RECOMMENDATION ITU-R M.1182-1*

Integration of terrestrial and satellite mobile communication systems

(Question ITU-R 112/8)

(1995-2003)

Scope

This Recommendation provides five levels of different architecture for the integration of mobile-satellite service (MSS) systems with terrestrial public switched telephone network (PSTN) or cellular network. Annex 1 addresses the concepts of such an architecture, and Annex 2 describes an example of a closely integrated broadband terrestrial and satellite mobile communication system.

The ITU Radiocommunication Assembly,

considering

a) that various satellite mobile systems are being implemented;

b) that there are some satellite mobile systems that interwork with terrestrial systems;

c) that worldwide roaming capability is a key feature of International Mobile Telecommunications-2000 (IMT-2000) and the satellite component defined in Recommendation ITU-R M.687 is one of the important components that encourage the IMT-2000 capability;

d) that the satellite component is an effective method to provide low volume and widespread traffic areas;

e) that interworking of the satellite mobile system with the terrestrial system can encourage user convenience within not only IMT-2000 but also general MSS;

f) that the channel capacity of the satellite component is relatively limited compared to the terrestrial component;

g) Question ITU-R 112/8,

recommends

1 that the level shown below and explained in Annex 1 should be referred to when considering the integration between terrestrial and satellite systems.

Integration level:

– Level 1: geographical integration

– Level 2: services integration

– Level 3: network integration

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* Radiocommunication Study Group 8 made editorial amendments to this Recommendation in 2004 in accordance with Resolution ITU-R 44.

– Level 4[1]: equipment integration

– Level 5: system integration;

2 that mobile terminals of an integrated system should have a capability to select the relevant component either the terrestrial or satellite based on the receiving signal level and network availability to keep certain service quality over a wide and continuous service area;

3 that it is preferable that the integrated system should have roaming capability with unique user/subscriber identifier across both terrestrial and satellite systems if it is integrated into the terrestrial mobile system at the higher or equal integration level than Level 3 above;

4 that hand-off between satellite and terrestrial mobile component in an integrated system should be carried out within the extent that execution of hand-off does not significantly decrease the system capacity or increase system complexity.

Annex 1

Levels of satellite mobile system integration with terrestrial mobile system

1 Concepts

There are a number of relationships and approaches that are appropriate in developing concepts for integration of satellite land mobile systems with terrestrial mobile systems. Figure 1 gives a general representation of the overall concepts.

2 Approaches

Various levels of integration between independent coexistence and full integration can be considered. In the approach which follows, five levels are examined, ordered according to increasing integration, in the sense that each level includes the basic features of the previous one:

– Level 1: geographical integration

– Level 2: services integration

– Level 3: network integration

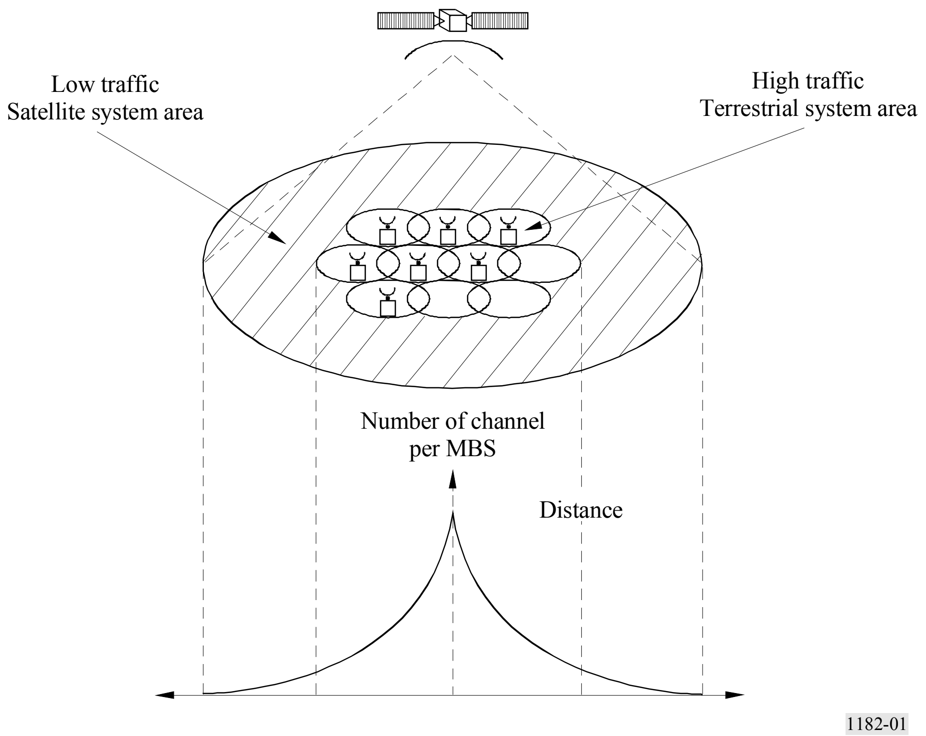
– Level 4: equipment integration

– Level 5: system integration.

[1] One example of integration between terrestrial and satellite systems creating a multi-segment access network and aiming to Level 4 integration is provided in Annex 2. The content of this informative Annex reflects the outcome of multi-segment SUITED (**S**ystem for broadband **U**biquitous access to **I**n**TE**rnet services and **D**emonstrator) Project and as such it refers to the concepts developed within SUITED, that are therefore valid only in that context. In particular, this Annex is an example of integration of satellite and terrestrial components in the framework of the SUITED Project, which has no impact on IMT-2000 and systems beyond, neither on the architecture nor on any of its elements.

FIGURE 1

Concept of integrated system



2.1 Geographical integration

This case refers to a situation where the terrestrial and the satellite system are independently conceived, so that they are based on different techniques and do not necessarily provide the same or compatible services.

Rather than speaking of "integration" of the two systems, it would be probably more correct to say that the satellite system "complements" the terrestrial one, offering communications services to users travelling in geographical areas not served by the terrestrial system. A representation of this case is given in Fig. 2.

