# Hybrid satellite/terrestrial networks: State of the art and future perspectives


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## ABSTRACT

In this paper, the main role of satellite systems in hybrid satellite/terrestrial networks will be highlighted, as well as the main functions which should be performed to optimize the performance of these hybrid networks. Then, some typical services believed to occupy a great portion of the future telecommunication service market and benefiting from these hybrid architectures will be presented.

Generally speaking, the list of hybrid architectures presented in this paper is not exhaustive but reflects the main work carried out in the institute of communications and navigation of DLR and in the framework of the Satellite Communications Network of Excellence “SatNEx” subsidized by the European Union, more accurately in the focus topic “Hybrid broadband network architectures” of the Joint Activity 2130 “Broadband Access Network”.

The critical issues related to hybrid satellite/terrestrial architectures will be identified and analyzed all along this paper and illustrated by selected realistic examples.



## Keywords

Back-hauling, Collectively Mobile Heterogeneous Networks, Hybrid satellite/terrestrial networks, Multimedia Broadcast/Multicast Services, Near Video on Demand, Peer-to-Peer application, Quality of Service, Satellite Radio Access Network.


## 1. INTRODUCTION

The choice of a satellite telecommunications system rather than a terrestrial one is usually driven by its intrinsic capabilities, for instance very large coverage areas, speed of implementation and inherent multicasting and broadcasting capabilities ([1]).

Nevertheless, satellite systems suffer from many drawbacks such as technological complexity, high costs, and deep fading at high frequencies (Ka band).

Most successful satellite systems such as television broadcast and back-hauling of data in remote areas have up to now extensively exploited theses advantages in a competitive way with respect to classical terrestrial networks. Other satellite systems providing for instance mobile telephony or aircraft telecommunications services have suffered from severe concurrence or insufficient market and have not enjoyed the expected success.

Despite the recent enhancements at different layers increasing the efficiency and competitiveness of telecommunication satellite systems, they still have to face a harsh concurrence from terrestrial networks and do not succeed in asserting on the market of telecommunication services, except the ones traditionally provided over satellite, i.e. TV-broadcast and specific portable, nomadic telecommunications services. One reason for this is the way satellite and terrestrial telecommunication systems currently coexist: in a competitive manner.

Therefore, the idea of jointly benefiting from the advantages and capabilities of both terrestrial and satellite telecommunication systems was developed. This has been strongly acknowledged by the institutions, since greater level of integration between satellite and terrestrial telecommunication systems has been described as necessary for the future of satellite systems in the first phase of the SatNEx project ([1]) and interworking between satellite broadband networks and terrestrial wireless access networks (e.g. WiFi, WiMAX) has been identified as a strategic research element by the Integral SatCom Initiative ISI ([3]).

This collaborative use of the two kinds of networks nowadays seems to be part of the future of satellite systems. Indeed, such hybrid networks composed of a diversity of superimposed telecommunication networks display the following advantages:

- They can support a diversity of services, and especially efficient multicast and broadcast services,
- They enable the user to be anywhere and anytime connected by ubiquitously extending the coverage area of the telecommunication systems, at the best price and with the best possible connection,
- They optimize the usage of the resources of the telecommunications networks by selecting the most appropriate network for the transmission of each service (e.g. multicast or broadcast services are preferentially carried over satellite systems, whereas conversational or point to point services are transferred over the terrestrial networks), and by decreasing the traffic load in congested terrestrial areas with the transfer of part of the traffic over the satellite systems thanks to appropriate load balancing mechanisms.

The aim of this paper is therefore to highlight the advantages of hybrid satellite/terrestrial architectures and to present the most realistic ones, according to the work currently carried out at DLR and in the SatNEx network of excellence. In section 2, the role of the satellite systems in hybrid architectures will be highlighted. In section 3, the network functionalities which should be harmonized and improved in such systems will be presented, then some specific, promising services benefiting from these hybrid architectures will be introduced in section 4. Conclusions will be drawn in section 5.

## 2. THE ROLE OF SATELLITE SYSTEMS IN HYBRID ARCHITECTURES

Four main categories of roles can be identified for the satellite network in hybrid systems, described in the following sub-sections with illustrative examples.

