Technical Report

Universal Mobile Telecommunications System (UMTS); Technical characteristics, capabilities and limitations of mobile satellite systems applicable to the UMTS (UMTS 30.20 version 3.1.0)

UMTS

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ETSI Secretariat

Postal address

F-06921 Sophia Antipolis Cedex - FRANCE

Office address

650 Route des Lucioles - Sophia Antipolis
Valbonne - FRANCE
Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16
Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° 7803/88

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c= fr; a=atlas; p=etsi; s=secretariat

Internet

secretariat@etsi.fr
http://www.etsi.fr

Contents

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Foreword

This ETSI Technical Report has been produced by the Special Mobile Group (SMG) of the European Telecommunications Standards Institute (ETSI).

Introduction

There are significant differences between satellite-based and terrestrial-based mobile communication systems in both design and type of service. It is only by combining the attributes of satellite and terrestrial services that it becomes feasible to fulfil the UMTS objective for widespread availability of third generation mobile telecommunication services.

This TR explains the reasons for these differences and then describes some candidate satellite constellations that may be adopted for the satellite component. Separate Clauses cover specific capabilities, characteristics, and limitations that are associated with any satellite-based mobile system.

A table of technical characteristics identifying likely ranges of values for key parameters is then presented. A final Clause discusses these characteristics from four specific viewpoints, namely services, radio, networks, and security.

1 Scope

This ETSI Technical Report (TR) identifies the key technical characteristics, capabilities and limitations of mobile satellite systems that are likely to need particular consideration during preparation of associated Universal Mobile Telecommunications System (UMTS) TRs. The objective is to ensure that the satellite component is adequately taken into account in each UMTS TR.

This TR does not focus on any particular satellite orbit or operational implementation but highlights the parameters and characteristics that are associated with candidate satellite systems and which may be significantly different to the terrestrial cellular environment. This TR will therefore assist the trade-offs to be made in selecting radio, services and network standards.

No assumptions are made on the relative time scales regarding introduction of satellite or terrestrial services but it should be recognised that in some regions, satellite UMTS will be available ahead of the terrestrial service. Users will therefore expect a common set of services (and terminal equipment).

2 References

[1] CCIR Recommendation. 465-5: "Reference Earth-Station Radiation Pattern for use in Co-ordination and interference assessment in the frequency range from 2 to about 30 GHz".

3 Abbreviations and symbols

3.1 Abbreviations

CDMA	Code Division Multiple Access
C/I	Carrier-to-Interference
C/N	Carrier-to-Noise
EIRP	Equivalent Isotropic Radiated Power
FDMA	Frequency Division Multiple Access
FSS	Fixed Satellite Service
GSO	Geostationary Satellite Orbit (see note)
HEO	Highly-inclined Elliptical Orbit
ISL	Inter-Satellite Links
LEO	Low Earth Orbit
LES	Land Earth Station
MEO	Medium-altitude Earth Orbit
PES	Personal Earth Station
S/N	Signal-to-Noise
TDMA	Time Division Multiple Access
UMTS	Universal Mobile Telecommunications System

NOTE: Geostationary Satellite Orbit - This term is in accordance with ITU Radio Regulation 182 but is sometimes termed GEO (Geostationary Earth Orbit)

3.2 Symbols

G/T Receive Performance Parameter dB/K, expressed as “(Antenna Gain dBi) minus (System Noise Temperature dBK)”

4 General aspects of mobile satellite systems

Differences between satellite and terrestrial systems exist in spite of common objectives for high quality services and excellent spectrum efficiency. Some differences arise because:

- user costs are closely related to satellite transmit power;
- the satellite propagation channel is highly predictable;
- satellite paths introduce significant propagation delays and Doppler shifts;
- frequency co-ordination has to be on a global basis and frequency re-use options are more limited, hence bandwidth is a tight constraint;
- satellite beam shaping and sizing opportunities are limited;
    - depending on the satellite constellation the footprints of the satellites' spot beams may move very fast across the earth's surface;
    - depending on the satellite constellation the associations between a PES and a spot beam's footprint, between a PES and a satellite, and between a satellite and a LES, respectively, may change frequently.

The first two points lead naturally to the emphasis placed on the line-of-sight satellite link budget when establishing the system design. The base link budget is derived from theoretical path losses to which link margins are added to compensate for inevitable impairments in equipment and propagation characteristics. All impairments, even if not directly calculable in terms of signal loss (e.g. group delay and rate of change of Doppler shift), are converted accurately to dB so that the compensating increase in transmit power can be established. The total margin over the theoretical ideal path is only a few dB and precision in calculating the contributory impairments is essential. The resulting link budget then allows the availability and quality of service to be estimated over the coverage area.

