LOOPUS Mob-D: System Concept for a Public Mobile Satellite System providing Integrated Digital Services for the Northern Hemisphere from an Elliptical Orbit

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ABSTRACT

The market for Mobile Communications Services is presently in a process of revolutionary development not only in terms of quantity but also in terms of quality of services. Sophisticated end user equipment allows intelligent signalling and comfortable user interfaces at reasonable prices.

In 1988 the Groupe Spécial Mobile (GSM), a group jointly sponsored by European PTTs and industry, submitted a set of standards for a fully digital mobile communications system to be implemented in the 90s in at least 18 European countries. However, providing Mobile Services at any place within Europe implies a major investment on one hand and a considerable implementation period on the other. Satellite systems, inherently, would not only offer an immediate availability in the entire anticipated service area once they are implemented, but also provide options to extend a regional service into a European or even worldwide accessability.

This paper will introduce a new concept for a satellite based public mobile communications system, LOOPUS Mob-D, where most of the "classical" problems in mobile satellite systems are approached in a different way. The LOOPUS system will offer a total capacity of 6000 high rate channel in three service areas Europe, Asia and North America, covering the entire Northern Hemisphere, with a set of GSM compatible mobile services eventually providing the "office-in-the-car".

This paper we will briefly highlight special characteristics of the LOOPUS orbit and the communications network architecture.

SYSTEM REQUIREMENTS

Different from the links in the fixed satellite service, mobile links suffer generally from the fact that user terminals are in motion and hence, great variations in terms of signal strength are induced by frequency selective multipath propagation and other degrading effects.

Consequently, the system requirements for a Mobile Satellite System differ from those for the fixed services. A mobile satellite system can be characterised by a great number of individual users accessing directly the satellite from non-stationary locations. All this with preferably small and low cost user terminals. In common with the fixed services is the fact that also in the mobile environment a firm demand for voice <u>and</u> data services exists.

Because of the real-time nature of "voice", real-time transmission channels are required. This is considerably less critical in the case of data services. Absolute Bit Error Rates (BER) can to a certain extend be improved by appropriate error correction. However, taking into account the inherent propagation delay of the satellite channel the overall time delay really becomes the critical issue for voice services if too complex FEC procedures, e.g. interleaving, has to be applied. This requires a communications channel with a basically uninterrupted direct line of sight characteristic. These conditions are particularly well satisfied from orbits with high inclination. LOOPUS has been designed to provide the equivalent of all services offered by the GSM [1] hence including voice .

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The maximum number of user channel has been evaluated as 2000 32kbit/s (full-rate) or 4000 16kbit/s (half-rate) respectively. The channel granularity reflects a 32kbit/s channel for a voice signal with speech encoding i.a.w. a Regular-Pulse Excitation combined with Linear Predictive Coding (RPE-LTP) resulting in bitrate of 13kbit/s, i.e. 260bit per 20ms. A detailed description of this encoding process is given in refs.[2,3]. This capacity is determined by a number of system parameters i.e. the size of the satellite (thermal dissipation), the DC provisions of the solar generator, the efficiency of the DC/RF conversion in the power amplifier and, last but not least, by the overall gain of the spacecraft and user antenna.

One of the interesting aspects of an inclined elliptical orbit is that the satellites appear to be quasi-stationary during a long period around the apogees. It actually remains visible for several hours at a very high elevation angle for the user terminals particularly for those in high northern lattitudes. This fact led to the name for this program LOOPUS: (Quasi-Geostationary) Loops in Orbit Occupied by Unstationary Satellite.

Due to the relative movement of the spacecraft with respect to the Earth the track of the subsatellite points creates two cross-over points. The elapsed travelling time of each satellite between the one closer to the apogee, through the apogee itself and back to the same cross-over point takes about 8 hours of 14.4 hours for an entire orbit. The coherency in the travelling of all nine satellites in their orbits creates for an earth bound observer the effect shown in Fig.   It seems as if all satellites would follow each other on the same ground track. One satellite after the other becomes "visible" until after 71h 46min the number one satellite shows up again.

