Study of satellite role in 4G mobile networks

Background, system scenarios, requirements and technical issues

Annex to SoW
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1 Introduction

In this Annex, some background information and preliminary requirements for a possible 4G satellite system are described. This Annex is divided in three sections:

- The background section provides information on some 2G/3G satellite systems currently operational or being investigated. It also provides some background of beyond 3G terrestrial systems under definition/development. However, they are not representing an exhaustive list of results of studies looking at systems beyond 3G. Some preliminary considerations on the kind of architectures that can be looked at for a 4G satellite system are also given in the last part of this section.

- The Requirements section first presents a set of requirements in terms of user mobility, data rate, services and terminal types. Then, the general requirements for a 4G satellite system are given.

- The last part of the Annex addresses some of the technical issues considered relevant for this study.

2 Background

There are few examples of satellite systems incorporated in the 2.x/3G network. Satellite systems such as BGAN [Ref1] and Thuraya [Ref2] are currently in operation providing mobile services to different kinds of user terminals. Other systems such as MBSAT [Ref3] use an hybrid architecture combining the satellite and terrestrial components to provide broadcast services to mobile users; taking advantage in this way of the broadcast capability to complement 3G services.

The other trend in satellite systems consists in providing broadband services to terminals on the move. The term “broadband mobile” is commonly used to describe the provision of multimedia services to planes, ships, trains and vehicles. The general idea is to start from systems and standards designed originally to provide multimedia services to fixed terminals and to use and adapt them for delivering the same or slightly limited services for users that want to be connected on-board one of mentioned transports. Several concepts have been developed for dedicated environments (i.e. only planes or trains) using proprietary solutions but now the idea come to re-use existing standards such as DVB-S2 and DVB-RCS. This is the object of a specific on-going ARTES 1 "Study of DVB-S2/RCS broadband mobile systems". For what concerns the evolution of the 3G in the terrestrial side, HSDPA (High Speed Downlink Packet Access) is considered as the first example of a 3.5G system. From a user perspective, it consists basically in an improvement of the downlink speed, with expected data transmission rate up to 8-10Mbps, over a 5 MHz bandwidth downlink channel and using W-CDMA. HSDPA implements numerous novel techniques such as ACM, H-ARQ, MIMO or FCS. In 3GPP Release 4 specifications [Ref4], these techniques are presented and analysed.

NTT DoCoMo is developing a 4G system which, up to know, is out of any standardization entity [Ref6]. This system is dealing only with the terrestrial domain and it introduces several new technologies to meet the stringent requirements compared to the 3G system in place (higher throughput, lower latency, higher spectrum utilization efficiency). A much wider bandwidth is expected to support broader broadband wireless services. The solution is based on an FDD channel
configuration with different access schemes on the uplink and downlink that are evolutions of the CDMA-related technologies. The downlink transmission is using the so-called VSF-OFCDM, which is a combination of MC-CDMA with OFDM. The uplink transmission is based on the so-called VSCRF-CDMA (Variable Spreading and Chip Repetition Factor CDMA). This system has been already tested in laboratory and field trials have been performed with 1 Gbps reached on the downlink for a terminal moving at 20 km/h in the 5-6 GHz bandwidth. The start of commercialization is planned to start in 2010.

2.1. Considerations of the possible role of the satellite in 4G network

Different satellite architectures may be considered in order to answer different needs. For example, linguistic beams or multi-beam satellite systems may offer an extended coverage over a large region and guarantee service continuity in areas where the terrestrial network is inefficient to provide such services. Multibeam satellite systems could provide mobile unicast services (evolution of INMARSAT current system), mobile multicast services (evolution of the S-MBMS system), and/or broadband services (Evolution of DVB-S2/DVB-RCS systems to the mobile environment). Another possible solution consists in a “Hot-spots” coverage where a narrow satellite beam is directed to a particular area. A several hundreds Km diameters spot beam could serve an area where the data rate demand per squared km exceeds what is currently available from the terrestrial network. Satellite can also provide multicast/broadcast services to mobile terminals over that area in a more efficient way than terrestrial networks. Furthermore, if the location of the spots is reconfigurable, a satellite system could offer a fast and efficient solution to solve temporary high traffic demands in a specific area. This reconfiguration capability can be key element especially for the professional and governmental market. These markets may require a quickly deployable mobile broadband capacity over crisis regions or in case of disasters. In this case, the satellite component will be required to provide high quality multicasting and interactive services provision with a high level of reliability and security by means of a reconfigurable coverage with several linguistic or narrow spots.