Large link margins have a major impact on system build cost and operating tariffs simply because of the impact of additional power requirements on spacecraft size — a 3dB excess margin would almost double user charges. For this reason, mobile satellite communication systems have lead the way in very power-efficient modulation formats and low bit rate voice codecs (2,4 kbit/s and 4,8 kbit/s) as well as adaptive power control. The drive for efficient use of satellite power is noticeably reflected in terminal equipment design with:

- very low loss antennas coupled with very low loss receive filters;
- very tight transmit/receive filter specifications;
- very low noise amplifiers;
- excellent carrier/signal acquisition in presence of Doppler, noise and interference;
- power-saving and spectrum-efficient forward error correction;
- multi-path discrimination techniques might facilitate low signal-to-noise demodulator operation

The satellite-mobile uplink and downlink are inevitably more fragile than the corresponding feeder links (land earth station-satellite). However the feeder link itself needs a very substantial link margin in order that the aggregate up/down performance may be largely determined by the mobile link. These feeder links operate in higher frequency bands where Doppler and atmospheric/meteorological disturbances can become even more significant.

The following clauses of this TR focus on particular characteristics, capabilities and limitations of mobile satellite systems together with typical values for key parameters where possible. However it must be recognised that most parameters are inter-dependent and will also vary with architecture of the ground infrastructure, the satellite orbital arrangement, and the user terminal configuration.

5 Candidate satellite constellations

The majority of present day satellites operate in the geostationary orbit to provide regional or global coverage although alternative orbits are now being considered for future mobile services. Each satellite's orbit is determined by gravitational laws and can be broadly classified by orbit period, orbit inclination, and orbit shape:

- Orbit period:
  - geo-synchronous (e.g. GSO, HEO/Tundra);
  - medium (e.g. MEO, HEO);
  - short (e.g. LEO);
- Inclination: non-inclined (equatorial);
  - highly-inclined;
  - polar.
- Shape:
  - circular;
  - elliptical.

Geostationary satellites have virtually zero inclination (less than 5 degrees) and circular orbits. figure 1 is an approximate scale drawing of (dynamic) satellite positions. The following paragraphs describe four particular examples of satellite orbits: Geostationary Satellite Orbit (GSO), Highly-inclined Elliptical Orbit (HEO), inclined Low Earth Orbit (LEO), and Medium-altitude Earth Orbit (MEO), all of which could operate to hand-held terminals.

