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Satellite and Terrestrial Hybrid Networks

1.1. Designing satellite and terrestrial hybrid networks

The satellite is a suitable medium for filling in white zones and gray areas due to its wide coverage and accessibility from areas which are not covered by terrestrial infrastructure.

The development of very high-speed access has led to the emergence of new services and uses, which are more and more frequently based on highly demanding audiovisual media for communication purposes. In the short and medium term, in a context where information and communication technologies are assuming increasingly important positions in all sectors and in people's daily lives, it is becoming vital for telecommunication operators to be aware of improvements to existing services on the networks and to have the flexibility to rapidly integrate such new services made possible by this very high-speed access.

The consequence of these efforts is that, for the satellite telecommunications operator, it is necessary to create hybrid systems to forge a convergence between broadcast networks and bidirectional satellites (for fixed and mobile services) on one hand, and terrestrial networks on the other hand, in order to provide higher quality and more transparent access with greater coverage for applications and services which are increasingly demanding in terms of network resources.

The first challenge to overcome with regard to these issues involves the "system" and the need to integrate an effective architecture which takes account of the convergence between satellite and terrestrial networks in an optimized and transparent way (to ensure the delivery of services).

Next-generation networks (NGNs) and next-generation access (NGA) specifications have provided such a convergence by using packet-switching (Internet Protocol (IP), multiprotocol label switching (MPLS), Ethernet, generic stream encapsulation (GSE)/return link encapsulation (RLE), etc.) as a means of interconnection. They look to eliminate the barriers between the various heterogeneous networks by connecting the services between themselves in a secure and accessible way. This is done by using different types of fixed or mobile access terminals, regardless of the underlying transport network. Services can, therefore, be generalized over all types of networks.

This convergence has an impact on the entire value chain and therefore on all of the various stakeholders involved, including service providers, network providers, access network providers, satellite operators, home networks and the terminals of the end user.

Modifications are necessary at different levels of the open systems interconnection (OSI) model and technological challenges need to be overcome. Several hybrid scenarios must be considered in which the satellite can play a technically, economically and socially useful role.

1.2. Hybrid scenarios

Over the last decade, a number of new access network technologies emerged for access to Internet services. At the same time, cellular networks, initially designed for mobile telephone and voice services, evolved to offer more advanced services and above all Internet access.

Moreover, the progress of mobile terminals (mobile telephones, smartphone, ultrabooks or laptops), whose size and weight have been significantly reduced, incorporate increasingly wireless network interfaces (3G/4G, WiFi, Bluetooth, near field communication (NFC), etc.) and communication capacity. These wireless communication technologies (WIMAX and 3G/4G-LTE) have given the user the ability to connect to services from anywhere, anytime, while enabling mobile Internet access.

This trend is so strong that the offer of an “always on” service is now one of the requirements for the design of new network infrastructures.

The NGN and 4G concepts are entirely in line with this approach. Services or applications are designed with no specific type of access network in mind (wireless, cellular, cable, optic, etc.), but are based on core IP technology, which is now a cornerstone of convergence between telephone and data services.

In NGNs or 4G networks, the “always on” paradigm is intended to give general mobility to service users, with a fully transparent change of access network as long as it is compatible.

Application, as well as the underlying protocols, must be consistent with the changes in networks. However, this requirement remains very ambitious since the networks are heterogeneous and potentially operated by a wide variety of stakeholders. Therefore, a number of economic (business, role model, etc.) and technical (quality of service (QoS), authentication, authorization and accounting (AAA), security, etc.) questions arise.