Summarizing, there are three major rationales for the use of satellite in the 4G network:

- The exploitation of the broadcast/multicast capability
- The extended coverage provided by the satellite
- The possibility of fast coverage deployment (in the case of beam reconfigurability)
3 Preliminary Requirements

3.1. 4G services and applications

Mobile systems have started from transmission of voice in 2G and they have evolved towards data transmission with more and more demanding data rates in 2.5G systems. GSM and GPRS are sufficient for simple transmission of voice and data up to 160 kbps with GPRS. The third generation and 3.5G are under CDMA, WCDMA, EDGE or HSDPA technologies. This allows transmitting high-speed voice and data. Typically the average data rate noticed with UMTS is 250kbps. The 3.5G represented by HSDPA should provide a few Mbps, up to 15Mbps; HSDPA can allow downloading music or video, watching television and participating to videoconferences.

The 4G systems will be required to provide high speed, high bandwidth full packetized data communications. One of the main services to be provided by the 4G systems will be Internet style functionality via wireless communications. Customers for this set of services will be found in the three targeted market sectors. The consumer sector will demand social and entertainment applications (on line video games, mobile TV...). For the professional market, users will focus on the information applications (personalized news services and streaming news feeds). There will be also professional users that will require the 4G network in order to conduct day-to-day business (mobile faxing, emailing and instant messaging). Contrary to the first class of professional users, these users are more concerned by the availability of the services than by the cost. The emphasis shall then be done on providing worldwide roaming using a single communication device. The governmental sector also aligns with this demand requiring at the same time secure communications.
In addition, location aware services can be an added-value for service providers. This type of services concerns primarily instant messaging in order to provide the user with information related to the place he is (road traffic, weather, …). In today’s networks, location can be determined by looking at the serving cells that are communications with the user’s handset but this technique does not provide the accuracy needed for 4G applications. This type of services in 4G requires the knowledge of the position of the mobile either by GPS-like system or by a function built in the mobile network.

3.2. Mobility requirements

Different kind of mobile users can be identified which are associated with different requirements. In this respect, market can be segmented between the mobile users and the nomadic access users. The focus of this study will be on the mobile users. Mobile users can be classified according to their requirements in speed: pedestrian, land vehicular, maritime, airplanes. Table 1 shows the requirements in terms of speed and acceleration.

<table>
<thead>
<tr>
<th>Maximum speed of terminals</th>
<th>10 km/h</th>
<th>For pedestrian</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>150 km/h</td>
<td>For cars and trucks</td>
</tr>
<tr>
<td></td>
<td>1200 km/h</td>
<td>For long-haul flights</td>
</tr>
<tr>
<td></td>
<td>30 km/h</td>
<td>For maritime environment</td>
</tr>
<tr>
<td></td>
<td>350 km/h</td>
<td>For fast trains</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Maximum acceleration of terminals</th>
<th>-</th>
<th>For pedestrian</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 m/s²</td>
<td>For cars and trucks</td>
</tr>
<tr>
<td></td>
<td>17 m/s²</td>
<td>For long-haul flights</td>
</tr>
<tr>
<td></td>
<td>5 m/s²</td>
<td>For maritime environment</td>
</tr>
<tr>
<td></td>
<td>10 m/s²</td>
<td>For terrestrial environment</td>
</tr>
</tbody>
</table>

Table 1 : Speed and acceleration requirements for mobile terminals

3.2.1. Channel model requirements:

From these mobility requirements, it shall be derived the requirements for a channel model. The model used for the mobile channel shall be based on accurate estimation and modelling of propagation statistics. It should combine the effects of weather attenuation process (if relevant in the considered frequency bands) and the effects of mobility: Doppler, multipath and shadowing. The model shall also consider channel state changes adapted to environment configuration and mobile terminal speed.