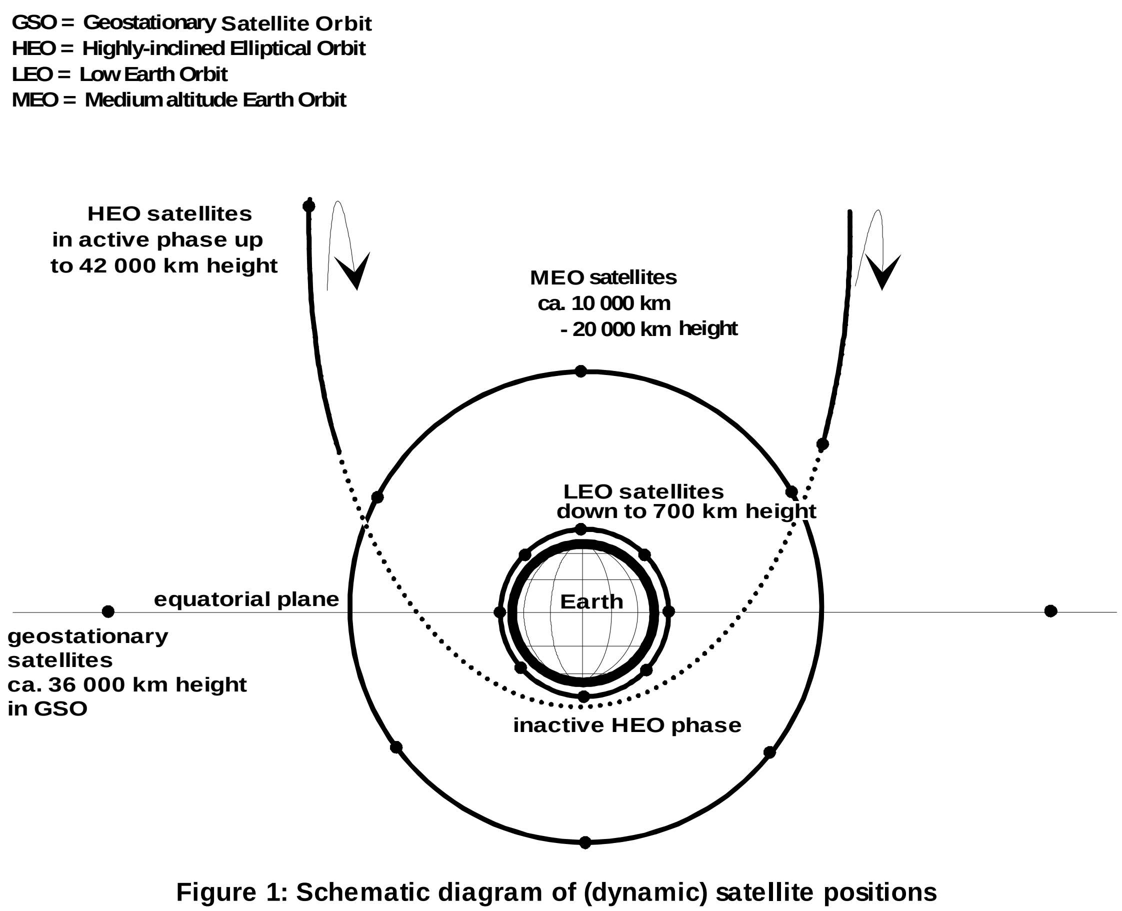

Figure 1: Schematic diagram of (dynamic) satellite positions

5.1 Satellites in GSO

GSO satellites orbit the Earth in the equatorial plane with the same angular velocity as the Earth at a height of about 36 000 km above the equator. Geostationary satellites therefore appear stationary to an earth-bound observer (see figure 1, GSO) and a single satellite can provide continuous service to roughly one third of the Earth's surface (but excluding polar regions above ± 75 degrees of latitude). The maximum distance the satellite can "see" on the Earth's surface is about 42 000 km and means the propagation delay for a single hop via the satellite (once up and down) can be up to 280 ms. Geostationary satellites also move about their nominal positions causing a small but noticeable Doppler shift on both the feeder and mobile links.

For personal and vehicle terminals, handover during a call between GSO satellites is unnecessary because the coverage is static and wide. However handover might be contemplated for aircraft terminals between different spot beams of the same satellite. In the latter case there is practically no difference in path length to consider.

Within Europe, GSO satellites appear at low elevation angles. For the geographical latitude of 50°North (e.g. Luxembourg), the satellites reach approximately 31° elevation as a maximum when the satellite is due South: either East or West of this position the elevation slowly reduces. Frequent blocking of the line-of-sight signal therefore occurs from trees, buildings and hills. GSO satellites can work in such a shadowed environment but the satellite Equivalent Isotropic Radiated Power (EIRP) would have to be increased by 15 dB to 20 dB or more depending on the coverage required. This could be achieved but has a serious impact on the size and cost of the satellite. In addition, assuming that the mobile EIRP is limited, the satellite receive sensitivity also has to increase and this can only be done with very large spacecraft dish antennas. For this reason, only very low bit rate services (i.e. paging, alerting, etc.) might be viable under such circumstances until the user moves to a more favourable position to receive a voice call.

5.2 Satellites in HEO

Satellites in HEO constellations orbit the Earth in planes that are inclined nominally 63,4° against the equatorial plane. This is necessary in order to keep the apogees in the most northern (southern) positions within their elliptical orbits. Typically HEO orbital periods are between 8 and 24 hours. HEO satellites are normally active only about their apogees where they appear nearly stationary to an earth observer for about eight hours, and then have to hand over to a following satellite.

The satellites belonging to one particular system appear in time shift in the same celestial region. In figure 1, the HEO track is sketched in profile showing at every point the true distance to the Earth's surface. In this specially depicted case, the orbital period is 12 hours and the satellites appear alternatively at the opposite sides of the rotating globe. Therefore the illustrated HEO track reaches a maximum height at both ends above the geographical latitude of 63,4° North. At both upper ends (solid line), the satellite payloads are active. The dotted line constitutes the part where the satellite payloads are (typically) switched off. For comparison, see figure 2, where two HEO loops are indicated corresponding to the two ends in profile in figure 1.

Under the above conditions, the HEO apogee (maximum height above the Earth's surface) can be up to 42 000 km. However the maximum range to the Earth's surface is in the order of 47 000 km resulting in a maximum propagation delay of the order of 310 ms. HEO satellites reach high relative speeds during their active phase (order of magnitude: 2 km/s), so that the Doppler shift (1.3×10^{-5} of radio frequency and bit rate) cannot be neglected: the radio frequency shift is mainly due to the microwave feeder link and is of the order of 50 kHz for C-band feeder links. The satellite motion is mainly radial relative to the user community, so that common compensation of the Doppler main component is feasible.

Irrespective of any user roaming, HEO systems require handover from the descending to the ascending satellite typically every eight hours. Depending on the specific system design, the distance to the two satellites at handover could be significant and a jump in path length cannot be excluded. However, a large Doppler jump will always happen.

Within Europe HEO satellites can appear near the zenith. Therefore the user can work under vertical line-of-sight condition for most of the time, with blockage only being experienced in tunnels or under bridges, trees, etc. However vertical propagation is not very good within multi-storey buildings and hence paging, alerting, etc. may not be satisfactory.

Because vertical propagation can be in principle multipath-free, high data rate services are possible for outdoor operation.

A number of HEO orbits have been studied extensively and given names such as "Molnya", "Tundra", and "Loopus".

5.3 Satellites in LEO

LEOs are typically circular orbits where satellites fly low above the Earth's atmosphere typically 700 to 1 500 km, bounded by outer atmospheric drag and the Van Allen radiation belts with an orbit time of about 90 minutes. For orbits near 1 500 km, inclinations near 50 degrees reduce the risk of debris collisions. Whereas polar orbits provide a whole Earth coverage including the poles themselves, inclined orbits can provide improved coverage over the populated areas located between latitudes -75 to +75 degrees.

One proposed system is known to stay 700 km above the surface (see figure 1; LEO) where the coverage area at any point in time may measure up to 3 000 km in radius for about 10 degree elevation. This implies a maximum propagation delay of 20 ms and while higher altitude LEO systems would have higher propagation delays, they will never approach the values associated with GSO or HEO systems for a single satellite hop. However, on-board processing and Inter-Satellite Links (ISL) can increase delays considerably.