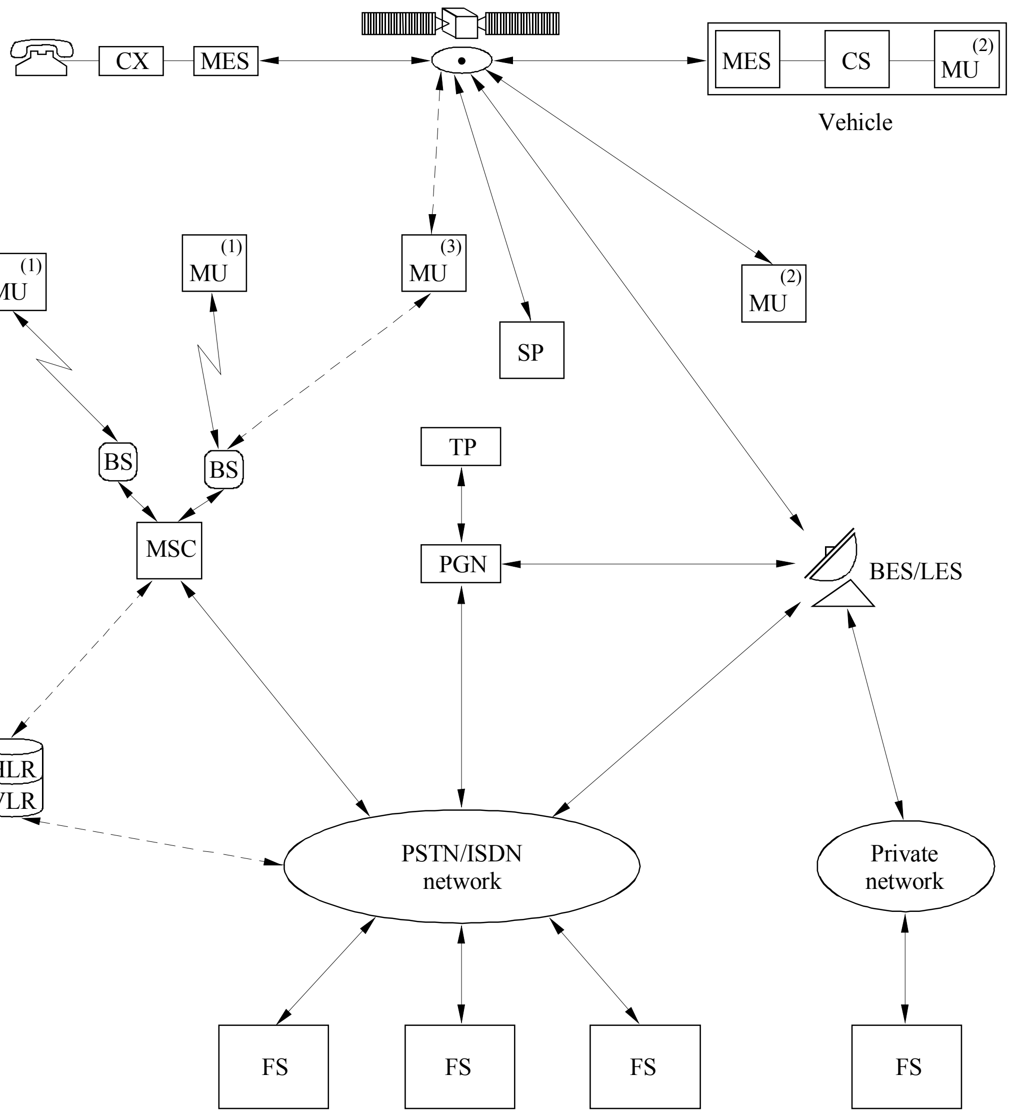
The mobile user (MU) of the mobile station (MS) or personal station (PS), will have the choice to buy a terrestrial system terminal, a satellite terminal or a dual-mode one, depending on his particular requirements and, in this last case, he will utilize, for MU-originated calls, the one which he expects to be the best for that moment.

The fixed subscriber (FS), wanting to place a call to the MU, shall have the responsibility to select the terrestrial or the satellite system, by dialling either the terrestrial system number or the number which provides access to the closest satellite base earth station (BES) or land earth station (LES). This means that the FS must have available to it knowledge of the kind of terminal (and service authorization) available at the MU.

If the MU has a double service authorization and a dual-mode terminal station, the FS may be forced to repeat his call over the satellite system, should the first attempt via the terrestrial system fail. In this situation, it may well happen that, for instance, a FS, intending to place a voice call, may need to accept a message service, where the satellite system is designed to only provide this.

FIGURE 2

Geographical and service integration concept
(the calling party selects the routing)



(1) Terrestrial terminal (mobile station (MS) or personal station (PS))
(2) Satellite-type terminal
(3) Dual-mode terminal
– – – Routing selected by FS

BES: base earth station
BS: base station
CS: personal base station (cell site for PSs)
CX: small rural exchange, etc
FS: fixed subscriber
HLR: home location register
ISDN: integrated services switching centre
LES: land earth station
MES: mobile earth station
MSC: mobile services switching centre
MU: mobile user
PGN: terrestrial paging network
PSTN: public switched telephone network
SP: satellite pager
TP: terrestrial pager
VLR: visited location register

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An advantage of the geographical integration is the possibility to independently optimize the characteristics of the two systems, for each of which one tailored technical solution is to be used, in consideration of the significant and different constraints affecting the two cases.

It can be concluded that, with this approach the satellite system fulfils its role in extending the coverage area.

2.2 Services integration

The network configuration is essentially the same as in case 1 (see Fig. 2). In this case, in the satellite system design phase, the system parameters are selected in such a way that the satellite links are able to support services compatible with those offered by the terrestrial system, in the sense that the local terminals (either ITU-T terminals or any future terminals) utilized by the user to support the desired service can be employed independently of whether a terrestrial or a satellite link is selected. This does not imply that the technical solutions (e.g. access scheme) adopted for the two systems are the same.

It can be expected that the satellite system will only be capable of supporting a subset of the services available from the terrestrial system because of limitations in the radio path. Additionally the service quality may not be the same for the two cases.

Harmonization of services is also important to ensure the possibility of interworking between MUs of the satellite system and MUs of the terrestrial system, for MU-to-MU communications.

2.3 Network integration

This is a key concept because it is the first integration level allowing features to be shared between space and terrestrial systems.

2.3.1 Network architecture

The objective is to use as far as possible the same equipment and protocols, i.e., the same hardware, software and facilities for both satellite and terrestrial cellular networks to minimize costs. Because of propagation delays and frequencies, etc., which are different for the satellite network compared to the terrestrial cellular network, some elements however differ. Figure 3 shows the global system architecture.

An example of network architecture featuring network integration with GSM is presented hereafter and in Fig. 4.