3.3. Preliminary Requirement per terminal classes and market sector

Typical data rate requirement for 4G terrestrial systems are considered to be 100 Mbits/s for high mobility and 1 Gbits/s for nomadic terminals. Although satellite systems may not be able to offer such peak data rate, their ability to have an extended and flexible coverage may make them a key element in the 4G architecture. Bearing
in mind these considerations, the main requirements classified per terminal classes can be summarized as follows. It is understood that some of the requirements (highlighted in bold) may be extremely constraining for the satellite system and therefore are subject to further analysis:

**Handheld terminal requirements:**
- These terminals shall have the capability of accessing the satellite directly and/or via another satellite terminal.
- Provide multimedia services (mainly “infotainment”, radio, data, video)
- **Data rate >1Mbps downlink, 500 kbps uplink (TBC)**
- Line of sight outdoors availability > 95 % for consumers >97% for professional and governmental
- Real time service availability: > 90 % for consumer >95% for professional and governmental
- Non real-time service availability: > 97 % (TBC) for consumer > 99% for professional and governmental
- **Indoor coverage**
- Low power, high autonomy
- Memory (requirement to be specified w.r.t. technology)
- Speed: from pedestrian to vehicular (car/trucks)
- **Price of the order of hundreds of euros for consumer market.**
- **Return link (only professional and governmental market terminals)**
- Integration with navigation terminals.

**Land Vehicular terminal requirements:**
- Two kinds of land vehicular terminals: Individual terminals that connect one user to the satellite and collective terminals that can connect several users to the satellite (expanding for example, the capabilities of the handheld terminals). The individual terminal can address the three market sectors, the collective terminal will be dedicated to the professional and governmental markets.
- Provide multimedia services, Internet (TBC) and high-quality mobile television
- **Data rate > 10Mbps downlink, 2 Mbps uplink (TBC)**
- Low cost (for consumer market)
- Integration with navigation terminals (real time traffic information, location related multimedia reception…)
- **Line of sight outdoors availability 98 %**
- Real time service availability: > 95 % for individual and >97% for collective
- Non real-time service availability: > 99% (TBC)

**Mobile platform terminal (train, ships and airplanes) requirements:**
- These terminals are dedicated to the professional and governmental market. These terminals access directly the satellite and shall provide access to the 4G network to the users in planes and trains.
- Kind of services: Voice, data, multimedia, Internet access, Virtual Private Networks
- **Data rate > 50Mbps downlink, 10 Mbps uplink**
- **Line of sight outdoors availability 99 %**
- **Real time service availability: > 97 %**
- **Non real-time service availability: > 99 % (TBC)**
- **Security**

