Feasibility of an EHF (40/50 GHz) Mobile Satellite System Using Highly Inclined Orbits

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ABSTRACT

The pan-European GSM cellular system is expected to provide service to more than 10 million users by the year 2000. This paper indicates the feasibility of a new satellite system at EHF (40/50 GHz) to complement at the end of the decade the GSM system or its descendants, in order to provide additional services at 64 kbit/s, or so. The main system aspects, channel characteristics, technology issues, and both on-board and earth terminal architectures are highlighted in the paper. Based on the performed analyses, a proposal has been addressed to the Italian Space Agency (ASI) and the process is advanced aimed to the implementation of a national research plan.

INTRODUCTION

The pan-European L-band terrestrial cellular system (GSM) will provide mobile users with digital voice and low bit rate data services starting from early 90's. According to market forecasts, at the end of the century the GSM system will serve a population between ten and twenty millions terminals all over Western Europe. However, up to now this system is not intended to transparently provide the mobile user with 2B+D ISDN channels. Even a small demand of ISDN services (few percent of the overall GSM traffic) can motivate the deployment of a new satellite system to be integrated with the GSM system. Main objectives of such a new system are: (1) to provide higher data rates (64 kbit/s and possibly n x 64 kbit/s), for both high speed data and facsimile, video services and high quality voice, (2) to widen coverage to Eastern Europe, to the Middle East Countries and to Northern Africa, also filling possible temporary holes of the GSM system coverage, and (3) to better cope with the networking needs of private users in small regional areas.

Being the L-band very congested, it is mandatory to exploit higher frequency bands. Our feasibility study identified the EHF (40/50 GHz) frequency band as the most suited candidate in a ten year perspective. Putting into account technological trend data for RF components at EHF, some solutions have been proposed for a new mobile satellite system. This system utilizes Highly Inclined Orbits (HIO) with the apogee on the zenith of central Europe to minimize the probability of link obstruction.

The present paper highlights problems and possible solutions, both at system and subsystem level, that characterize the proposed satellite system. On the basis of the feasibility study, a proposal [1] was addressed to the Italian Space Agency (ASI) and the process is advanced aimed to the implementation of a national research plan.

SYSTEM ASSESSMENT

EHF Channel Model

In mobile systems the acceptable link unavailability generally ranges from 1 to 5 percent. The unavailability time can be estimated through the evaluation of the blockage probability due to obstacles (buildings, plants, etc.), the probability of severe multipath conditions, and the excess attenuation probability due to atmospheric effects.

Some experiments on blockage at 1.5 GHz showed that the unavailability time at 43° elevation is about 0.2 % on motorways and more than 50% in an urban environment [2]. Therefore, on the one hand the unavailability figure of a HIO system at EHF can be almost fully allotted to the atmospheric effects in rural areas. On the other hand, in metropolitan areas an adequate grade of service can only be provided under particular circumstances.

The 40/50 GHz mobile radio channel mainly suffers from rain and snow effects, clouds and fog, water vapour, molecular absorption and tropospheric turbulences. With respect to these channel impairments the 1 to 5 % unavailability range still lacks deep investigations. Therefore, to the purpose of the present preliminary analysis, some measured data, collected in the frame of the Sirio and the OTS satellite programmes, have been elaborated and extrapolated in frequency (Tab. 1) [3]. Acceptable performance is expected even at 50 GHz with reasonable power margins.

	SITE / UNAVAILABILITY % / ATTENUATION (dB)	SPINO D'ADDA		FUCINO		LARIO	
		0.1	1	0.1	1	0.1	1
40 GHz	RAIN	20	4.3	15.9	6.4	23.6	4.4
	CLOUDS	0.6	0.4	0.4	0.3	0.6	0.4
	WATER VAPOUR	0.6	0.6	0.4	0.4	0.6	0.6
	OXIGEN	0.5	0.5	0.4	0.4	0.5	0.5
	SCINTILLATION	0.4	0.4	0.3	0.3	0.4	0.4
	TOTAL	22.1	6.2	17.4	7.8	25.7	6.3
50 GHz	RAIN	26.6	5.4	21.1	8.6	31.4	9
	CLOUDS	1.1	0.8	0.9	0.6	1.1	0.8
	WATER VAPOUR	0.9	0.9	0.6	0.6	0.8	0.8
	OXIGEN	4.5	4.5	3.2	3.2	4.4	4.4
	SCINTILLATION	0.5	0.5	0.4	0.4	0.5	0.5
	TOTAL	33.6	12.1	26.2	13.4	38.2	15.5

Tab. 1: Estimated values of excess attenuation at 40 GHz and 50 GHz.