The global architecture would be composed of:

– a satellite constellation,

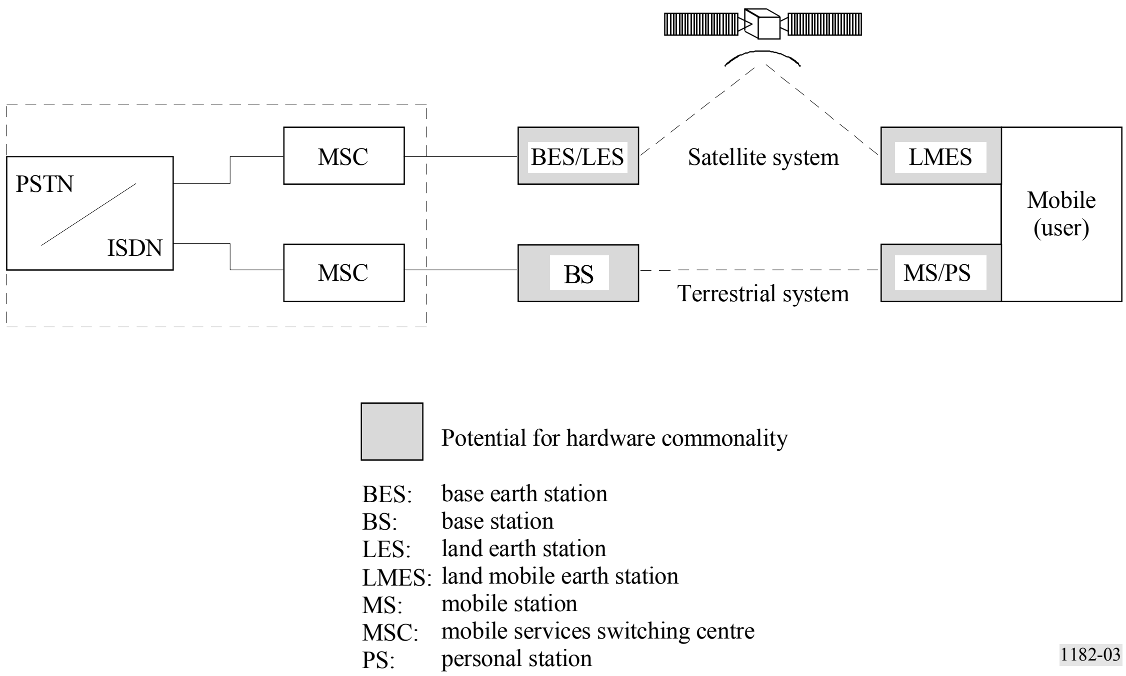
– mobile station,

– gateway station,

– mobile networks facilities: switching, locations registers and authentification centres.

FIGURE 3

Concept of commonality for mobile and base station facilities



The different interfaces would be:

– the "Air" interface which defines the exchanges between the MS and the GS;

– the X interface which defines the exchanges between the GS and the MSC;

– the MM (mobility management) interface which defines the protocol between the MSC and the HLR and VLR.

All these interfaces would be proposed to save development costs of the satellite system ground segment.

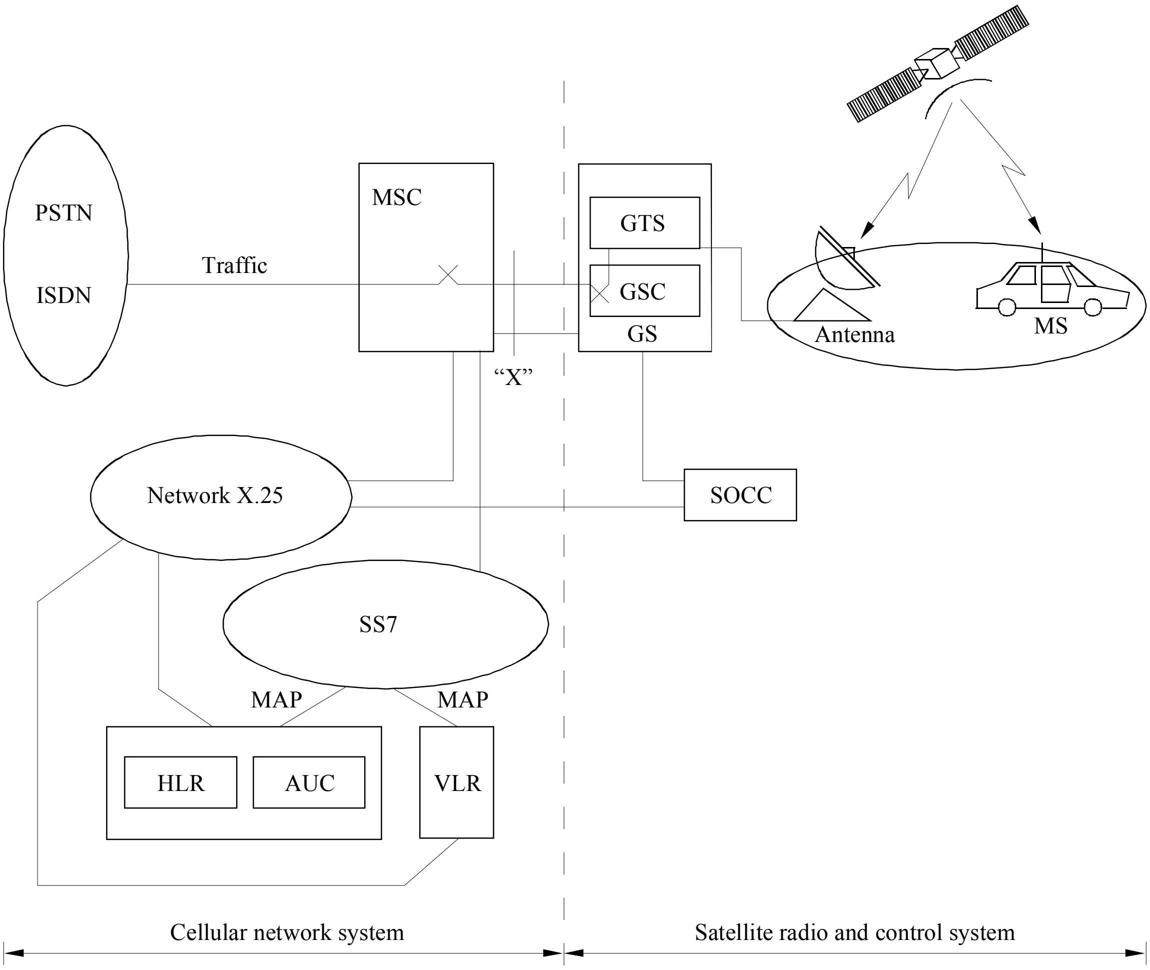
The signalling information exchanged among the different functional entities (except the MS) in the terrestrial network would use the ITU-T signalling system No. 7 (SS No. 7).

The data messages between the gateway station and the other entities (more particularly for the exchanges between the MSC, HLR and VLR) would use X.25 protocol.

The MS-GS link would use its own signalling system.

The choice of X as GSM A interface and "MAP" as MM interface would bring up, in mobile network GSM type, the following consequences: modify in the network where X would be connected, report in the GS the functions linked to satellite communications system (handover), reuse as far as possible the protocols and the MM entities (MSC, HLR, VLR and AUC) of cellular terrestrial networks.

FIGURE 4



AUC: authentification centre
GS: ground station
GSC: ground station controller
GTS: ground transceiver station
SOCC: satellite operation control centre
SS7: common channel signalling system No. 7

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2.3.2 Protocol aspects

It has been assumed above to use as far as possible the same protocols for the mobile satellite communications system and the terrestrial cellular system. As an example, the same channel types (same functionalities) as for the terrestrial and satellite link could be adopted.