### 3.4. Summary of the preliminary requirements.

This table hereafter summarizes the preliminary requirements for a 4G satellite system.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency band</td>
<td>L, S, C, Ku, Ka, Q</td>
<td>The frequency band on uplink and downlink can be different</td>
</tr>
<tr>
<td>Type of beams</td>
<td>Linguistic beams or multibeams or/and hot spots</td>
<td></td>
</tr>
<tr>
<td>Coverage</td>
<td>EU25</td>
<td></td>
</tr>
<tr>
<td>Number of beams</td>
<td>&gt;6 for linguistic beams in C, L or S bands</td>
<td>To be adapted depending on the market and on the frequencies</td>
</tr>
<tr>
<td></td>
<td>Several tenths for multibeams in all bands</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;5 for hot spots in Ku or above bands</td>
<td></td>
</tr>
<tr>
<td>Number of users</td>
<td>TBD</td>
<td></td>
</tr>
<tr>
<td>Bandwidth per beam</td>
<td>TBD</td>
<td>To be analyzed depending on system dimensioning</td>
</tr>
<tr>
<td>Frequency re-use</td>
<td>TBD</td>
<td>To be analyzed depending on frequency</td>
</tr>
<tr>
<td>Type of terminal</td>
<td>Handheld</td>
<td>1 user</td>
</tr>
<tr>
<td></td>
<td>Individual vehicular</td>
<td>1 to a few users</td>
</tr>
<tr>
<td></td>
<td>Collective vehicular</td>
<td>Several tenths of users</td>
</tr>
<tr>
<td></td>
<td>Mobile platform terminal</td>
<td>Hundreds of users</td>
</tr>
<tr>
<td>Maximum speed of terminals</td>
<td>3km/h</td>
<td>For pedestrians</td>
</tr>
<tr>
<td></td>
<td>120km/h</td>
<td>For car and buses</td>
</tr>
<tr>
<td></td>
<td>1200km/h</td>
<td>For long-haul flights</td>
</tr>
<tr>
<td></td>
<td>30km/h</td>
<td>For ships</td>
</tr>
<tr>
<td></td>
<td>350km/h</td>
<td>For fast trains</td>
</tr>
<tr>
<td>Maximum acceleration of terminals</td>
<td>Negligible 8m/s² 17m/s² 5m/s² 10m/s²</td>
<td>For pedestrians For car and buses For long-haul flights For ships For fast trains</td>
</tr>
<tr>
<td>Applications supported</td>
<td>Broadcast and multicast “infotainment” Internet applications</td>
<td>For handheld consumer For handheld professional</td>
</tr>
<tr>
<td></td>
<td>Broadcast, multicast, interactive/multimedia, internet applications and high quality mobile television up to 10Mbps</td>
<td>For individual and collective vehicular terminals</td>
</tr>
<tr>
<td></td>
<td>Broadcast, multicast, interactive/multimedia, reliable voice and data communications, VPN up to 50Mbps</td>
<td>For mobile platform terminals</td>
</tr>
</tbody>
</table>
### Parameter | Specification | Comment
--- | --- | ---
FWD link data rate | 1 Mbps | Handheld
| 10 Mbps | Land vehicular
| 50 Mbps | Mobile platform
RTN link data rate | - | For consumer handheld
| 500 Kbps | For handheld (professional governmental)
| 2 Mbps | For vehicular
| 10 Mbps | For collective vehicular
| | For mobile platform
Doppler drift and shift | TBD | To be evaluated for each terminal and type of coverage
Link availability | Between 95 and 99 % depending on the terminal | TBC
Cost of satellite terminal | ~100 euros | For handheld terminals
| ~1000 euros | For individual vehicular
| TBD | For collective vehicular
| TBD | For mobile platform
Interconnection with terrestrial networks | Dual mode (terrestrial satellite) also possible connection with collective vehicular terminals. | For handheld terminals
| Dual mode | For individual vehicular terminals
| User connected via LAN and dual mode | For collective vehicular terminals
| User connected via LAN and dual mode | For mobile platform

### Technical issues

Although this is not an exhaustive list, some technical points can already be highlighted as key elements enabling the role of satellite in 4G networks:

- Advanced Multiple access scheme

One important issue for 4G systems is the choice of a multiple access scheme adapted to the kind of traffic and number of users. Different kinds of CDMA, FDMA, OFDMA, TDMA and SDMA access schemes have been proposed for the 3G and 4G networks.

- MIMO techniques [Ref7] [Ref8] [Ref9]

MIMO systems exploit the space-time properties of wireless channels in order to improve the overall system performance in terms of capacity and spectrum efficiency. Multiple antennas at the transmitter and receiver provide diversity in a fading environment. One of the most important challenges of MIMO is how these advantages can be exploited on systems with small mobile terminals operated with batteries. Current work in this area seems to indicate promising results in the development of low consumption chipsets for handheld terminals.

- Multi-user detection

Multi-user detection deals with the detection of data in interference channels in order to optimise the received signal. Different studies have already shown the interest of
these techniques in multibeam satellite systems [Ref10]. In combination with MIMO, MUD techniques could improve system capacity in a high user density environment.