LEO satellites move at very high speeds relative to the Earth's surface (7 km/s) and produce large Doppler frequency shifts ($4{,}7 \times 10^{-5}$ of radio frequency and bit rate). As the velocity is tangential to the Earth, Doppler compensation may need to be applied individually for each user.

LEO systems, in common with HEO systems, also require to handover between adjacent satellites, but at a much more frequent rate of about ten minutes. Although the two LEO satellites are widely spaced, the individual path lengths can be similar and it is possible to minimise any path length jump. However, the Doppler shift jump will still always happen.

As LEO satellites orbit very close to Earth, they can be considered as moving base stations. For the user the satellites appear most of the time below 30 degree elevation. Therefore LEO satellites work much of the time in a multipath environment. The additional satellite EIRP and receive sensitivity to compensate for multipath losses are achieved with a much smaller antenna on a LEO spacecraft (compared to GSO) because of the much shorter range (roughly 1/12th). Diversity techniques may offset some of these multipath effects.

The total number of satellites required to give total global coverage depends on many factors including quality of service and system capacity but the total could be as high as 70. Lower numbers are possible using special orbits or by using a mixture of LEO and GSO (for example). The cost for large numbers of LEO satellites is offset to some extent by their lower complexity and easier launch requirements. However their orbital life tends to be half that of typical GSO satellites (10 - 13 years). Another factor in LEO design is the required battery capacity and solar panel size to allow operation for nearly 50% of time in eclipse.

5.4 Satellites in MEO

MEO satellites are in principle the same as LEO satellites. The differences are that MEO systems cause more propagation delay (80 ms to 120 ms), their Doppler shift is smaller, and handover happens less frequently and is less problematic. MEOs also need to work in a multipath environment as the number of satellites is usually smaller than for LEO but the average margins can be lower since many calls will be at a continuously high elevation angle.

The typical MEO altitude is between 10 000 km and 20 000 km, just outside the Van Allen belts with an orbital period of around 6 to 12 hours. A complete MEO constellation would probably require between 10 to 15 satellites. MEO satellites are used to provide current global radio navigation services and are optimum for such services.

6 Capabilities of Mobile Satellite Systems (MSS)

The most significant attribute of any satellite communication system is the wide area coverage that can be provided with very high guarantees of availability and consistency of service. The satellite component of UMTS can potentially provide the terrestrial service user with a global service without regard to incompatible terrestrial standards used elsewhere. Existing satellite mobile services have proved very attractive to the maritime and aeronautical sectors and they have also been of great benefit to emergency services, relief agencies, journalists, and expeditions over recent years.

Services are now extending to the land mobile market where hand-portable voice terminals are now technically feasible. The next subclauses address the key attributes of wide area coverage and types of services appropriate for satellite UMTS.

6.1 Large area coverage

A single satellite can see very large areas of the Earth: a single LEO can illuminate an area of 6 000 km diameter and a GSO can illuminate about 1/3rd of the globe. Within these areas, the spacecraft antenna can be designed to maintain a near-constant power flux density on the Earth's surface irrespective of range. However for the GSO and HEO (and possibly the LEO or MEO), the spacecraft antenna may need to be arranged as a cluster of spot beams (1 000 to 2 000 km diameter) in order to make hand-held terminals feasible and to achieve spectrum efficiency. Such spot beams require large spacecraft antennas for either GSO or HEO systems.

The advantages of HEO and GSO are that it is possible to deploy a satellite system to fulfil a regional requirement rather than a global one, and frequency planning and co-ordination may be relatively straightforward. Furthermore, the ground infrastructure to support the satellites could follow traditional Land Earth Station (LES) approaches.

The only satellite system that cannot provide polar coverage is GSO. With this restriction, any satellite constellation can provide assured line-of-sight global coverage unaffected by weather. Operation to shadowed or in-building terminals would require an additional link margin in the order of 20 dB or more, depending on the coverage required. Note that in cities, the terrestrial UMTS service is likely to be available and therefore in-building and city coverage may not be essential.

The line-of-sight case requires polarisation matching between the satellite and the mobile terminal. To avoid the need for polarisation tracking, mobile communications have traditionally used circular polarisation.

6.2 Flexible networks and services

A feature of most present day satellites is the use of "transparent transponders". Compared to conventional cellular base stations, the satellite transponder is little more than a frequency shifting amplifier. This does have drawbacks with regard to some aspects of system design but it also means that any one satellite is reasonably independent of modulation system or access method, or of service data rate or networking. This has led to satellites being used for a variety of applications, each with different terrestrial architectures. Provided the basic satellite parameters are satisfactory, these services can be introduced long after launch.

Future satellites may not be quite so flexible as some studies propose to use on-board processing to improve capacity, spectrum efficiency and satellite payload performance. The transparency concept has however proved extremely cost-effective and any on-board processing function is likely to be at least re-configurable and re-programmable. Another feature that might be introduced for MEO or LEO is the inter-satellite link to simplify terrestrial networking between satellites during handover.