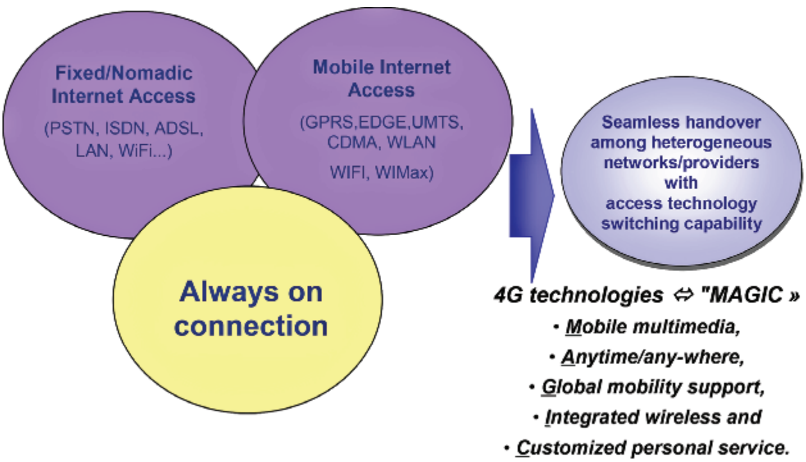

Figure 1.1. *Trends with 4G/NGN*

Therefore, it is crucial for satellite systems to follow this trend and demonstrate their compatibility with NGN/4G networks. This is of utmost importance for the satellite broadband market. Indeed, most stakeholders (industries, suppliers and research laboratories) are arguing for the integration of satellites into this architecture.

There are a number of cases where satellite/terrestrial hybrid networks would be particularly advantageous. As a supplement traditional terrestrial access technology, satellite systems offer a real benefit for mobile users, and in a more general sense, for the deployment of mobile networks. Satellite networks offer extremely wide coverage and a high accessibility rate, with capacity in terms of performance, QoS management or security, which is entirely comparable to traditional networks. Of course, satellite networks will not compete with terrestrial networks, but can supplement their coverage and offer an alternative solution which can be very useful when terrestrial infrastructure becomes ineffective (mass congestion and attack) or is destroyed (natural disaster), or is simply not available (no coverage).

Therefore, the typical use would now be mainly in the sectors of civil protection, military (theater of operations) or transport (maritime, aeronautical, railway, etc.).

The following section analyzes the impact of these uses on the overall architecture of the hybrid network, while remaining compatible with NGN/4G architectures (protocols and standards).

First, we will describe how the integration at the system level could be done, and then we will examine various scenarios.

1.2.1. *Network architecture: integration of hybrid networks*

The integration of satellite networks with terrestrial networks can be carried out in a number of ways. There are several technical solutions for this problem, but the main criterion for integration will largely be dictated by the role models and businesses which come from it.

Nevertheless, it is possible to define three generic types of integrations:

1) *Tight coupling integration*, where the mobile system (3G, long-term evolution (LTE) and WIMAX) is extended to use the satellite as an alternative access channel in a completely transparent manner.

2) *Gateway integration*, where the satellite is integrated into the infrastructure of the mobile network, not directly at the level of the air interface, but via a specific gateway enabling access to the core mobile infrastructure.

3) *Loose coupling integration*, where a specific satellite system interface is added to the mobile satellite terminal in order to enable access to a terrestrial IP network via this interface. Multimodal and multitechnology

terminals capable of generating several interfaces and their specific protocols (e.g. DVB-RCS+M) are, therefore, necessary.

These three scenarios are described in the following sections to provide more technical details.

1.2.2. *Tight coupling integration: an integrated approach*

With the "tight coupling integration" approach, the satellite is completely merged into the targeted mobile system (3G, LTE and WIMAX), in a transparent manner for the mobile user. The radio access interface is extended (infrastructure and protocols) in order to integrate a satellite channel as an alternative access interface for the mobile user.