For the satellite system, it would be necessary to consider a specific synchronization channel in order to estimate and compensate the delay and the Doppler effects for mobile-satellite link. The reduction of frequency errors and mobile positioning errors would allow the reduction of preambles and would increase the frame efficiency.

The localization procedure is specific for satellite systems, but the other procedures like registration, set-up, clear-down and mobility management could be considered the same as those of the GSM system.

A brief description of the three layers involved in the definition of satellite protocols is given below.

Layer 1

The physical layer (frame structure) only on the radio path between the MS, the satellite or satellite constellation, and the GS.

Layer 2

It specifies the link access procedures on the control channels to be used to convey information between layer 3 entities across the GSM radio interface. The layer 2 protocol is a Link Access Protocol Dm (LAPDm) type protocol.

Layer 3

This layer has to implement the dynamic routing of information related to the localization of the MS when idle and the dynamic routing of calls in progress when the MS leaves the cell or the area covered by a VLR. This layer is subdivided into three parts: circuit-switched call control (set-up, clear-down, etc.); mobility management and radio frequencies transmission management.

The first layer of the network (layer 1) requires important modifications (specific synchronization channel, modulation, interleaving, coder, channels structure). The layer 2 has no need to be changed, just the adaptation of a few parameters is necessary (temporization due to propagation delays, etc.). The layer 3 (the radio frequencies transmission management part) has to undergo modifications to perform initial localization and handovers. The other sub-layers (mobility management and call control) do not need much change.

2.4 Equipment integration

This approach is architecturally equivalent to that of network integration, with the main difference that the techniques (access parameters, bit rates, protocols, etc.) adopted for the satellite system are similar to hardware commonality or even the same as those of the terrestrial system (see Fig. 3).

The advantages of this approach essentially concern the simplification of the dual-mode mobile terminal implementation, as a common core (logic, baseband and possibly modulation equipment) can be utilized for both the terrestrial and satellite operating modes.

It has however to be noted that, due to the possible utilization of adjacent or different frequency bands for terrestrial and satellite communications, the upgrading of a terrestrial terminal to operate also with the satellite system will probably require extra equipment.

Despite the fact that this approach appears very close to a full integration of the two systems, it has to be noted that the terrestrial system still looks to the satellite system as an alternative routing, in cases of being unable to support the call request due to coverage limitations, and not as part of its system.

2.5 System integration

This last solution envisages the maximum conceivable level of integration of the satellite network with the terrestrial system, in the sense that the coverage(s) provided by the satellite system are regarded as one (or more) "big cells" of the cellular system.

All the advanced system features, such as handover of calls in progress from one cell to another, also apply to the big cell(s). (Handover across the satellite spot beams may not be mandatory, in consideration of the size of these beams.) The terrestrial/satellite handover procedure will clearly only be enabled, if the MU has a dual-mode terminal (information available at the HLR).

3 Conclusion

Several projects are presently being developed to provide a worldwide, regional or national service for mobile terminals using different satellite constellations. These systems could stand as a complement to the terrestrial cellular systems: this points out the interest of dual-mode terminals.

Some degree of integration between space and terrestrial systems would be desirable to reuse to the extent possible existing facilities. As far as the GSM integration example described in § 2.3 is concerned, a great part of the Open System Interconnection (OSI) Layers 2 and 3 protocols could be re-used.

Annex 2

Architecture of a closely integrated broadband terrestrial and satellite mobile communication system (SUITED Project)

1 Introduction

The SUITED (multi-segment **S**ystem for broadband **U**biquitous access to **I**n**TE**rnet services and **D**emonstrator) project is a project approved by the European Commission to define, design and demonstrate a global mobile broadband system (GMBS) based on an integrated satellite/terrestrial infrastructure where all the network components are fully merged into each other in order to achieve at least "Level 4 integration".

2 SUITED/GMBS system components and system architecture

The provision of broadband ubiquitous services can be assured only by envisaging a global service coverage area. Nevertheless, neither wireless terrestrial networks nor satellite systems operated by them are able to assure such a worldwide coverage. The only solution is to exploit the complementary features of different kinds of networks by creating a multi-segment access network allowing a generic user to select the most suitable system depending on several factors such as environment, type of services, cost effectiveness, etc. This is the solution proposed by SUITED.

The access networks envisaged in SUITED – also referred to as "segments" – are as follows:

– *20-30 GHz on board processing (OBP)-based satellite system*: broadband satellite segment operating at Ka-band with advanced on board processing capabilities, e.g. fast circuit switching, dynamic bandwidth allocation. This segment allows a wide range of terminal typologies suited for different service environment (transportable and mobile, individual and collective) with proper service rates as summarized in Table 1. The satellite system has also advanced connectivity capabilities being able to provide both access network capabilities and core network capabilities, and optimized interworking functions with many terrestrial networks, e.g. Internet, including quality of service (QoS) support, security, and service mobility support.

– *General packet radio service (GPRS) system*: land mobile system, which in the short term will provide bearer services allowing an efficient wireless access to packet data networks. This segment allows both individual and collective mobile terminal typology with transmission data rate as summarized in Table 1, the collective terminal concept being based on grouping together a set of individual terminals. This segment has specific network capabilities to interwork with terrestrial data packet network, e.g. Internet, including QoS support, security, and service mobility support.

– *Terrestrial IMT-2000*[2]: land mobile system, which in the medium term will provide bearer services allowing an efficient wireless access to packet data networks, then will represent the target solution aiming at complementing/replacing the GPRS system. This segment allows a wide range of terminal typologies suited for different service environments (transportable and mobile, individual and collective) with proper service rates as summarized in Table 1.

– *Wireless local area network (W-LAN) system*: access network to complement the satellite segment for both indoor and short range outdoor environments where satellite availability is poor or not available at all. This segment allows mobile terminal typology with transmission data rate as summarized in Table 1. This segment has no specific network capabilities apart from access to a satellite termination node, e.g. a satellite fixed earth station (FES).

The service data rate is a major critical requirement to be satisfied; it is worth noting the strong compatibility of the GMBS segments' service data rates as summarized in Table 1, for the different service environments and different kinds of user terminal usage.

[2] The SUITED Project is focused on the universal mobile telecommunication system (UMTS) architecture and protocols.