The transparency concept has enabled mobile satellite systems to efficiently support a range of services beyond that of voice telephony:

- high data rate services (up to 64 kbit/s) to larger antenna (0,15 m ~ 1,0 m, 8 dBi ~ 20 dBi) mobile or fixed terminals;
- group call and broadcasting;
- low data rate paging, alerting and two-way messaging;
- terminal location finding.

Some current satellite systems are designed so that extra services can be provided at very little additional cost. This is particularly effective when services are offered as a package to perhaps offset the requirement for line-of-sight paths for low-cost voice telephony.

7 Limitations of Mobile Satellite Systems

7.1 Delay and Doppler

The delay and Doppler effects associated with satellite links are due entirely to the mechanical laws governing the satellite orbit. Any system design must take full account of these effects. For example, simple delay has an impact on speech quality that will require echo cancellers to be used at interfaces with the analogue network. Delay also requires allowances to be made in signalling protocols and power level control.

Changes in delay are the result of integrated Doppler shifts on the bit data rate and are significant for all orbits except GSO during a call and particularly during satellite handover. Such changes are likely to require a data buffer to maintain the delay at a constant maximum value. The data buffer can reside in either the LES or the mobile terminal between the two echo control devices and is required for both receive and transmit.

Doppler shift itself complicates signal acquisition and spectrum management. The Doppler shift will not be identical for the in-bound and out-bound links due to the different feeder and mobile link microwave frequencies. Furthermore, the shift is in different directions if corrected at the mobile terminal. For LEO and MEO orbits, the shift may need to be individually corrected for each mobile; for HEO, common Doppler compensation can be incorporated in the LES or onboard the satellite.

7.2 Low link margins

Emphasis has already been made on the importance of keeping impairment margins low. An illustration can be based on the calculation of Carrier-to-Noise (C/N) ratios for uplink, downlink, and the total link. Assuming the downlink has C/Nd = 10 dB and is near the performance threshold, the feeder will need a 13 dB margin (C/Nu = 23 dB) to maintain the degradation to less than 0,2 dB (i.e. C/Nt = 9,8 dB).

Operation at levels just above threshold are only feasible for satellite because of the stable propagation path and because most impairments (including the large noise contribution) can be considered to be random. These low margins, compared to the terrestrial environment, result in longer signal acquisition times.

All impairments must be carefully analysed and include: imperfect in-band filtering, group delays, out-of-channel emissions (which demand very tight power amplifier linearity requirements, carrier to interference ratios, etc.)

Multi-path also requires especial attention. In the terrestrial environment, multipath propagation normally results in inter-symbol interference that can be compensated with equalisers. The effects of multipath fading itself are often negligible within the main service areas because the detected signal level is sufficiently above threshold. In the satellite path, multipath delays are often short enough to be ignored (except for aircraft and ships) due to the comparatively high elevation angle of the radio path. However multi-path fading, in which a multipath signal partially cancels the main signal, can reduce the final signal below the modem operating threshold.

Hand-offs between successive LEO, MEO, or HEO satellites will be more complex because of the small operating margins which makes it difficult to promptly detect signal disappearance. Satellite signal qualities often cannot be assessed from signal level (which is swamped by thermal noise) but are often estimated from the activity within the forward error correction algorithm. This requires time averaging and cannot be an instantaneous measurement. Satellite diversity reception might alleviate some of these issues.

Mobile terminals with high gain (directive) antennas have further problems with signal acquisition as the antenna may need to be mechanically or electronically steered towards the satellite before the signal rises above the detection threshold.

7.3 Spectrum and orbit matters

Limited spectrum availability will constrain the potential capacity of the satellite component and hence will orientate personal satellite services towards low bit rate voice and data.

Spectrum issues are very complex but can be broadly classified into three areas:

- feeder link planning;
- mobile frequency co-ordination;
- mobile frequency re-use and spectrum efficiency.

Global agreements exist for planning GSO systems via the ITU RS (formerly IFRB) for designated frequency bands. Feeder links are normally in one of the established Fixed Satellite Service (FSS) bands and are straightforward except for the large bandwidths required to support peak traffic on each satellite. Mobile frequency co-ordination is not simple however, particularly as their antenna patterns are near omni-directional and any mobile system is likely to require exclusive access to a frequency band. The next problem, that of re-using the frequencies as frequently as possible, is very similar in concept to terrestrial cellular planing except that isolation is provided by satellite antenna beam shaping rather instead of geographical spacing.

Feeder links for non-GSO satellites are more complex, particularly because of the lack of established procedures for the many possible orbits. Furthermore, there is no orbital registration akin to that in the GSO orbit where orbital positions are assigned to particular operators and countries. LEO and MEO may require several widely spaced feeder LESs per satellite sector or inter-satellite links to prevent the feeder link interfering with the geostationary orbit. In either case, there will be additional delay and Doppler jumps. For HEO orbits where the satellites appear to operate at the same part of the celestial sphere, feeder link planning may not be difficult as GSO-type procedures could be applied.