### 2.1 Satellite multicast/broadcast network

One of the main, traditional roles of satellite systems has been and will likely remain the broadcasting or multicasting of the same content to a wide, geographically spread community of users.

This is for instance performed at Ku band by several classical TV systems (e.g. SES-ASTRA, Eutelsat via their Hotbird satellites). Most of these systems, at least in Europe, use the DVB-S Standard [4] to broadcast information. However, such classical systems lack interactivity. For this reason, the DVB-RCS [5] standard has been proposed, providing a return channel via satellite to the terrestrial users. Nevertheless, DVB-RCS systems are not yet well spread because they raise several issues, among them the additional costs for the satellite terminals, limited return link bandwidth, and complexity of the management of the satellite systems.

For this reason, the most straightforward hybrid architecture envisaged is based upon a forward link using a geostationary broadcast satellite whereas the return link takes benefit of already existing, low bandwidth network architectures such as the classical Public Switched Telephone Network (PSTN) or even xDSL connections. This also enables the seamless migration of classical satellite systems providing streaming services into hybrid systems providing near video or audio on demand services and interactive services such as web browsing or file transfer (relying upon the ability of the DVB-S standard to carry IP traffic) in addition to the classical satellite broadcast services.

Such hybrid systems already exist. One can quote for instance the AstraNet system [6] providing IP telecommunication services using an ASTRA satellite in the forward link and a terrestrial telephone line in the return link.

### 2.2 Satellite radio access network

In 2 or 2,5 G networks (GSM, GPRS) and 3G networks (UMTS), satellite systems can advantageously be used as additional Satellite Radio Access Network (S-RAN). Nevertheless, in case of hybrid satellite/terrestrial networks, the S-RAN is not supposed to be a standalone RAN, but a collaborative extension of the classical terrestrial cellular 2G/3G RAN used for two specific purposes, the geographic extension of the services and the traffic sharing, detailed in the two subsequent sections respectively.

The satellite system should preferentially work in frequency ranges close to the ones used in the terrestrial networks (L band (1.5 to 2.65 GHz) and S band (2.65 to 3.95 GHz)) and use similar, adapted communication standards. The integration of satellite/terrestrial UMTS networks for IP services delivery has already been subject of many studies, for instance in the Satellite UMTS IP based networks project (SATIN, [7]).

#### *2.2.1 Geographic extension of services by the hybrid Radio Access Network*

When a S-RAN is available, the most obvious gain consists in the possibility to greatly extend the coverage of classical cellular terrestrial wireless RANs which are not covering remote areas.

With such a coverage extension, telephony for maritime and aeronautical users, remote surveillance of high value objects e.g. pipelines and industrial plants in hard to access regions, news gathering and database access for journalists operating in remote parts of the world, tele-diagnostic in emergency cases, and many other telemetry applications can be supported.
In this case geostationary satellite systems with on board switching or constellations of low earth orbit satellites with inter-satellite links can provide direct User Equipment to User Equipment connections without using the terrestrial URAN provided that the Uu and Iu interfaces are slightly modified as explained in [10].

### 2.2.2 *Traffic sharing in the hybrid Radio Access Network*

In case the S-RAN and RAN coverage areas overlap, traffic can be shared among the different available RANs. For instance, the S-RAN could be used to relieve the congested RAN by carrying a significant part of the traffic. In this case, the S-RAN can be efficiently used in high population density areas, potentially with terrestrial repeaters for a better penetration into buildings, in urban or sub-urban areas. Combining terrestrial RAN and S-RAN considerably increases the capacity of the UMTS network.

Load balancing or traffic differentiation can also be performed in this case. Further details about load balancing are provided in section 3.1, traffic differentiation can take into account either Quality of Service criterions (conversational traffic over terrestrial network, streaming traffic over satellite) or application type (point-to-point application over terrestrial networks, Multimedia Broadcast/Multicast Services (MBMS) over satellite). Due to the difficulties for the classical T-UMTS networks to efficiently support MBMS, one can even say that the satellite system provides a powerful complement of services thanks to its inherent broadcast capabilities.

