basis, for the provision of fixed, transportable and mobile services.

Similarly, in the United States a slightly different synchronized CDMA concept has been introduced by Qualcomm [3] in the case of satellite based communications systems.

Only a few months ago the same technique was experimentally applied to digital cellular radio communications [4] obtaining an improvement in capacity of 20 times, compared with the present cellular techniques.

The big advantages of these CMDA concepts are represented by the reduced carrier-to-interference ratio which can be accepted by a CDMA system (allowing the reuse of the same frequency in every cell or in every satellite spot), by the less stringent requirements in terms of required Eb/No (because of the more powerful codes which can be used and because of reduced fading margin) by the exploitation of the voice duty cycle (allowing active spectrum and power reuse) and by the implementation of a sophisticated power control algorithm able to cope with the different signal levels from different users because of their location or because of different service requirements (the system is inherently able to dynamically provide different services at different data rates for different users).

Concerning the specific cellular implementation CDMA allows also soft transition from the already existing analog cellular networks to the digital network because of the inherent robustness to interference of the CDMA system and because of the low level of interference generated by each user vis-a-vis the existing analog network. In practice it is possible to double the system capacity reusing the same frequencies at the beginning of the new service and then, as the demand for CDMA service grows, some band segments can be removed from analog service and dedicated to the CDMA service. Finally, very accurate position location together with privacy can be provided by the cellular system because of the spread-spectrum nature of CDMA.

Therefore taking into account all those advantages and the common nature of the used technology in the terrestrial-based and satellite based scenarios, there is an opportunity to develop an interworking network for fixed, transportable and mobile applications to provide voice/data services to closed user groups. The idea could be to have on one side a common CDMA system for terrestrial based and satellite-based PMR applications in which a simplified hand-over philosophy can be applied.

Only hand-over from the terrestrial network to the satellite network will be considered and, due to the long propagation delay and the slightly different nature of the terrestrial based and satellite based systems, this hand-over will be performed breaking for a few hundred milliseconds the conversation/datalink in order to abandon the terrestrial network and set up a call in the satellite network.

On the other hand, it is possible to reuse the same CDMA technique/technology in the case of fixed and transportable voice/data services (Personal-VSAT) for closed user groups, and an eventual integration of the different services in a single trunked PMR network should be further investigated.

Finally, in order to reduce the number of terrestrial tails and connections to a minimum the PMR satellite network architecture has to be based on a distributed relevant private hub-station configuration. In practice feeder link access to the network should be provided through private VSAT hub stations (located at customer premises) while only the network coordination functions should be centralized at the satellite operator/service provider premises (see fig.6).

With reference to the first two options given in sect. 2.1.2 an analysis has been recently performed [5] in order to give an assessment of the capacity which can be obtained using a synchronized CDMA access technique with the two above-mentioned space segment configurations:

	EMS (42dBW)	LLM (51dBW)
Total number of available channels	480	3200

Starting from the capacity calculation in the case of the EMS payload it is possible to address a nominal market of at least 75,000 users in Europe. This figure could virtually be doubled if the Italsat I-F2 is the selected space segment.

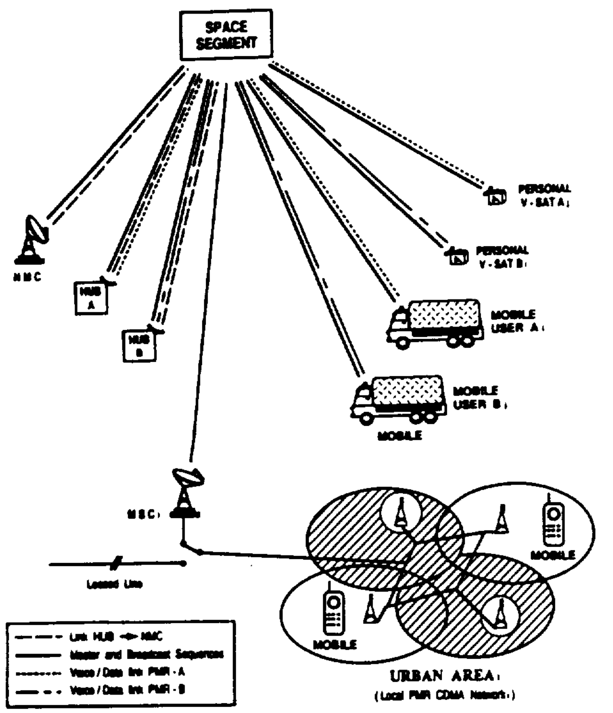

Fig.6. A CDMA-based terrestrial/satellite architecture

Therefore, considering on the present cost for the development, launch and operation of such a small piggy-backed payload (1/4 of a medium size satellite including in-orbit sparing) there is the possibility of offering a voice/date service to closed user groups at a cost well under 500 ECU/year/user.

This figure does not include the investment for the mobile terminals and for the mini-hub station.

As already mentioned, more than 50% of the overall system cost for an MSS is due to the investment for the procurement of mobile terminals.

For this reason the support in the development of appropriate (in financial and technical terms) user terminals (mobile and fixed) is at least as important as the funding and development of an appropriate space segment. Several activities have been started by ESA in this domaine, and a few units for the experimentation of future personal satellite services will be available in 1991.

3. CONCLUSION

In order to increment the economical attractiveness of future personal (fixed, transportable and mobile) satellite services a new access technique has been proposed. In 1991 the experimental viability of such a technique will be experimentally tested and trialed in Europe. Should the present performance estimation be confirmed by the experimental results, the large-scale industrialization of personal satellite communication terminals shall be initiated with the aim of developing integrated closed user network services.

Concerning the development of public mobile satellite services the same technology could be applied limiting to network level the integration with the terrestrial mobile system.

A more detailed analysis will be necessary to define a satellite/terrestrial integrated mobile system (reusing the same protocols) aimed at the development of the future UMTS services.

REFERENCES

[1] **G. Perrotta, F. Rispoli, T. Sassorossi** "Payloads development for European Land Mobile Satellites" IMSC '90, Ottawa (Canada), June 1990

[2] **R. De Gaudenzi, R. Viola,** "A synchronous Code Division Multiple Access System for High Capacity Mobile Satellite Systems" IMSC '90, Ottawa (Canada), June 1990

[3] **K.S. Gilhousen, I.M. Jacobs, R. Padovani, L.A. Weaver Jr.,** "Increased Capacity Using CDMA for Mobile Satellite Communication" IEEE-J-SAC, January 1990

[4] **Qualcomm, Pactel Cellular,** "CDMA Cellular the Next Generation" San Diego, November 1989

[5] **A. Vernucci, S. Arenaccio, R. Padovani, A.Arcidiacono,** "Performance, Implementation and Network Management Techniques of a European CDMA-Based Land Mobile Satellite Systems" Submitted for approval to IEEE-Globecom 90, San Diego, December 1990.