The use of highly directive earth terminal antennas that is compatible with vehicular applications at millimetre waves strongly reduces the multipath effects. Therefore, in the limit the channel can be c onsidered either AWGN or fully obstructed by ostacles. An exception to this will presumably be the case of personal communications where the channel turns out to be again a Ricean channel.

The preliminary link design indicates the following achievable performance [1]: (1) system availability between 95% and 99 % ; (2) BER $\leq 10^{-6}$; (3) capacity of about 1000 channels with less than 1kW class satellites.

HIO Implications

The joint adoption of satellites located on non-geostationary HIOs and of millimetre waves presents several implications at system level to be carefully evaluated. Among them the following two are here considered: zooming effect and Doppler effect.

During the activity period of a satellite (between two successive satellite hand-overs) the on-board antenna footprint dimension continually varies (zooming effect). In case of Continental coverage with multibeam antennas, pointing of each single beam must be independently controlled by electronic means.

The zooming effect can be partially compensated by providing the on-board antenna with a phased array feed subsystem, so to keep constant beam boresight directions. Therefore, individual beam coverage zones have variable dimensions, being minimum at hand-over and maximum at apogee.

In order to totally compensate the zooming effect, the beam radiation function must be controlled. This can be achieved either by time varying the beam gain so that it is maintained constant at the edge of beam coverage, or by keeping constant the power density at edge of coverage.

In the first case the on-board antenna main reflector is normally over-dimensioned, and is used with maximum illumination efficiency at hand-over. In the second case the power density is constant at edge of coverage: this can be achieved by statically shaping the beam to put into account the variation of the free space loss between the hand-over point and the apogee.

The Doppler effect is primarily due to the satellite movement and secondarily to the movement of the vehicle. The contribution due to the vehicle is about 3 kHz at 50 GHz for an elevation angle of 50° and vehicle velocity of 100 km/h.

By assuming the vehicle located in a given site, the satellite contribution can be split into a first component in the fixed link and a second component in the mobile link. Both these components can be evaluated as a function of the frequency and of the orbital parameters. At 50 GHz the maximum Doppler shift ranges from about 90 kHz to about 400 kHz, depending on the choice of orbital parameters. Due to the above extremely high values of Doppler shifts, some measures have to be taken. In case of a transparent satellite, the fixed earth station can provide a pre-compensation in the forward link. To avoid frequency compensation on the mobile, in the return link the correction of the up-link and the compensation for the down-link frequency are performed on-board.

A possible solution is to provide the Doppler compensation with respect to the centre of the beam, thus accepting a residual Doppler that increases towards the beam edge. The maximum value of the residual at 50 GHz ranges from about 3.5 kHz to about 6.5 kHz, depending on orbit selection (case of 500 km beam diameter).

SYSTEM DESIGN

On-board Architecture

A possible payload configuration is shown in Fig.1. This configuration assumes frequency division coverage of the mobile link, a transparent transponder on-board and the use of the 20/30 GHz frequency band in the fixed link.