## 2.3 Satellite trunking and backhauling

In rural and remote areas, or for specific applications (corporate networks of wide spread business units), satellite systems can be employed as a transparent backhauling link characterized only by its maximum throughput, latency characteristics, and error rate, connecting several parts of the same network or several independent networks. Differentiation among the possible types of satellite trunking and backhauling in hybrid systems will be performed in the following sections.

### 2.3.1 *Trunking in the core network*

This solution is already applied in many systems, for instance by “France Telecom”, the French operator, for communication with the DOM-TOM (overseas departments and territories). It consists in connecting two sections of the PSTN with a satellite link. Users can communicate directly, without using the satellite link, in the local PSTN network. As soon as several remote users desire to communicate together, their data are gathered and carried over satellite, and experience therefore a high delay characteristic of the transmission over geostationary satellites.

### 2.3.2 *Backauling satellite systems*

The need for providing telecommunication services with rapidly deployable wireless telecommunication technologies to specific groups of users, for instance members of rescue teams, or collectively mobile groups of users (e.g. in an aircraft), is one of the targets of several European Space Agency (ESA) and European Union (EU) projects. This seems necessary in order to support situations during which conventional telecommunication services have broken down for instance in case of a disaster, or to reach new markets (e.g. groups of users in aircraft or train) by providing connectivity anywhere and at anytime.

In most of the cases, the hybrid system consists of three different sections:

1. The local access network, composed of different local access technologies (e.g. GSM, UMTS, WiFi, WiMAX, Private Mobile Radio such as TETRA) and the associated functional entities (GSM/UMTS/TETRA Base Stations, WiFi or WiMAX access points, local cache and content proxy, traffic monitoring, billing and scheduling system). The functional units of the local access network shall be designed to enable satellite independent communication among users in the local network. In addition, convergence of data formats and protocols is an issue for an easy transmission over the satellite link of the data generated/destined to the local access network. Up to now, the trend is to carry all IP traffic over satellite, using either the IETF (SIP, SDP) or the ITU-T (H.323) protocol stack over UDP/IP for conversational applications.
2. The fixed terrestrial (wireless or not) core network composed of the classical PSTN, ISDN, PLMN and IP networks as well as some specific entities such as BSC or MSC for the GSM network, or interoperability gateways for TETRA,
3. The satellite system, ensuring the interface between the two aforementioned sections and enabling any user in the local access network to access the telecommunication services provided by different service providers in the fixed ground networks.

Hybrid telecommunication systems performing back-hauling of data between the local access network and the terrestrial network have been extensively investigated in the DLR projects WirelessCabin [13], Fifth [14] and

WISECOM [15] (please refer to Figure 1), for provision of connectivity in aircraft, trains and for emergency communications in disaster areas respectively.

Nevertheless, the area of applications of such an architecture is wide, for instance for military purposes, oil rigs, ships, or any other public transportation mean carrying a large group of collectively mobile users, scientific missions in remote locations, etc….

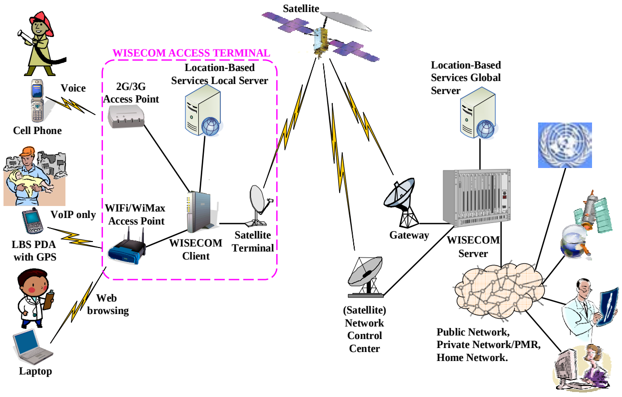


**Figure 1. High layer architecture of the WISECOM system for emergency situations.**

### *2.3.3 Interconnection of private local area networks*

Another widespread use of satellite systems in hybrid networks consists in the interconnection of private, Local Area Networks (LANs) or of Mobile Ad-hoc NETworks (MANETs).