TABLE 1

SUITED segments' user terminal data rate comparison

Segment		Mobile			Transportable
		< 10 km/h	< 120 km/h	< 250 km/h	
Satellite	Individual	Uplink: 160 kbit/s Downlink: 6 Mbit/s	Uplink: 160 kbit/s Downlink: 6 Mbit/s	Not applicable	Uplink: 160 kbit/s Downlink: 6 Mbit/s
	Collective	Uplink: 0.512/2 Mbit/s Downlink: 16 Mbit/s	Uplink: 0.512/2 Mbit/s Downlink: 16 Mbit/s	Uplink: 2 Mbit/s Downlink: 16 Mbit/s	Uplink: 0.512/2 Mbit/s Downlink: 16 Mbit/s
GPRS	Individual	150 kbit/s	150 kbit/s	150 kbit/s	150 kbit/s
	Collective	$N \times$ 150 kbit/s(1)	$N \times$ 150 kbit/s(1)	$N \times$ 150 kbit/s(1)	$N \times$ 150 kbit/s(1)
IMT-2000	Individual	2 000 kbit/s	384/512(2) kbit/s	144/384(2) kbit/s	2 000 kbit/s
	Collective	$N \times$ 2 000 kbit/s(1)	$N \times$ 384/512(2) kbit/s(1)	$N \times$ 144/384(2) kbit/s(1)	$N \times$ 2 000 kbit/s(1)
W-LAN	Individual	11/5.5/2/1 Mbit/s	Not applicable(3)	Not applicable(3)	11/5.5/2/1 Mbit/s
	Collective	11/5.5/2/1 Mbit/s	Not applicable(3)	Not applicable(3)	11/5.5/2/1 Mbit/s

(1) Collective terminal will be achieved by grouping *N* individual terminals.
(2) Planned.
(3) The current utilization of the W-LAN is limited to low speed application, e.g. parking area.

The Internet network considered in the SUITED/GMBS system is assumed to be formed by subnetworks operated by a federation of Internet service providers (ISP). The term federation refers to a set of ISPs which have defined peer service agreements to provide QoS sensitive Internet applications to a common user community.

The integration of the access segments envisaged in the GMBS/SUITED system allows coverage of any possible user environment:

– *open area/rural/suburban environments* served by a geostationary, regenerative satellite (supporting delay/non-delay/security sensitive applications) operating at 20-30 GHz with bandwidth on demand and dynamic resource allocation;

– *urban environment* served by either GPRS or IMT-2000 as well as, with some limitations, by the satellite (for the non-delay sensitive applications tolerant of frequent link shadowing);

– *indoor environment* served, in addition to the GPRS and IMT-2000 segments, also by the W-LAN; satellite-based services are foreseen for the aggregated W-LAN traffic so that, by also envisaging the use of collective terminal, the QoS offered to the business end-users is significantly improved.

A multi-segment access network consisting of the components described above would not cover the polar zones. This is due to the GSO orbit's inability to provide visibility to the polar regions. In order to remedy this situation, in the SUITED/GMBS system, the service coverage provided by the geostationary satellites may be complemented by low Earth orbit/highly elliptical orbit (LEO/HEO) constellations. This solution is useful, not only to solve the problem of the complete absence of the GSO footprint in certain zones (like polar zones), but also to cover areas where the performance of GSO satellites are not optimal or where addressing spot-beams could be not economically convenient.

Figure 5 schematically depicts the SUITED/GMBS system architecture. The Figure shows a multi-segment access network consisting of:

– broadband satellite segment;

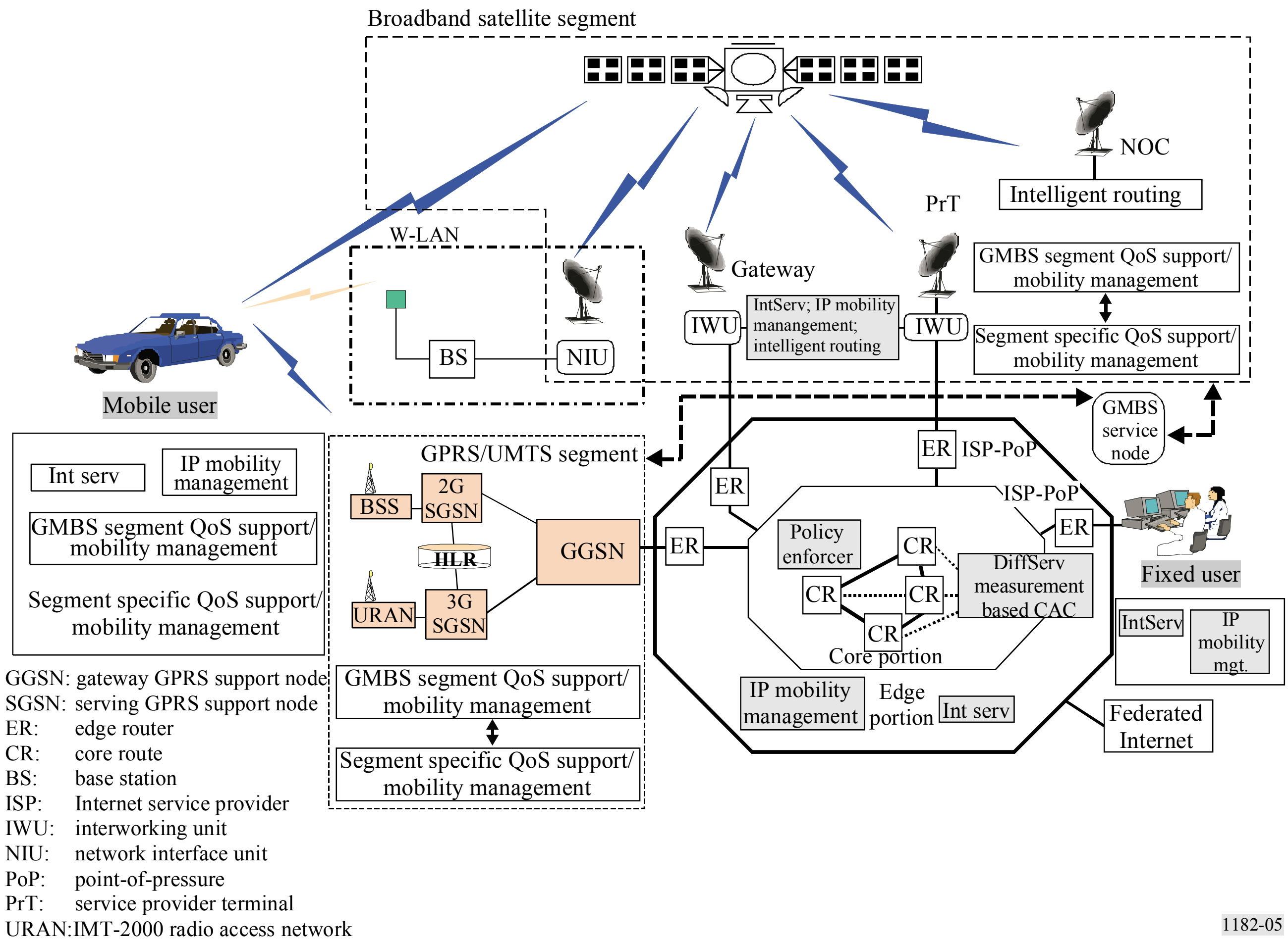
– GPRS segment;

– IMT-2000 segment;

– W-LAN component.