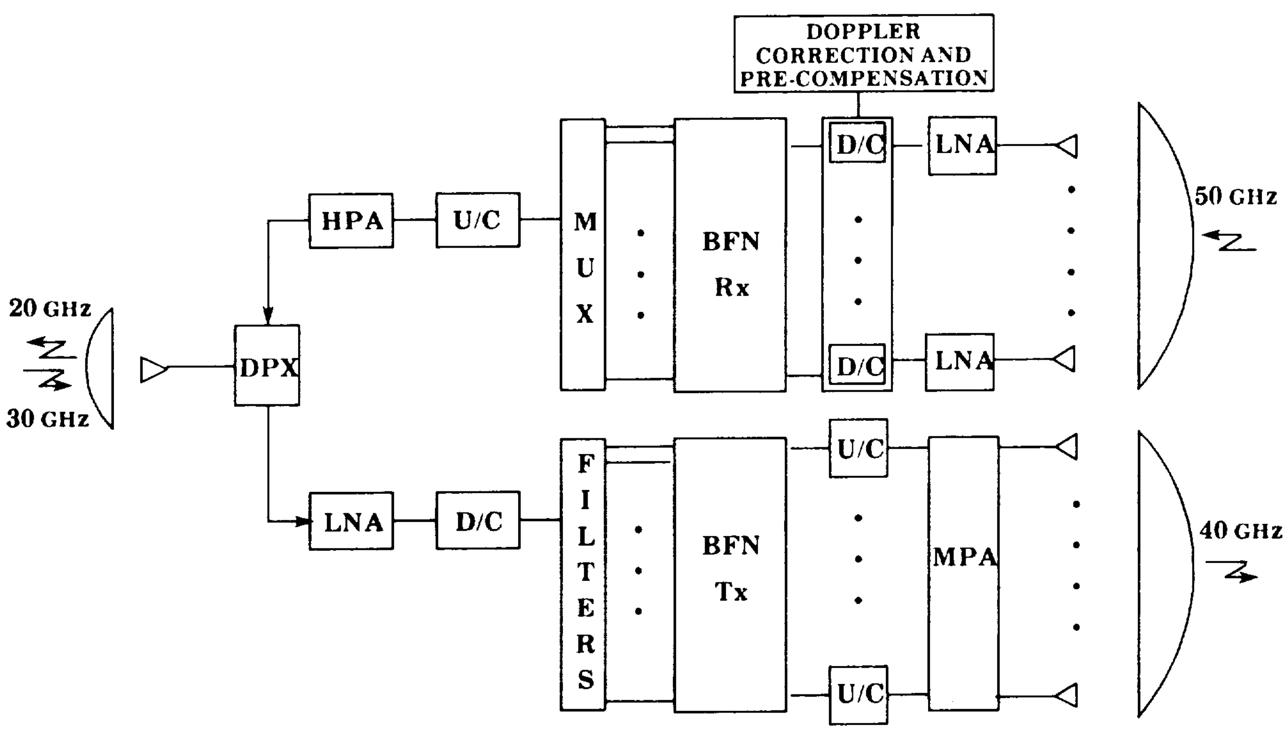

Fig.1: Payload configuration.

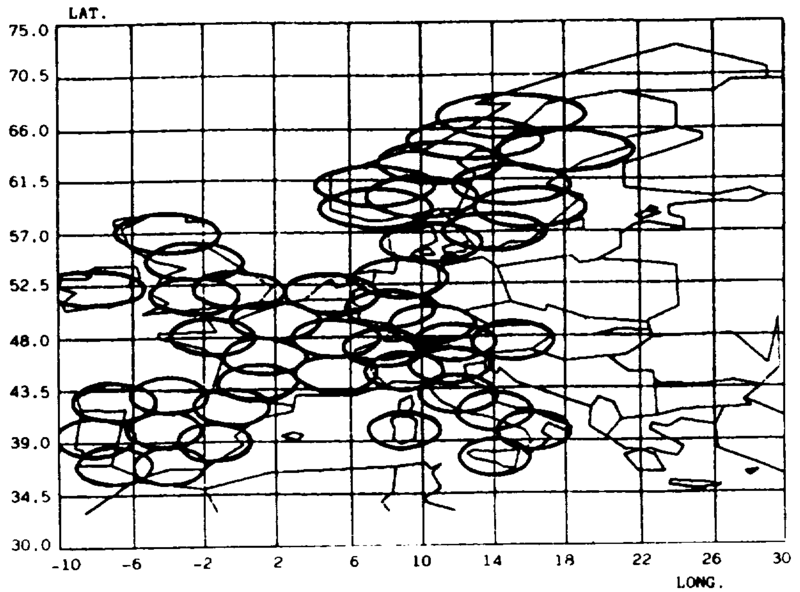

Fig.2: Mobile-links multibeam coverage of Europe.