In the ESA project ULISS [16] in which DLR has been involved, the emphasis has been put on the definition of the architecture of a satellite system with ultra fast on-board switching and processing, providing within a single satellite hop fully meshed connectivity between satellite terminals, connected to LANs or even Wide Area Networks (WANs) of professional users for corporate applications. With such a system, it is possible to create secure and fully meshed Virtual Private Networks (VPNs) of users over satellite, and of course also to connect these professional users to terrestrial networks and further to different service providers. The use of a satellite system with on-board switching enables to provide single satellite hop connections among users, which improves the satellite bandwidth usage, reduces the transmission delay and in practical allows the use of all kinds of applications, from the conversational ones (e.g. video conferencing) to the background ones (file or email transfer).

In the focus topic "hybrid broadband network architectures" of SatNEx II, broadband satellite systems (preferentially with on-board switching) have also been proposed to provide Mobile Ad-hoc NETwork (MANET) interconnections and connections of MANETs to the ground networks (please refer to Figure 2).

Indeed, MANETs usually move in rough areas, with no line of sight between them and therefore limited possibilities to communicate. Up-to-now, research has been focused on communication between the different hosts of the same MANET. On the other hand, the hybrid architecture described in SatNEx II focuses on broadband inter-MANET connectivity, using in each MANET a specific central node for communication with other MANETs. Of course, the access to the internet for specific applications, for instance the down-loading of digitalized maps, is also possible with such architecture. Nevertheless, the design of the central node, responsible for the inter-MANET connections, is critical and may prevent real-time applications to be successfully supported, since the different hosts of a MANET are not always connected.

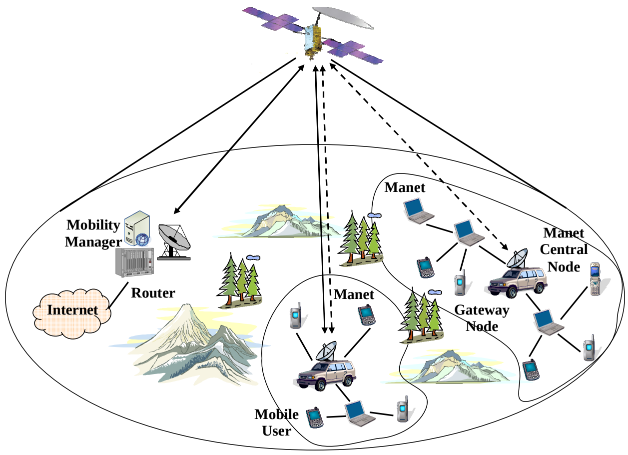


**Figure 2. Hybrid satellite/terrestrial architecture with MANETS.**

## 2.4 Satellite as backup solution for critical infrastructures

In case of communication critical infrastructures such as oil refineries, banks, stock exchange places, or critical applications such as telemedicine, stock management, money transfer or military applications, the necessity of a reliable, and always available network is crucial. Such high availability cannot be provided by a unique terrestrial network, especially in some specific situations such as a disaster or a break down of the telecommunication infrastructures. This necessity has been highlighted in the aftermath of e.g. the east American gulf coast hurricane of 2005 or the electricity blackout in Europe in November 2006.

For this reason, satellite systems can be used in hybrid architectures as alternative, redundant systems to ensure the continuity of the telecommunication services for critical infrastructures. Integrated solutions are already provided by

GILAT and CISCO using Very Small Aperture Terminals (VSATs) [8], or by Hugues [9].

# 3. SPECIFIC NETWORK FUNCTIONALITIES OF HYBRID SYSTEMS

In hybrid systems, some specific network functionalities should be supported. For instance, handover becomes much more complicated. Whereas in classical cellular wireless systems handover between two different adjacent cells is performed taking into account SNIR measurements, terminal location and congestion statistics, in hybrid architectures, also inter-system handover shall be performed. With this respect, soft and seamless handovers may be hard to achieve. Also, the question about the handover initiation becomes more tricky and depends in addition upon load balancing in the system, as explained in section 3.1, or can even depend on more complicated procedures such as different cost functions, network state and specific connection admission control procedures with forced handover.

In addition, protocol convergence shall be achieved in order to facilitate these handover procedures and the design of multi-mode terminals: this is now envisaged for instance with the development of the DVB-S and DVB-T (Terrestrial) standards, or the DVB-H (Handheld) and DVB-SH (Satellite services to Handheld devices). Harmonized network management procedures shall also be performed, for instance in case of emergency, rapid and seamless switching to the satellite system for the continuation of the telecommunication services shall be performed with tools which are common for all possible networks.