By appropriate selection of the six parameters defining such orbits, the hand-over from the descending to the ascending satellite, referred to the cross-over points, can be handled by one earth station. It is further ensured that any of the five resulting apogee loops is occupied by exactly one satellite at a time ref.[4]. Since all satellites are only active transmitting within the defined loop, the remaining time of the orbit can be used for attitude and orbit corrections by means of an electrical ion thruster system.

System Design Rationale

Not particularly for mobile systems, but here this aspect is more critical than in fixed systems, is the generic conflict of illuminating large service areas such as one third of the Northern Hemisphere with sufficiently high power flux density (PFD). Large coverage and high PFD are basically conflicting requirements. As a result from a first analysis on maximum antenna size, a footprint of about 1000km in diameter has been determined as optimum. This spot corresponds to an antenna gain of 38.6dBi which would also be in line with the requirements from link calculations.

In terms of frequency selection, the restrictions induced by the rather limited bandwidth of the L-band for mobile satellite services, the investigations for LOOPUS have led to a different solution. It is expected that in the mid 90s the entire L-band is almost worldwide occupied by geostationary satellites, particularly by 2nd and 3rd generation INMARSAT. An interference analysis showed that frequency re-use (e.g. by polarization decoupling) can not be guaranteed under all mobile link propagation conditions. We, therefore, came to the conclusion, that the Ku-band provides a good compromise between sufficient bandwidth for further services on one side and a reasonable link attenuation on the other.

Today, the Ku-band already receives much attention mainly in the field of direct broadcasting and VSAT services. The growing market for Ku-band equipment in consumer technology has therefore not only significantly increased their availability at reasonable prices but also improved their performance (noise figures).

The application of Ku-band implies the use of high gain antennas for mobile terminals. This requires on one side a minimum tracking capability of the mobile antenna but on the other side offers the advantage of inherent frequency re-use due to large angular decoupling between satellites on inclined orbits from those on the geostationary orbit.

SYSTEM CHARACTERISTICS

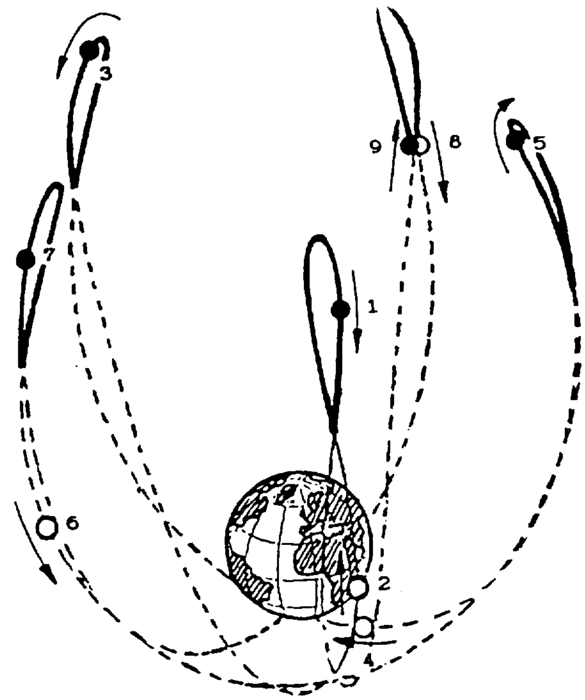
Highly-inclined Elliptical Orbit

Main characteristic of the full scale system is that nine satellites will eventually travel along three highly inclined (63.4°) elliptical orbits (HEO), three on each orbit. The selected orbit configuration with heights of 41450km and 5784km for the apogee and perigee respectively provides a simultaneous 24h-visibility in three major economic regions of the Northern Hemisphere: Europe, North America and Asia. The large potential visibility of the entire Northern Hemisphere and the resulting Earth coverages due to the high inclination is shown in Fig.

However, to cover the anticipated service area would still require 75 spots of this size. It is obvious that this approach for a fixed spot configuration is not only technologically but also economically unfeasable. Moreover, many of the provided spots would quite probably never require any communications at all. On the other side also areas of less frequent communications should not be discarded from the beginning (e.g. distress communications). A comprehensive market survey particularly for the LOOPUS system has not yet been performed. Comparison with or extrapolations from the terrestrial mobile market is inherently incomplete because the provisions of the potential service areas offered by this system are unique and are therefore hard to compare to other systems.