FIGURE 5

SUITED system architecture



The IMT-2000 system is assumed to play a strategic role in the final phase of the GMBS system deployment, since it will be in charge of complementing the satellite component. In the near term vision, the global service coverage area will be obtained by complementing the satellite segment with the GPRS system. Taking into account that the IMT-2000 core network may evolve from that of GPRS, and according to the requirements defined by the authorities in charge of granting the IMT-2000 licences to telecom operators, in the SUITED/GMBS system architecture a unique IMT-2000/GPRS core network is envisaged. According to this assumption, it is possible to envisage that the evolution of the IMT-2000 system will go through the development of a dual-mode GPRS/IMT-2000 terminal addressable by the same mobile station ISDN (MSISDN) number and directly associated to the International Mobile Subscriber Identity (IMSI) of the subscriber using the dual-mode terminal at a certain time. A unique GPRS/IMT-2000 core network characterized by a unique HLR is therefore the solution able to satisfy such requirements.

For what concerns the GPRS/IMT-2000 system, as shown in Fig. 5, the gateway GPRS support node (GGSN) is physically linked to the edge router of an edge subnetwork. A dynamic address assignment for the IP user accessing Internet through the GPRS/IMT-2000 system is envisaged. This implies that the IP packets directed to such an IP user are always transmitted towards the subnetwork connected to the GGSN. Different GPRS public land mobile networks (PLMNs) are connected via an inter-PLMN backbone network represented by whatever packet data network (e.g. Internet itself).

The broadband satellite segment is characterized by multiple points of attachment to the Internet network, each one represented by an FES. An appropriate network interface unit (NIU) placed between an FES and an edge subnetwork router, allows interworking between the IP protocol and the satellite specific protocols. The satellite network operation centre (NOC) represents a centralized entity, which is in charge of executing synchronization, registration, authentication and connection admission control procedures. In the GMBS system devised in SUITED, the NOC is directly connected to the Internet network. Even though this solution implies a higher complexity for the NOC, it allows the design of optimized procedures requiring an exchange of signalling information over terrestrial links. As far as the selection of the most suitable FES to be used to support the communication is concerned, several strategies can be envisaged, each one characterized by a different impact in terms of network architecture and mobility management procedure execution.

The W-LAN segment mainly aims at providing a short-range connectivity for outdoor and indoor environments. The collected aggregate traffic can reach the Internet network through two different paths:

– it can be delivered to a subnetwork edge router through terrestrial lines, or
– it can be delivered to a satellite FES directly connected to the W-LAN segment and then transmitted over the satellite radio link.

The GMBS system architecture at the network side envisages a GMBS service node which, by interacting with the terminal interworking unit (T-IWU) at the terminal side, performs specific tasks for the management of inter-segment mobility and QoS provision on the multi-segment access network.

3 QoS provision and mobility support in a multi-segment IP infrastructure

3.1 End-to-end QoS provision

One of the most challenging objectives of the SUITED GMBS system is to support Internet QoS sensitive services providing the users with end-to-end QoS guarantees.

In the last years, work performed in the framework of the Internet Engineering Task Force (IETF) standardization body to provide the Internet with QoS support capability, led to two distinct approaches:

– integrated services (IntServ) architecture with the relevant resource reservation protocol (RSVP);

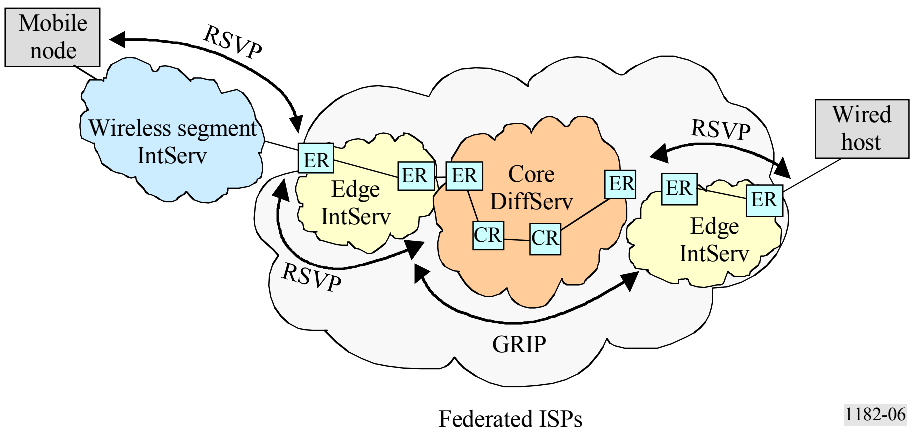
– differentiated services (DiffServ) architecture.

Considering that the IntServ architecture and the DiffServ architecture can be seen as complementary technologies in the pursuit of IP end-to-end QoS, the solution adopted in the SUITED system is based on the so-called hybrid IntServ-DiffServ approach. The rationale is to exploit on one side the possibility for the hosts to request quantifiable resources along end-to-end data paths, possibility provided by the IntServ architecture, and on the other side the scalability properties provided by the DiffServ architecture.

The SUITED hybrid IntServ-DiffServ approach, conceptually shown in Fig. 6, foresees that all the wireless segments, acting as access networks, provide QoS assurances by adopting the IntServ solution while as far as the terrestrial Internet network (federated ISPs network) is concerned it is envisaged that some subnetworks adopt the IntServ approach and others the DiffServ solution. More precisely the subnetworks at the edge of the federated ISPs network implement the RSVP signalling protocol by means of which strict QoS guarantees can be provided, whereas in the core of the federated ISPs network the scalable DiffServ model is adopted.

FIGURE 6

SUITED hybrid IntSev-DiffServ approach for IP QoS support



Moreover, as the DiffServ approach provides distinguished and predictable service levels (better than best effort traffic) but does not provide strict end-to-end QoS assurances, in the core portion of the federated ISPs network in order to improve the user-perceived QoS performance, an innovative solution, called gauge and gate reservation with independent probing (GRIP), is implemented. This solution, based on distributed admission control schemes, foresees that each router supports a per hop behaviour defined in terms of service priority between two classes of packets: the active packets, which correspond to the information packets, with higher service priority and the probing packets, with lower service priority, which are delivered in order to determine if the considered connection can be admitted to the network while maintaining the QoS of the already admitted connections and of the new one. If the assumption is made that all the traffic entering the network is regulated by dual leaky buckets, the GRIP technique allows providing hard guarantees to the admitted connections so that QoS performances are improved with respect to a simple DiffServ network.

It is important to note that other Internet network topologies, envisaging either an extension of the DiffServ core portion to the entire Internet or a full IntServ architecture, represent only particular cases which do not prevent the utilization of the above-mentioned approach. The reference topology shown in Fig. 6 is the most general case which allows the definition of an Internet architecture suitable for evolution towards all the predictable QoS architectural solutions.