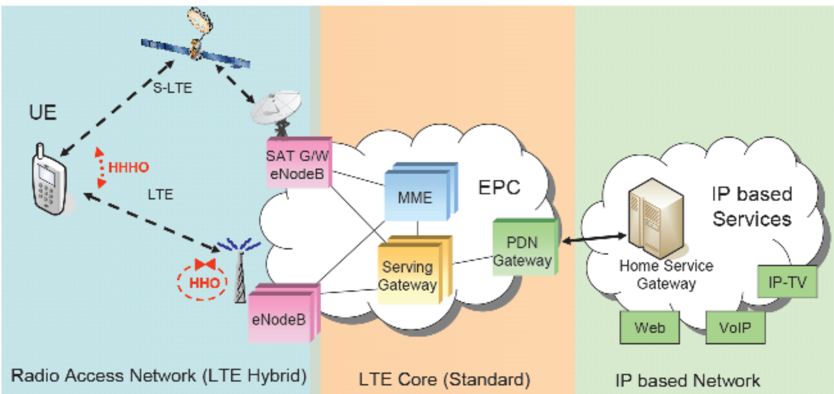

Figure 1.2. *Tight coupling architecture*

The *Centre National d'Études Spatiales* (CNES), or national centre for space studies, is currently carrying out studies based on this approach, most notably as part of the SWIMAX project. If we examine the LTE system, the satellite would be directly integrated into the core infrastructure and the gateway satellite would become a standard interface (an enodeB). The mobile terminal can communicate with the gateway satellite via a channel satellite by using traditional terrestrial protocols (which can, however, be adapted to work on a channel satellite).

This approach is considered as the final step in the integration of the satellite into the hybrid network. The satellite system is designed to be fully compatible with the mobile protocols and is fully integrated into the core network via a standard interface eNodeB. This is also the most powerful approach from a user's point of view.

Unfortunately, it is also the most complex since it requires very powerful hardware performance in order to maintain the small size of the portable equipment.

The terminal is hybrid since it can interact with the satellite or a terrestrial antenna by using the same protocol stack (LTE or WIMAX). The management of mobility is handled by these protocols like in a traditional terrestrial cellular network.

The characteristics of this approach in an LTE network are:

– access protocol: LTE (standard scope);

– terminal: hybrid or dual (integrated terrestrial/satellite);

– radio access network: hybrid (terrestrial/satellite infrastructures);

– satellite: mobile satellite services (MSSs) satellite;

– satellite gateway: specific gateway with the role of enodeB;

– mobility: provided by LTE.

Important points include:

– horizontal hand-over (HHO) between terrestrial enodeBs;

– hybrid HHO (HHHO) between satellite/terrestrial enodeBs;

– the mobility at the network level is ineffective. The IP address is maintained by a single packet data network-gateway (PDN-GW).

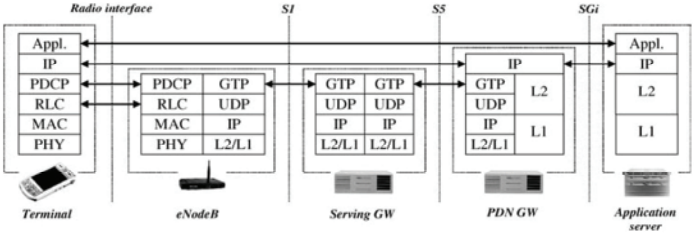

Figure 1.3. *LTE protocol stacks (User Plan – 3GPP standard documents)*

1.2.3. *Gateway integration*

With the "gateway integration" model, the satellite is integrated in the mobile network as a gateway. Indeed, it is not placed at the radio interface with the mobile, but as a specific gateway to allow access to the core of the mobile network.

Therefore, the mobile terminal is a traditional terminal, in compliance with the standard of the mobile network targeted (e.g. LTE or Wimax). This is no longer dual equipment and the satellite interface remains a traditional fixed satellite interface (fixed satellite service (FSS)). The mobile is connected to a traditional eNodeB, which is interconnected with the core network by a satellite link. The satellite network has an interface with the core terrestrial mobile network. In an LTE model, it may fulfill the role of an eNodeB or a serving gateway (SGW).

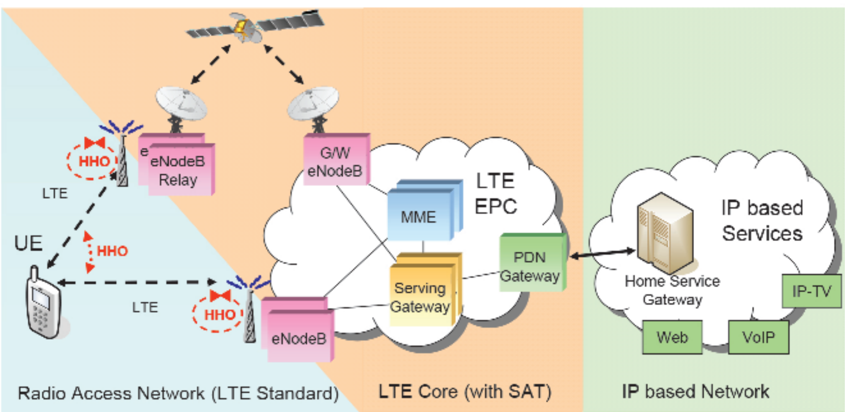

Figure 1.4. *LTE gateway architecture*

The characteristics of this approach in an LTE network are:

– access protocol: LTE (standard);

– terminal: LTE (standard);

– radio access network: LTE (standard with satellite gateway to core);

– satellite: fixed satellite services satellite;

– satellite gateway: standard gateway in the role of an enodeB or SGW;

– mobility: provided by LTE.