The magnitude of the orbit and spectrum planning problems is partly illustrated by figure 2 which shows an azimuth - elevation diagram for a fixed land earth station site at a latitude of approximately 50° North (It is not computed from simulated systems but shows only the principle. Therefore slight differences to simulated orbit constellations may exist).

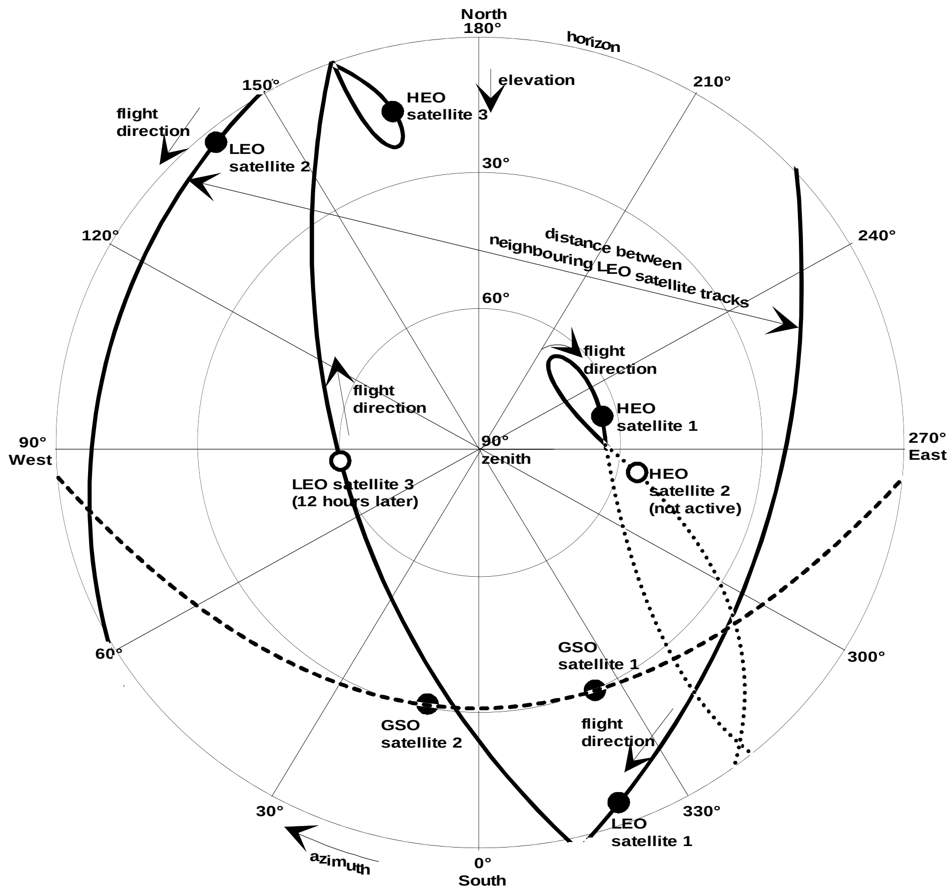

Figure 2: Azimuth - Elevation diagram of satellite tracks adjusted with the Earths rotation

The dotted line, extending from East to West in the shape of an arc, represents the geostationary orbit with two fixed GSO satellites designated 1 and 2. The three LEO tracks belong to one system of approximately polar orbits. The LEO satellites designated 1 and 2 travel North-South. LEO satellite 1 is about to hand over to LEO satellite 2. The LEO satellite 3 travels South-North, but this satellite No. 3 appears here at this track, due to the Earth's revolution, only at a time shift of half a day with respect to the satellites travelling North-South. The slight drift of the three LEO satellites towards West is caused by the Earth's rotation, and hence the rotation of the earth station site, towards East.

At the north-north-western horizon and in the East of the zenith there are two loop-shaped tracks of the HEO satellites designated 1, 2 and 3. The dotted lines extending from the loop near the zenith show the branches of the track where the communication payloads are inactive, as is here the case for the HEO satellite 2.

From the diagram one can conclude that a fixed earth station (according to CCIR Recommendation 465 [1]) at this site can communicate with GSO satellite 1 and HEO satellite 1, even when the LEO system is in operation. On the contrary, the links with GSO satellite 2 and HEO satellite 3 could not co-exist with LEO satellite 3, since it passes both the other satellite positions.

Assuming, the LEO satellites' orbit period were not adjusted with the Earth's rotation, then the LEO satellite tracks would scan across the sky like the lines on a television screen, and co-existence with neither GSO nor HEO satellites on the same frequencies would be possible.

7.4 Scope for technical developments

7.4.1 Signal to Noise (S/N) levels

Satellite systems operate very close to theoretical signal to noise demodulation thresholds. There is virtually no scope for reduction in receive thermal noise levels at the satellite or at the mobile terminal as noise levels are dominated by the Earth's background thermal noise (290 K). The noise performance of modern amplifiers is almost insignificant against this background. The only scope to improve signal to noise margins (for example to provide shadow or in-building operation) is to improve satellite antenna gain.

7.4.2 Hand-held terminal antennas

Present operational mobile satellite systems provide voice services with medium gain steered antennas in the gain range 8 dBi to 15 dBi. Low data rate services can use unsteered lower gain antennas with gains between 0 dBi and 4 dBi.