Finally, the issues of authentication, security and billing shall be carefully and consistently addressed. End-to-end security shall be provided in a coherent way and at different layers (login and password at application layer, encryption over the satellite air interface, etc…). The amount of traffic carried over different sections of the hybrid system shall also be carefully accounted, since prices may widely vary from e.g. terrestrial systems to satellite systems.

In the two following subsections, the critical issues of load balancing and QoS support in hybrid systems will be addressed with more details.

## 3.1 Load balancing

In hybrid satellite/terrestrial telecommunication systems, usually more than one path is available in point-to-point communication, and the traffic should be routed over a specific path according to different criterions such as cost, QoS, application type, etc…, used as input parameters in a specific cost function.

This problem is known as load balancing and has been addressed in SatNEx II [2] for IP applications in hybrid systems using simultaneously terrestrial wireless networks, high altitude platforms, and satellites. In this case, three different possibilities for load balancing have been foreseen: per packet, which guarantees equal load per link but which suffers from the need for packet reordering at the reception side, per destination, which suffers from unequal traffic distribution among the different available links and from the handling of a lot of independent destinations, and finally per flow which uses higher layer information (e.g. TCP layer in addition to the IP address) to determine the network that shall be used to carry each independent traffic flow.

## 3.2 Quality of Service

The inter-working of QoS mechanisms is a critical issue in hybrid systems so that end-to-end QoS support can be efficiently provided. Recent work in the European Telecommunication Standards Institute (ETSI) has addressed in the Broadband Satellite Multimedia (BSM) group the issue of enabling QoS for IP-based multimedia satellite systems, based on the DiffServ model, and released the corresponding standard [11].

This standard distinguishes Satellite Dependent (SD) from Satellite-Independent (SI) layers, linked together via a standardized, SD layers agnostic interface called the Satellite Independent Service Access Point (SI-SAP). The standard relies upon the management of abstract queues called Queue IDentifiers (QID). Each QID is associated with a given class of quality of service. IP datagrams saved in these queues shall be processed according to their QoS class by the SD layers, responsible for the assignment of the satellite capacity and of a particular forwarding behavior. Quasi-static QID allocation can be supported, even if more sophisticated services with dynamic resource reservation can be foreseen, introducing a complex resource control problem for the SD manager.

# 4. SPECIFIC SERVICES FOR HYBRID SYSTEMS

## 4.1 Peer-to-peer applications

Nowadays, peer-to-peer (p2p) applications are extensively used and represent a large part of the traffic carried over the internet network. This has created a new paradigm in the usage of the internet network: data-centric applications, unaware of the topology of the underlying network(s), are creating overlying application data networks. In these high layer data networks, communicating peers, i.e. the set of peers among which data are transferred for a specific purpose, are only selected according to their characteristics (e.g. the type of data saved in each peer). This last point means especially that the underlying network resources are not optimized at all with p2p applications which can decide to create a connection between distant peers whereas another connection could have minimized the number of IP routers crossed along the path between the selected peers and therefore reduced the amount of traffic carried over the internet network. This congests all the more the network that p2p applications are usually broadband applications and make extensive use of broadcast for searching purposes within the data application network overlay which has been constructed. For this reason, a satellite system can be used to carry traffic generated by p2p applications and to provide broadband connections among super-peers, which are special entities in a system directly connected to a significant amount of peers and aggregating their data streams. For any connection between a couple of super-peers, there will be only a single, direct satellite transmission. In addition, the inherent broadcast capabilities of the satellite systems could be used to perform the broadcast actions requested by the p2p applications. The use of hybrid satellite/terrestrial network for the carriage of peer to peer applications would free up a lot of resources on the terrestrial infrastructures optimally used to carry classical IP applications such as point to point web browsing. This concept is currently under study in SatNEx II.

## 4.2 Near Video on Demand applications

Video on Demand (VoD) is a classical service provided by terrestrial networks (e.g. cable networks) and satellite systems. It consists in providing the users with their requested video saved in one or several servers on a "press a button" basis, with classical VCR functionalities, while meeting stringent response time requirements.