To achieve the required multispot coverage of the mobile link, a suitable on-board antenna configuration consists of a reflector and a phased array feed subsystem located in the focal region. A single antenna could be used for both transmission and reception, however, due to the antenna limited size (diameter: about 0.5m), separate reflectors for the mobile up-link and down-link are assumed. The European coverage at 40/50 GHz is achieved with about 40 spots (Fig.2), approximately 500 km diameter each

The 40 GHz high power section is configured as a Multi-Port Amplifier (MPA) [4]. This configuration seems particularly advantageous in the proposed system thanks to: (a) efficient use of payload power in the presence of variable traffic loads; (b) graceful degradation of performance in case of failures of amplifying modules. Furthermore, when a set of low-power amplifiers with adjustable gain is adopted together with the MPA, the additional capability of a dynamic spot power reallocation results.

Most of the challenging aspects of the proposed payload architecture are related to the multibeam antenna subsystems and to the high power section. In particular, a MPA is envisaged with a number of ports equal to the number of radiating elements, adopting 40 GHz SSPA modules.

Link budgets show the need for 150 mW per carrier for an optimized selection of orbital parameters. This figure seems compatible with near-term technological outcomes.

Mobile Terminal

A focal aspect of the proposed system is the need for a high gain earth terminal antenna equipped with automatic tracking. Among possible solutions [5], active direct-radiating phased arrays with electronic steering seem to be the most promising in the envisaged program time scale. Two separate square array antennas to be mounted on the same panel have been considered, one for the reception (900 radiating elements), Fig.3, and one for transmission (400 elements). Antenna gains of about 37 dBi and of about 33 dBi result for reception and for transmission, respectively.

An overall radiated power of about 6 W is obtained by no more than 15 mW per radiating element. This figure is compatible with near-term power capabilities of monolithic amplifiers with FET devices at 50 GHz.

A low noise receiver of 500 K noise temperature is suitable for link budget needs. This figure is expected to be achieved at 40 GHz in the near future from HEMT monolithic amplifiers.

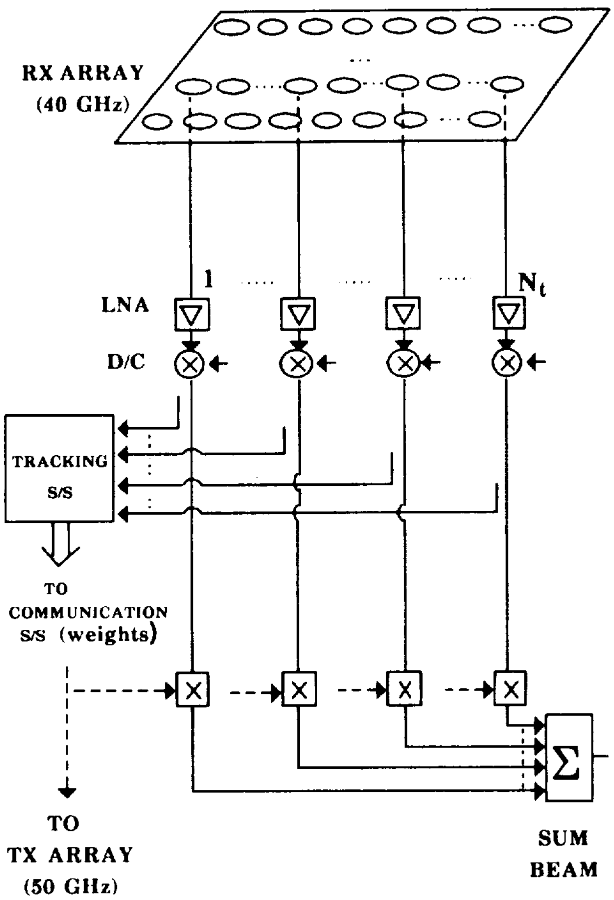

Fig. 3: Schematic of the mobile terminal receive antenna subsystem.

CONCLUSIONS

The satellite system here illustrated can be reasonably deployed within the end of the decade. Early technology development, experiments on channel characteristics and system definition can lead to a system capable to succesfully complement services provided by existing and near future terrestrial cellular systems.

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