Important points include:

– HHO between terrestrial enodeB and gateway eNodeB;

– HHHO between satellite/terrestrial enodeB;

– mobility at network level is ineffective. The IP address is maintained by a single PDN-GW.

1.2.4. *Loose coupling integration*

With "loose coupling integration", a specific satellite interface is added to the terminal to connect to the IP network via a specific access network. It can be differentiated from the first approach by the fact that this time, the supplementary interface complies with the standards of a traditional MSS. There is no integration through a specific protocol with the mobile terrestrial system like in the previous approaches. This approach uses multitechnology mobile terminals, which manage the usual interfaces with specific protocols (for the satellite, a DVB-RCS+M architecture can be used).

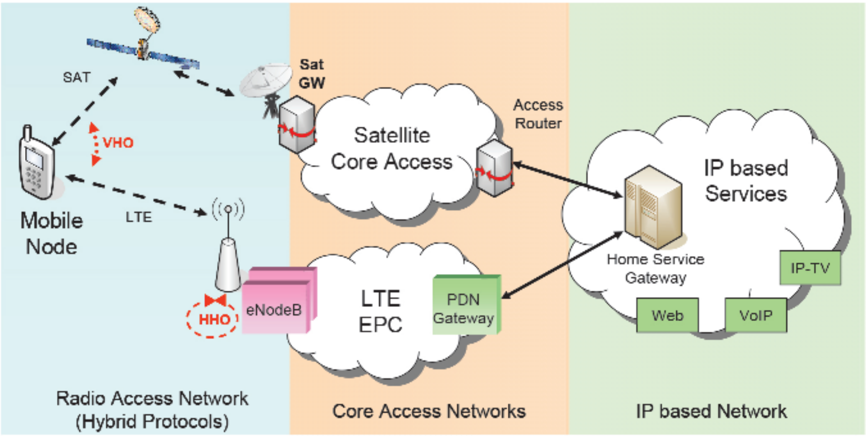

Figure 1.5. *LTE/satellite loose coupling integration*

This architecture can be applied generally to all technologies, and is not limited to LTE. The mobile terminal connects to an IP network via heterogeneous access networks.

1.3. Case study: loose coupling integration

1.3.1. *Use case and user profile*

To define the use case, it is important to define the following points which specify the user's profile:

1) *nature of traffic*: asymmetrical data streams, length of connections, variable flows, encryption if necessary, etc;

2) *nature of geographic mobility:* the distance which a mobile user can be from the home agent;

3) *hand-over frequency:* to be determined depending on the types of underlying access networks.

It is important to be aware of these parameters because they will guide the selection of suitable mobility mechanisms or may be used as requirements in the definition of an appropriate new mechanism.

Nevertheless, this is not an easy task because user profiles can vary greatly according to their needs, zones and types of movement. The nature of the traffic is possibly the least predictable parameter because the uses of the mobile network are very changeable, they have many variable applications, and an operator's service offer is greatly increased in line with its capacity for innovation.

1.3.2. *Proposal of a scenario*

We will pursue the analysis of the "loose coupling" approach. Indeed, although the "tight coupling" and "gateway" approaches are not excluded, we believe that it is interesting to develop a case with a real vertical hand-over (between multiple technologies). In the first two cases, mobility IS directly managed by the LTE and is therefore entirely transparent at the higher layers.