The problem of the delivery of VoD services can be summarized by the following paradigm, based upon the resolution of two seemingly conflicting issues: all users requests should be served within a short time, independently of their arrival time, and each multicast stream should serve a large amount of users. The immediate allocation of a dedicated channel upon each user request for the transfer of the required video is the only way to optimally support True Video on Demand. This nevertheless ends up in a multitude of independent, similar data flows, with different time shifts, which spoils transmission resources.

This is especially true in satellite networks with high coverage area and inherent broadcast capabilities but with limited and expensive available bandwidth. With such systems, the minimisation of the costs associated with the satellite transmission is traded off with the user satisfaction, mainly dependent on the time elapsed between the emission of a request and the reception of the associated video.

Classical methods for video on demand over satellite are relying upon the use of data carrousels, upon caching of the most popular films or of the ones corresponding to the declared user interests, or upon a DVB-RCS compliant return channel, used to transfer the user request to the video server. According to these requests, different algorithms can be applied by the video server to determine the videos' transmission schedule. Then, videos are transmitted using different techniques, for instance the splitting of the video into several segments of geometrically distributed sizes [17]. Nevertheless, current on-going work in the SatNEx II investigates a new hybrid satellite/terrestrial architecture using a broadband satellite system to feed several WIMAX terrestrial stations, used as cache and broadcasting the videos to the end users using special fountain codes [18], as sketched in Figure 3.

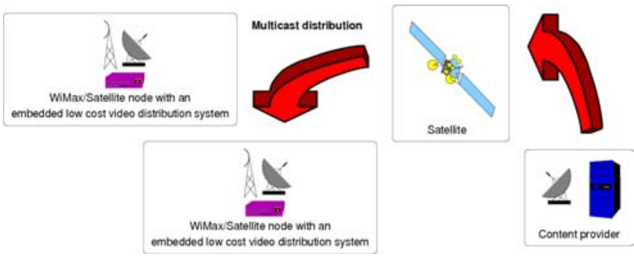


**Figure 3. Basic architecture representation of the Near-VoD distribution system.**

## 4.3 Multicast application in 3G cellular systems

The ITU has defined the UMTS Satellite Radio Access Network (USRAN) which enables multimode User Equipments (UE) to access the UMTS core network either via satellite, or via the classical URAN in case of terrestrial wireless coverage. The aim of the USRAN is either to provide coverage extension, or support to specific applications and especially Multimedia Broadcast/Multicast Services (MBMS). In this hybrid satellite/terrestrial network providing collaborative terrestrial and satellite radio access, the satellite gateway shall provide the same functionalities as the Radio Network Controller (RNC) and Node B. In indoor regions, an Intermediate Repeater (IMR) can be implemented to re-amplify the signal and propagate traffic towards the UEs.

The delivery of MBMS via satellite (i.e. S-UMTS) is addressed by the ETSI S-MBMS (Satellite Multimedia Broadcast Multicast Service) workgroup. S-MBMS is a unidirectional point to multipoint bearer service in which data is transmitted from a single source entity to multiple recipients [12]. Two types of bearer services are supported by S-MBMS: broadcast mode and multicast mode. For both modes, S-UMTS is one of the main components responsible for the transmission of multimedia data. In hybrid satellite/terrestrial UMTS networks, the BM-SC (Broadcast Multicast-Service Centre) provides functions for S-MBMS UE service provisioning and delivery, for example, it controls UE access to services, authorizes and initiates bearer services within the network, and schedules and transmits MBMS data across the network [12].

In the envisaged hybrid satellite/terrestrial UMTS architecture, classical UMTS services (point to point voice communication, data transfer and SMS) are ensured by the classical terrestrial UMTS network whereas MBMS services are supported by the UMTS satellite segment.

## 5. CONCLUSION

In this paper, a number of possible roles of the satellite component in hybrid satellite/terrestrial networks have been discussed, as well as the main functions which should be performed to optimize the performance of these hybrid networks. Also, some typical services suitable for the satellite component of such hybrid architectures have been presented.
The critical issues related to hybrid satellite/terrestrial architectures have been identified and illustrated.

## 6. ACKNOWLEDGEMENTS

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