The challenge for UMTS is to provide voice telephony to hand-held terminals using unsteered low gain antennas. The hand-held target imposes practical limitations on the form of antenna and it is unlikely that antennas will have usable gains greater than 0 dBi. However this does not prohibit the use of higher gain antennas for particular applications or circumstances.

7.4.3 Satellites

Satellite technology and commercial launcher capabilities have matured over the past ten years allowing systems planners to design complex systems with confidence. However, reliability is paramount for commercial satellite services and therefore only well established technology, proven in space, is normally considered for major projects.

The satellite antenna is a critical system element. In order to allow operation with low-performance hand-held PES's, the satellite antenna must provide a high gain. This can only be achieved by using advanced array-type antenna technology, including electronic beam forming and beam steering. The resulting spot (cell) diameters on the Earth's surface are typically in the range 1 000 km to 3 000 km.

7.4.4 Digital modulation techniques

The potential capacity of any satellite system is limited essentially by the availability of frequency spectrum and on-board satellite DC power. Hence, for most cost effective operation, it is of paramount importance that power and spectrally efficient transmission schemes are employed. Current research is continuing to make worthwhile progress in this area.

7.4.5 Voice coding

Lower bit rate voice codecs have been widely used in mobile satellite systems compared to terrestrial systems to reduce power and spectrum requirements. Continuing codec development, coupled with advances in semiconductor integration, is likely to yield improved speech quality and some reduction in overall power/spectrum demands. Target performances for UMTS speech codecs have been set for both terrestrial and satellite components, taking into account the progress that is expected to be made by the time UMTS is introduced.

8 Summary of technical characteristics

Table 1:

Characteristic	GSO	HEO	MEO	LEO	Units/Notes
Propagation delay (Mobile-Satellite-Earth)	280ms	200-310 ms	80-120 ms	20-60 ms	maximum. (See note 2)
Satellite handover during call	Unlikely	Every 4 - 8 hours	Every 2 hours	Every 10 minutes	Typical values
Delay jump on handover	None	12 ms	24 ms	4 ms	very approximate
Doppler shift	± 1 kHz	± 50 kHz	± 100 kHz	± 200 kHz	very feeder-link dependant (note 3)
Doppler jump on handover	None	100 kHz	200 kHz	400 kHz	very feeder-link dependant (note 3)
Multipath delay/delay spread in-building (echo)	200 ns	<100 ns	200 ns	200 ns	much higher for aircraft and ships
In-call Multipath fading margin	5 to 10 dB e.g. for paging	2 dB	5 to 10 dB	10-15 dB	rough estimate for European latitudes (note 4)
Signal/data buffer needed	No	Yes	Yes	Yes	
Protocol response timing	Fixed	Variable*	Variable*	Variable*	*= fixed when plesiochronous buffering is used
Orbit period	24 hours	8 to 24 hrs	6 to 12 hrs	1.5 hours	Approximate
Approximate number of LES for global cover	10	10	10	50 (note 5)	Possible number for UMTS purposes
Range of elevation angles	0 - 45 °	>40°	>10°	>10°	Typical values for European latitudes
Number of satellites for near global cover	3	5 - 12	10 - 15	>48	

NOTE 1: All values are for guidance only.
NOTE 2: Inter-satellite links will increase these maximum values.
NOTE 3: These values are based on C-band links (4 - 6 GHz): proposed systems using Ka-band (20 - 30 GHz) will be up to **five** times greater. Doppler compensation can be applied to cancel a substantial part of the frequency shift
NOTE 4: This is strongly system and implementation dependent.
NOTE 5: Inter-satellite links reduces the number of LESs for global cover.

9 Implications for UMTS design

The following subclauses and sub-paragraphs identify some areas that may need particular consideration.

9.1 Service-related considerations

a) UMTS satellite services can only be made economic by careful optimisation and trade-offs between system capacity, service availability, and quality of service. The selected satellite orbital configuration will also impact upon these three service parameters and it is entirely possible that more than one satellite system may exist to meet various market requirements around the globe. The UMTS satellite standards may also need to accommodate more than one system design provided UMTS principles are not violated.

b) The scarcity of spectrum, the cost of providing high spacecraft EIRP and G/T performance, and the overall objective to operate to handheld mobile terminals will require use of lower bit rate voice codecs than may otherwise be used for the terrestrial service. Codecs operating between 2 to 4 kbit/s are already well established but currently do not offer the same quality as second generation digital cellular codecs: it is not yet known to what extent the quality shortfall between UMTS satellite and (higher rate) cellular codecs can be offset by more advanced and more complex codecs but current research is encouraging.

c) The satellite radio propagation path should ensure UMTS services are available anywhere within line-of-sight of a satellite, subject to network capacity and regulatory constraints. However availability in shadow and inside buildings can be expected to be substantially less. To offset this limitation, the satellite terminal may need to operate in several modes, perhaps simultaneously: for example a two-way messaging service fully integrated with conventional voice telephony services could maintain a basic service with higher availability. Similarly, high penetration "ring alert" could warn the user to move to a more favourable location but the mobile terminal may not be able to communicate a response until the user has done so. Other "integrated" approaches may offset some of the other inherent satellite limitations.