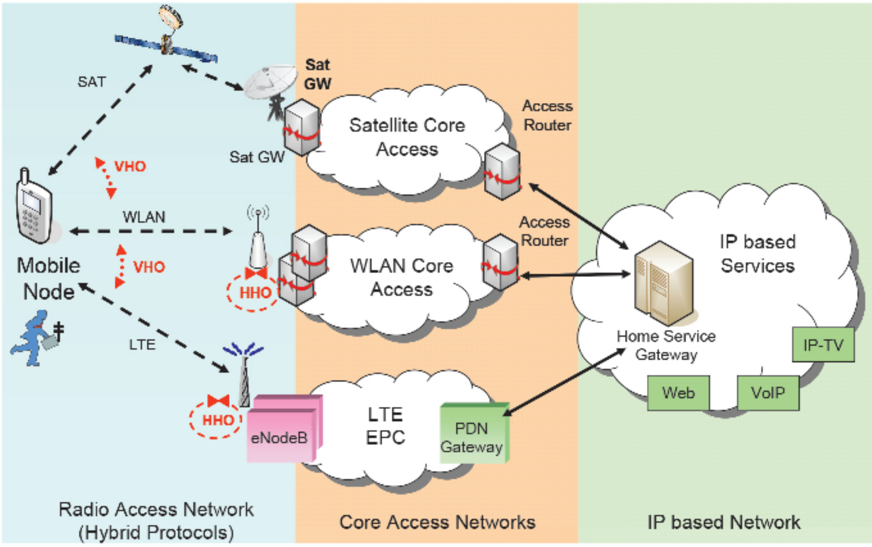

Figure 1.6. *Heterogeneous hybrid architecture for mobile nodes*

The characteristics of this approach are:

– access protocols: multiple, heterogeneous and hybrid protocols;

– terminal: multimodal, adapted to different networks;

– radio access network: terrestrial (LTE or other) and satellite;

– satellite: MSS satellite;

– satellite gateway: standard gateway;

– mobility: horizontal and vertical hand-over.

Important point:

– mobility is managed by the network level and therefore by IP mobility stacks.

Based on the previous architectures, it is possible to address the case of mobile networks. This case is particularly interesting in the sector of public transport, communication vehicles as well as the military. The satellite thus becomes an alternative to the terrestrial networks for access for vehicles. In this case, part of the network is mobile, referred to as "mobile networks".

Therefore, it is the router which manages its mobility, while the nodes it hosts appear as fixed in the rest of the network.

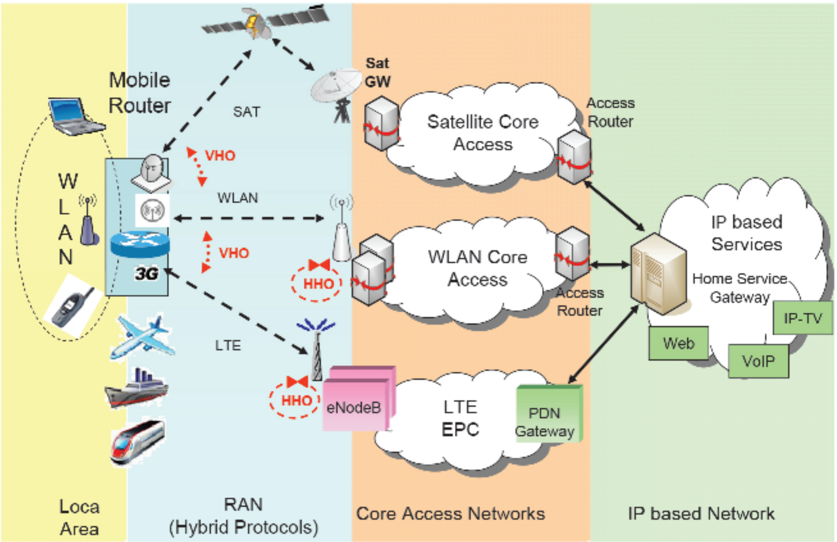

Figure 1.7. *Heterogeneous hybrid architecture for mobile networks*

1.3.3. *Profile of mobile users*

An example of a user profile in this case may be as follows:

– coverage: wireless local network (WLAN) and/or cellular network (3G/4G), supplemented by a wide coverage satellite network. Indeed, hand-overs are not frequent (vertical handover (VHO) and HHHO), since they will often be managed by access technologies (HHO in 3G or LTE);

– geographic mobility: from short distance (for mobile users) to intercontinental mobility (for transport, e.g. in an airliner);

– nature of the traffic: regular traffic for Internet access, including web navigation (HTTP), email (SMTP), file transfer (FTP) and audio/video streaming (RTP). Except peer-to-peer (P2P), all these protocols generate asymmetrical flows, mainly from the network to the mobile. The length of connections varies (short for HTTP and long for SMTP or RTP). For security reasons, an IPsec-type protocol may be adopted due to its extensive use;

– mobile equipment: mobile terminal or mobile router.