- **Adaptation techniques**
  The mobile channel presents high time and spatial fluctuations and different characteristics depending on the environment and speed of the mobile terminal. An efficient link adaptation is thus required in the system in order to optimise the resources and achieve transmissions with a good quality of service. As the nature and effects of the impairments are quite diverse, the efficiency of the link adaptation is synonym of flexibility in the techniques ensuring this link adaptation. Essentially two main techniques are interesting to combine for the mobile environment with multimedia services: Adaptive Coding and Modulation (ACM) and Hybrid Automatic Repeat reQuest (H-ARQ).

- **Multimode terminals**
  4G is characterized by the need to access numerous services with very different characteristics and possibly also the need to access different networks in different frequency bands using different transmission schemes.

  Since many years a lot of research work has been done in the domain of software radio, cognitive radio, self-adaptive terminals, multimode terminals… and whatever other denomination used. Basically there are two alternatives for designing the satellite terminal:

  1) All possible waveforms are implemented and the terminal only needs to switch depending on the waveform that is used.
  2) A subset of the waveforms is implemented on the chip and new waveform algorithms can be downloaded if necessary.

  Evolution of technologies allows today to choose the first approach as it is possible to implement many algorithms on a single chip, thus not specifically increasing the power consumption or the mass in the handheld terminal. Nevertheless this technique requires having an algorithm to select the appropriate waveform and eventually an RF front-end designed for operating in a multiband mode. Self-adaptive or cognitive radio mechanisms can help implementing this type of terminal [Ref11].

  Also of critical importance if designing a multiband terminal is the RF front-end, that needs to be flexible in terms of specification and functionality, possibly digitally controlled, in order to cope with variable bandwidth and dynamic range. In particular analog to digital converters design are of critical importance and new technologies might have to be envisaged.

  Multimode terminals studies have been up to now concentrated on terrestrial applications. The use of higher frequency bands for satellite scenario is adding complexity in the realization of such advanced terminals so that a terminal more “software radio” and less “multi-functions” might be more suitable; a trade-off has to be found in order to reach as well a low consuming and low cost equipment.

  Some interesting research and technology developments have been done by IMEC during the last years in their M4 terminal concept (M4 stands for Multi-Mode MultiMedia).

- **Exploitation of high frequency bands**
  Traditional satellite mobile services have been using the L band and more recently the S-band. Although higher frequency bands face very challenging propagation environment and present additional technological constrains, the availability of a
wider spectrum could make these bands suitable to offer some services to mobile terminals (either real or non real time services).

5 Acronyms

3G/4G/B3G  Third Generation/Fourth Generation/ Beyond Third Generation of mobile systems
3GPP  3rd Generation Partnership Project
ACM  Adaptive Coding and Modulation
BGAN  Broadband Global Area Network
DVB-RCS  Digital Video Broadcasting Return Channel by Satellite
DVB-S2  Digital Video Broadcasting by Satellite 2nd generation
E-DCH  Enhanced Dedicated Channel
EDGE  Enhanced Data rates for GSM Evolution
EIRP  Equivalent Isotropic Radiated Power
FCS  Fast Cell Search
FDD  Frequency Division Duplex
GPRS  General Packet Radio Services
GPS  Global Positioning System
GSM  Global System for Mobile communications
H-ARQ  Hybrid Automatic Repeat request
HSDPA  High Speed Downlink Packet Access
HSUPA  High Speed Uplink Packet Access
MBSAT  Mobile Broadcasting SATellite
MC-CDMA  MultiCarrier Code Division Multiple Access
MIMO  Multiple Input Multiple Output
OFDM  Orthogonal Frequency Division Multiplex
STCM  space-time coded modulation
TTI  Transmission Time Interval
UMTS  Universal Mobile Telecommunications System
VSCRF-CDMA  Variable Spreading and Chip Repetition Factor CDMA
VSF-OFCDM  Variable Spreading Factor Orthogonal Frequency and Code Division Multiplex
WCDMA  Wideband Code Division Multiplex
6 References

6.1. Applicable Documents

6.2. Reference documents

[Ref1] Inmarsat webpage
[Ref9] S.D. Blostein, H. Leib ”Multiple antenna systems: Their role and impact in future wireless access” IEEE Communications Magazine, July 2003