Moreover the proposed Internet topology, by means of the edge subnetworks implementing the RSVP protocol, provides the opportunity to set a fully IntServ-compatible end-to-end communication path (e.g. from a mobile node to a wired host) by-passing the federated ISPs core network. A typical scenario, where a fully IntServ-compatible end-to-end communication path can be set, is represented by the 20-30 GHz OBP-based satellite segment acting as access network to the terrestrial Internet network and implementing smart routing functionality. For example in the case of mobile originated communications between a mobile node and a wired host, when the satellite segment is selected as supporting network, smart routing/selective landing functionality will allow to select the FES directly connected to the edge router of the edge subnetwork the wired host is connected to so that the terrestrial path is minimized and it takes place only within the edge subnetwork implementing the RSVP protocol.

The inter-operation between the RSVP protocol and the GRIP mechanisms takes place within suitably devised gateways placed at the boundaries between the edge and the core portions of the Internet network. This hybrid IntServ/DiffServ solution devised in the SUITED system is particularly attractive for several reasons. Firstly, it solves scalability problems since in the core part of the network, which tends to continuously grow, a DiffServ-like mechanism is envisaged. Moreover, taking into account that IntServ mechanisms are also envisaged in the wireless access segments, in case of paths involving only the edge portion of the Internet network – where the RSVP protocol runs – the QoS provision can be completely managed, and consequently guaranteed, with an integrated service approach. Finally, it is worth noting that the hybrid structure for the QoS management allows to easily cope with the future evolutions of the Internet network towards a completely based DiffServ or completely based (actually not so likely) IntServ solution.

Each access segment is connected to the edge portion of the Internet network, i.e. it is connected to an edge Internet subnetwork implementing the RSVP protocol.

3.2 Mobility support

The GMBS system is obtained by integrating a multi-segment access network – consisting of several satellite/terrestrial components – with the Internet network. The overall SUITED mobility management scheme has been designed by taking into account that every GMBS segment is characterized by a suitably defined architecture and way of working. The methodological approach followed in SUITED is that the modifications to the system components should be as minimal as possible but at the same time guaranteeing an efficient cooperation among segments. The final objective is that, from a user perspective the GMBS system is perceived as a single network able to provide "anywhere" and "anytime" Internet services with a guaranteed QoS.

In order to support global mobility, a suitable GMBS mobility management (MM) scheme has been devised. Considering the main architectural features of the system, the GMBS MM scheme has resulted from the harmonization of the three following levels of mobility management:

– *IP mobility management*: based on the mobile IP protocol implemented in the Internet network. Mobile IPv6 has been considered as baseline even though full compatibility with mobile IPv4 is also taken into account.

– *Inter-segment mobility management*: devised in order to allow the GMBS user to move from one access segment to another.

– *Intra-segment mobility management*: completely handled by the entities of the access segment serving at a certain time the GMBS multi-mode terminal (GMMT), as long as GMMT remains within its radio coverage; the procedure devised in the framework of the project to guarantee an intra-segment handover for low range outdoor/indoor coverage and exploiting the W-LAN segment as prolongation of the satellite connection has to be considered as belonging to this class.

A generic GMBS user provided with a GMMT is able to connect to each of the multi-segment access network components. GMMT can be seen, from the Internet point of view, as a mobile node. A node can change its point of attachment from one link to another, while still being reachable via its home address. In order to access the Internet network, the mobile node represented by the GMMT can select one of the access components that, according to the results of an appropriate algorithm, is "the most suitable one". Since the different components of the GMBS multi-segment access network connect to edge routers belonging to Internet domains that, for the general case, are not coincident, the point of access to Internet will depend on the access network chosen to support the packet transmission. The GMMT will be assigned a different care of address (CoA) depending on the selected segment and a change in the access segment (inter-segment mobility) implies a change of CoA (IP mobility). At the same time, as long as the GMMT remains in the same access segment, no change in the CoA is required and the mobility is completely managed by the access segment specific entities (intra-segment mobility).

4 GMBS multi-mode terminal

Broadband satellite, GPRS/IMT-2000 and W-LAN access segments complement each other in order to allow a generic user to access QoS guaranteed Internet services regardless of his current location. Such a user will be provided with a GMMT where the satellite component is complemented by a wireless terrestrial one which is represented, in the first phase of the GMBS deployment, by the GPRS, while for the further evolution of the system, by IMT-2000. It is also envisaged that GMMT be provided with a W-LAN card allowing satellite intra-segment handover for low range outdoor/indoor coverage. Depending on several factors like coverage features, economic considerations, type of services etc., the most suitable access segment to support IP packet transfer will be automatically or manually selected.

Several optimized vehicular and portable solutions for diversified environments are envisaged. In particular, very promising market prospects for the mobile broadband satellite terminals have induced the selection of three basic terminal configurations to be designed and prototyped in the frame of the SUITED project:

– *Type A: Vehicular flat antenna (not protuberant) terminal* configuration for individual use provided with an active antenna specifically designed to avoid disturbances to the aesthetic of a car.
– *Type B: Vehicular protuberant antenna terminal* for collective utilization environment (e.g. for trains, buses, trucks, etc.) provided with a protuberant satellite antenna based on passive antenna solutions.
– *Type C: Transportable terminal* specifically conceived for easy transportation and fast activation of services, like those needed for construction headquarters, civil protection, institutions and business travellers. This will make use of a remotely controlled transportable antenna with coarse manual and fine automatic pointing.

The satellite access technique is the MF-TDMA (uplink) and TDM (downlink).

QPSK modulation is used on both uplink and downlink presenting good performances in terms of:

– spectrum efficiency;
– robustness against synchronization errors due to time jitter, phase noise, etc.;
– low implementation complexity.

As far as coding is concerned, FEC coding is adopted: Reed Solomon 76, 60 + parity check 10/9 coding on the uplink and DVB-S coding on the downlink.

Figure 7 shows the internal structure of the GMMT where the GPRS and IMT-2000 mobile terminals (MTs) have to be considered as alternative solutions for the wireless terrestrial component and where the W-LAN component is omitted just for simplicity. Table 2 lists the main blocks composing GMMT, describing the functionality they are in charge of. A vehicular and a transportable version of GMMT are envisaged presenting differences in the features of some constituting blocks.

In the following the structure of GMMT will be presented by considering the broadband satellite and GPRS components.