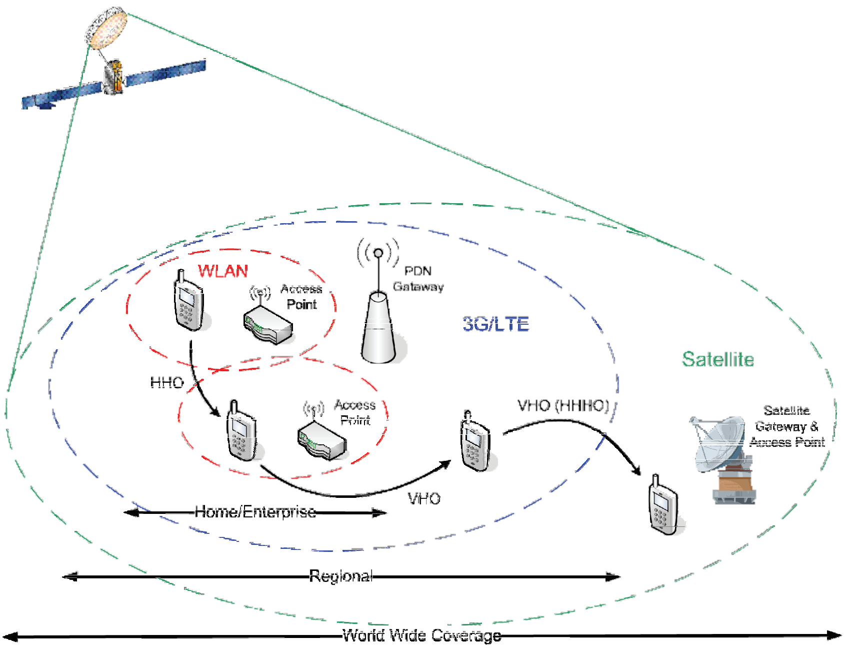

Figure 1.8. *Network coverage in the mobility scenario*

To complete the network integration, the terminals and routers which manage several interfaces must have an algorithm for selecting the "best" network according to the service or application activated by the user. This interface selection may be automatic or based on preferences (profile, cost, etc.) and/or on network availability (transmission capacity, signal level, bit error rate (BER), availability of resources, security, etc.).

1.4. Conclusion

Following this brief presentation of the important aspects of hybrid networks, it would appear that the market and technologies have accepted the integration approach and the process of creating hybrid networks. Indeed, dictated by users' requirements, emerging hybrid networks already exist due to the complementarity offered by WiFi networks and 3G/4G mobile networks. Nevertheless, these approaches may be considered as being completely uncoupled because, although some operators offer services for two types of network (WiFi or 3G/4G), it is rare for these networks to be interoperable, even by a common authentication, and more generally by a general service offer from both technologies.

It is difficult to predict the future of these mobile networks, although some trends are starting to emerge. The widespread distribution of femtocells, integrated into asymmetric digital subscriber line (ADSL) boxes, is encouraging general 3G/4G access at the expense of traditional wireless networks. However, the evolution of the Internet mobility architectures and very high-speed wireless access protocols could, on the contrary, lead to an increase in access via these networks. On the other hand, taking a more pragmatic approach, given the specifics of each access technology in terms of coverage, speed and services, it is highly likely that these technologies will continue to work side-by-side for some time to come. Nevertheless, as has been argued in this chapter, integration solutions for these networks need to be proposed despite the significant challenges which this presents.

The following chapters will focus on the main challenges currently faced in integrating satellites into these future hybrid networks. The first involves the management of the QoS, via QoS management architectures of terrestrial and satellite networks, and also via architectures and standards for new generation hybrid networks.