d) The emphasis in UMTS satellite system design will be to provide high capacity, low cost services to support low bit rate voice and fax/data operation. However some user terminals may employ higher gain (i.e. larger) antennas and these should not be prevented from accessing significantly higher data rate services. Higher performance mobile facilities are likely to be commonplace on fixed, maritime or airborne stations.

e) End-to-end delay in satellite-based links is caused by the path propagation delay (e.g. 280 ms for GSO), codec, coding, and possibly transcoding delays. In rural communities, a larger number of calls are likely to be satellite mobile to satellite mobile (via a land earth station and switching centre) with a consequent increase in total delays.

f) The satellite system, operator, or regulator may require to know the mobile terminal's geographical position to a reasonable degree of accuracy. A possible future service requirement may be to make such information available to authorised agencies, for example rescue co-ordination.

g) Non-satellite equipped mobile terminals require to operate via an intermediate UMTS mobile cell site connected to the satellite network. A typical scenario will be passengers on satellite-equipped vehicles. Note that Mobile Cell Sites may have significant impact on the design of radio, network, and security aspects., irrespective of whether UMTS service is provided via the terrestrial or satellite component.

h) Satellite diversity techniques may permit trade-offs between quality of service, and network complexity, and system costs.

9.2 Radio related considerations

a) Narrow spot satellite beams are critical to introduction of hand-held satellite terminals for two reasons: firstly the high gain antennas (leading to increased EIRPs and receive sensitivities) facilitate the concept for hand-held terminals and secondly multiple small spot beams allow improved frequency re-use to increase system capacity. The adoption of small spot beams is not necessarily limited to low or medium earth orbits but complex beam forming networks and very large deployable satellite dish antennas would be required for a GSO or HEO spacecraft.

b) At present, any significant spectrum sharing between UMTS satellite and terrestrial services appears not to be practicable, at least not in the same large geographical area.

c) Finely balanced system optimisation will be essential to make a low cost satellite hand-held service viable. For this reason, modulation formats consistent with good S/N, and C/I performance will need to be selected and may not be able to be the same as the terrestrial component where different constraints apply.

d) Satellite spectrum will be very scarce compared to terrestrial spectrum (where micro-cellular networks can be used, for example, to increase capacity). All channel overheads will need to be reduced to an absolute minimum. Some functions that might be handled in higher terrestrial layers could, for example, be embodied more efficiently within the satellite physical layer.

e) Satellite signalling and broadcast channels will generally operate at higher powers or with more robust protection than traffic channels.

f) Radio access protocols and link control must be tolerant of signal acquisition delays, variable propagation delays, Doppler shifts, and delay or Doppler jumps.

g) The speech coder should be designed such that bit rate is minimised, with possible compromise in speech quality and commonalty with terrestrial speech coders.

h) Radio multiple access techniques such as Code Division Multiple Access (CDMA), Frequency Division Multiple Access (FDMA), and Time Division Multiple Access (TDMA) are all potential candidate solutions for the satellite component. Each offers particular advantages and disadvantages dependent on the service requirements and the orbital/system characteristics.

9.3 Network related considerations

a) GSO and HEO satellites give the most straightforward network access in terms of wide coverage for a single station. Call routeing is therefore straightforward. At the other extreme, LEO's require a network access station for each coverage zone: typically 100 to 200 stations globally and this makes call routing and roaming more complex. Inter-satellite links can reduce this for LEO's to a smaller number but with increased satellite costs, increased delays and the added complexity of the ISL network itself as drawbacks.

b) Call routing will need to comply with UMTS principles (e.g. minimum cost) but with possibly additional complications due to the large area coverage of the satellite cell, and the need for beam-to-beam or satellite-to-satellite hand-overs which are likely to require network resources from a multiplicity of network operators.

c) Extension of UMTS satellite into countries without terrestrial UMTS services may need different arrangements for interfacing with fixed networks.

d) Access to a satellite from, say, the home network may need to utilise facilities associated with a third party terrestrial network who has satellite interfaces and is within range of the required satellite. Hand-over events between non-GSO satellites may also require hand-overs between different third party networks.

e) Network protocols and management (including charging, security, etc.) need to take account of mobile cell sites mounted on vehicles for the provision of satellite service to non-satellite mobile terminals.

f) More than one satellite system may exist, and may employ different orbital or technical characteristics.

g) The spot beam coverage associated with any one satellite is likely to cover a number of terrestrial networks in different countries.

h) Call set-up time constraints to satellite terminals should recognise the possible delay for a user to move the terminal to a more favourable location before establishing a return acknowledgement

i) Intelligent paging - depending on the satellite constellation - supports the efficient use of satellite power.

9.4 Security related considerations

a) Time dependent security functions must accommodate satellite delays.

b) Security aspects must consider the need for codec transcoding and reformatting of data/signalling information when a non-satellite equipped user terminal accesses the UMTS satellite component via a mobile cell site (see subclause 9.1 g)).

History

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