The conflict of high gain antennas with a large service area is solved in the LOOPUS case by means of an electrically steerable (flying) spotbeam implemented by an active phased array antenna. Thus, only one physical spot is used but capable to be directed and dwell on each required spot position on demand. Hence, no area is excluded per se but also no energy is wasted for unused spots.

Two active phased array antennas, one for receive one for transmit, are controlled by an on-board computer, allowing flexible beam hopping in accordance with a permanently updated, i.e. demand oriented, scan pattern.



Communications System Architecture

A number of up to 40 MSCs have been considered for each of the three regions to provide multiple access points to the terrestrial networks(ISDN or PSTN). This would provide one MSC in any significant area avoiding long and costly landlines. For a mobile call from Manitoulin Island e.g. into Ottawa it would be uneconomic to downlink via the Vancouver network and route by landline into Ottawa. Functionally, these MSCs are gateways between the satellite system protocol used on the space links and the required signalling protocols of the connected networks.

The operation of the satellite payload is performed in close cooperation with the Network Control Station (NCS). In the NCS all network management functions are implemented such as the

- configuration management
- fault management
- performance management
- security management
- accounting management

Also the special functions, Home Location and Visitor Location Register (HLR, VLR), are implemented in the NCS.

The spotbeams and the link concepts have briefly been outlined before. Now, Fig. shows the elements of the system architecture in one of the three defined regions. The satellite plays an active role in the operation of the system. It actually interconnects the mobile subscriber as well as the Mobile Switching Centers by providing all communications links.

The Communications System

The characteristics of the mobile channel, taking into account the high nominal elevation angle for mobile terminals, is expected to be dominated by direct propagation components. Particulary the degradations introduced by multipath propagation are less significant than those in L-band.

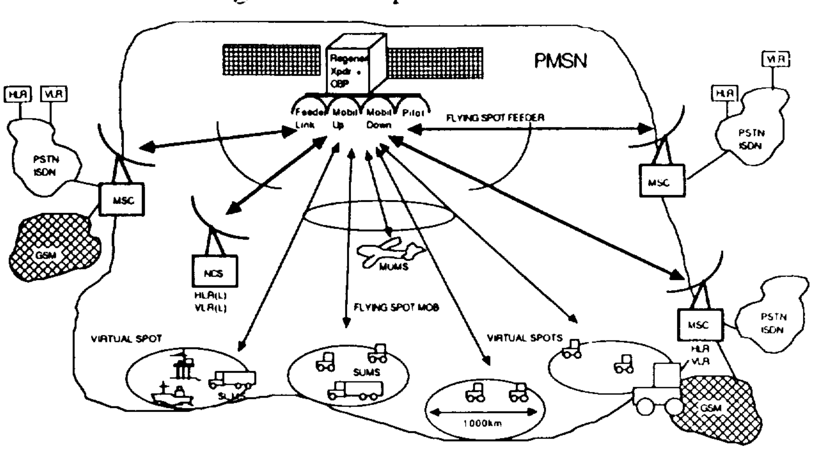
The flying spot concept makes a traditional FDMA approach impossible. Therefore, the existence of a time "slicer" (flying spot) leads to the application of TDMA, correlated and synchronized with the hopping of the beam. The resulting high bitrate for the indicated system summes up to 69Mbit/s, i.e. 2048 channel @ 32kbit/s each. The actual capacity of each virtual spot position is directly related to its dwell time.

Admittedly, at first sight, the high bitrate has a frightening impression due to its extraodinary magnitude. Theoretically, there is no difference in applying TDMA or FDMA to a given communication channel, it is simply not more than an exchange of time for frequency. However, a number of technical aspects do require a closer look before a final conclusion on the applicability can be taken. It is out of the scope of this paper to discuss the technical implications of using high bitrates, but a few remarks shall be given at this point.

The system is operated in Ku-band, i.e. 14GHz. At this frequency the ratio bitrate vs. bandwidth is moderate, hence power amplifiers and other frequency selective devices only have to provide a moderate bandwidth capability. As a further consequence, the unavoidable Doppler shift due to the relative movement of the spacecraft to the users becomes negligible against the necessary bandwidth of the broadband signal. The applied powerful modulation scheme is Rectangular Spectrum Modulation (RSM ref.[5]) providing excellent spectrum efficiency, fast acquisition combined with technological feasability.

The intelligent payload comprises a regenerative transponder with processing and routing capabilities and active phased array antennas. As mentioned before, these two antennas of $1m^2$ each are reserved for the reception and transmission of the mobile signals. A third combined receive/transmit antenna provides four spots for the Mobile Switching Centers.

All links are interconnected on baseband level, i.e. channel by channel, in the on-board switching processor. Control and the demand updating of the dynamic timeplan is performed in the NCS and permanently communicated to the on-board processor. The execution of the timeplan is then performed by the on-board processor. The updated timeplan reflects the actual change in demand in terms of channel capacity, dwell period and beam scan pattern of the system. With the availability of intelligent on-board facilities, many other functions in support of the overall system operation can be performed leading to autonomy in the overall system operation. This includes time management, present position calculation, information dissemination, initial access coordination monitoring and others.



PLMN - Public Land Mobile Network
MSC - Mobil Switching Center
NCS - Network Coordination Station
HLR - Home Localizing Register
VLR - Visitor Localizing Register
SUMS - Single User Mobil System
MUMS - Multiple User Mobile System

Flying Spot Antenna System
=> 93 Virtual Spots at 1000km diam
40 MSCs
Total System Capacity: 2000 Channel

SYSTEM ARCHITECTURE

OF ONE LOOPUS Mob-D PMSN

From looking at the overall topology of the LOOPUS system it becomes obvious that due to the excellent inherent coverage of practically any area of the Northern Hemisphere including the Northpole the offered services can be comprehensive. The clear cut separation of land, aero or maritime mobile diminishs in such a system environment. It has been pointed out that originally the orbits have been optimized for a coverage of the Northern Hemisphere. An extension into the Southern Hemisphere is hampered by the fact that the re-use of the Ku-band frequencies is achieved only as long as sufficient angular decoupling from systems in the geostationary orbit is ensured.

SYSTEM OPERATIONS

A beacon signal is transmitted via a global antenna from each active satellite to enable automatic tracking of the ground antenna. By receiving this signal, the system availability, system timing, direction of satellite and other system information can be obtained. In addition this beacon also serves as a return channel to a service request from a user terminal. The user terminal is inhibited to transmit during times that the beacon signal is not present. This beacon transmits on a separate frequency. It is important to note that the beacon can be received everywhere in the entire region and not only in the areas where the spot beam dwells.

A call can be initiated at any time the user sees the "ready" message on his terminal. After dialing, a short initial access burst carrying origin and destination information is transmitted from the user terminal on a separate frequency (slotted ALOHA coordinated by the beacon). This request is routed to the NCS. The NCS will in response acknowledge the request, check the authentication of the user card and will eventually allocate a channel in the on-board switch together with an update in the antenna scan pattern control. As a consequence, the spot will either extend its dwell time for another channel period or a new virtual spot position will be included in the pattern for the time of communication. At the same time the NCS determines the optimum gateway, i.e. the Mobile Switching Center closest to the desired destination of the call.

In analogy to the GSM, the call, its duration, service category and so on will be registered in the Visitor Location Register of the satellite system. The VLR function is located in the NCS. All information is then automatically communicated to the Home Location Register of the caller. So, one bill where all calls are listed is received at the end of the month.

Any satellite user terminal receives its network identity only after a smart card has been inserted. The insertion, even without an immediate call set-up, can be communicated to the system if desired and will create an update in the VLR. From that moment on, the user can be reached by any other subscriber in the system or caller from any other telephone in the world.

CONCLUSIONS

In this paper the HEO satellite based mobile communications system LOOPUS has been briefly described. It has been shown how the LOOPUS mobile subscriber can, via satellite, either communicate (voice, data, FAX, etc.) directly to each other or have access to any national public network (ISDN or PSTN) within three defined service areas: Europe, Asia and North America. Through the use of a sophisticated signalling in line with recommendations of the GSM group home and visitor location register (HLR/VLR), any subscriber in the entire LOOPUS system (i.e. Northern Hemisphere) would be within reach of any public telephone throughout the world.

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