FIGURE 7

GMMT internal structure

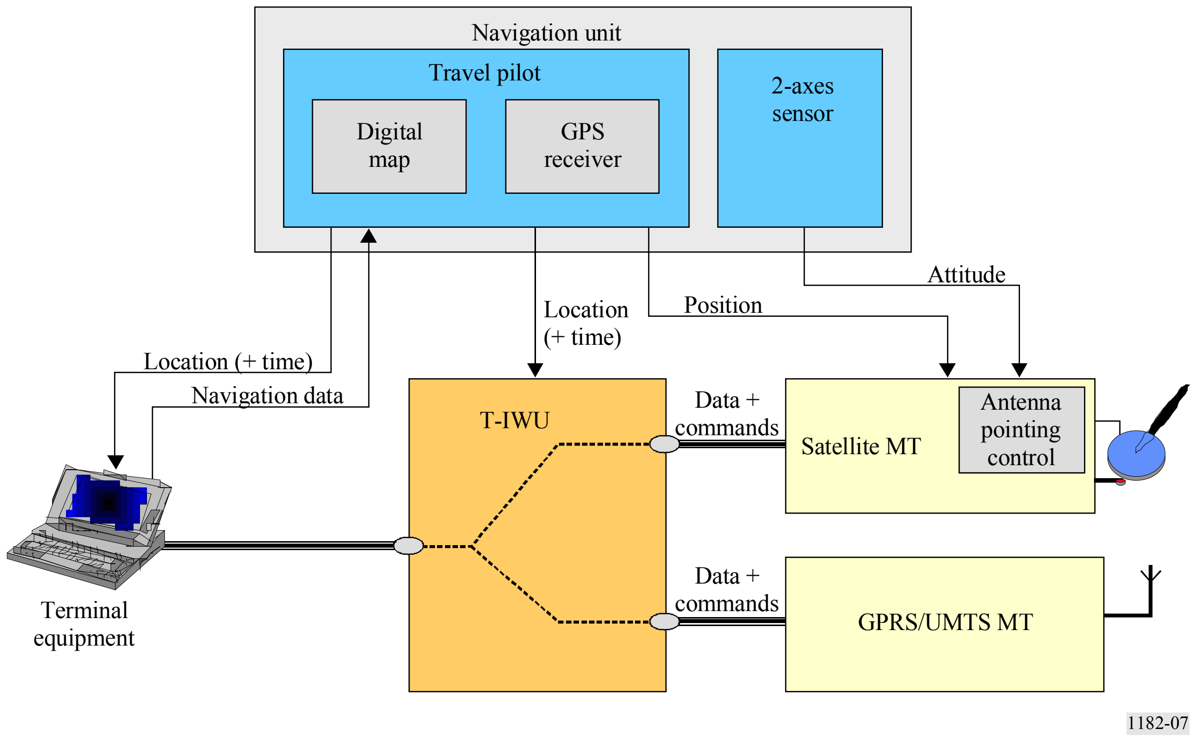


TABLE 2

GMMT constituting block functionality

Acronym	Component	Functionality
BSAT-MT	Broadband satellite mobile terminal	Satellite terminal operating in the 20-30 GHz band. Three types have been defined: – Type-A (for individual use); – Type-B; – Type-C (both for individual and collective use)
GPRS-MT	GPRS mobile terminal	GPRS MT, i.e. modem operating at 900/1 800 MHz band and providing access to GPRS radio resources
IMT-2000-MT	IMT-2000 mobile terminal	IMT-2000 MT, i.e. modem operating at the 2 GHz band, providing the access to IMT-2000 radio resources
W-LAN-MT	W-LAN mobile terminal	IEEE 802.11 modem operating at 2.4 GHz

TABLE 2 (*end*)

Acronym	Component	Functionality
T-IWU	Terminal interworking unit	It hosts GMBS specific functionality for management of inter-segment mobility and QoS over the access segments. It also implements routing functions to address IP packets towards the selected segment specific mobile terminal (i.e. towards the satellite or wireless terrestrial component)
TE	Terminal equipment	Standard equipment (e.g. PC, laptop, etc.) implementing mobile IP protocol. In the vehicular version of GMMT, several terminal equipment will be connected through a LAN to the T-IWU
NU	Navigation unit	It provides positioning data to: – T-IWU to support segment selection and handover procedures; – the pointing, acquisition and tracking module to facilitate the calculation of the satellite antenna's azimuth and elevation; – Internet applications (i.e. to TE) for the deployment of location-based services

Tables 3 and 4 show the main characteristics of the transportable user terminals and land mobile user terminals respectively.

TABLE 3

Transportable user terminal characteristics

Terminal	Type A	Type-B, C
Case	Laptop	Briefcase
Mobility in operation	No	
Coverage volume	360° Az, 20-90° El; ±10° from axis after manual pre-point	
Uplink maximum information rate (kbit/s)	160	512 (B), 2 048 (C)
Downlink maximum information rate (Mbit/s)	6	16
Receive frequency (GHz)	20	
Transmit frequency (GHz)	30	
Antenna type	Flat, detachable	
Maximum antenna dimensions (cm)	≈ 20 × 30	≈ 30 × 40
Antenna electrical design	Passive printed antenna	

TABLE 4

Land mobile user terminal characteristics

Terminal	Type-A	Type-B	Type-C
Mobile type	Car	Train, bus, truck	
Use	Individual	Individual/Group	Group
Pointing requirements	Auto (electronic pointing, full agile beam)	Auto (mechanic pointing)	
Target elevation range (degrees)	10-80		
Doppler effect correction	Yes		
Uplink maximum information rate	160 kbit/s	512 kbit/s	2 Mbit/s
Downlink maximum information rate (Mbit/s)	6	16	
Receive frequency (GHz)	19.7-20.2		
G/*T* (dB/K)	5.1	11.7	
Transmit frequency (GHz)	29.5-30.0		
e.i.r.p. (dBW)	39.8	42.8	48.8
Antenna type	Not protuberant	Protuberant acceptable	
Maximum antenna dimensions (cm)	Up to ≈ 32 × 32	Up to ≈ 25 × 70	
Antenna electrical design	Planar active array antenna	Passive antenna	

The car-mounted antenna for individual use is the most critical one, because this requires the design of a new active phased array antenna to solve the space constraints in a car. The pointing system is another innovative aspect of the terminal, to make the antenna suitable to track the satellite position in a critical environment, taking into account the speed of a car (more than 80 km/h) and the stability conditions on the road.

5 Possible scenarios for the integration between terrestrial and satellite mobile systems

The integration between terrestrial and satellite mobile systems aims at achieving a global wideband cellular system consisting of multiple (satellite and terrestrial) system components (segments) with different and mutually complementary characteristics.

In the integration scenario selected by the SUITED team the broadband satellite (BSAT) access network segment is seen as an access network directly linked to the IP routers. As explained in the following, the selected scenario foresees a natural integration with the IP network and allows the satellite segment to exploit the IP mobility features.

Figure 8 shows the proposed integration scenario. In this Figure the ovals represent the IP routers; in particular, the ovals are within rectangles in case the IP routers are provided with IMT-2000/ GPRS functions; in this case they become 2G (i.e. GPRS) or 3G (i.e. IMT-2000) GGSN or SGSN. The GGSNs are the IP routers provided with the GPRS/IMT-2000 functions, which interface the non-GPRS/IMT-2000 IP routers. So, the GGSNs interface the GPRS/IMT-2000 core network with the non-GPRS/IMT-2000 IP core network (Fig. 8 shows one such GGSN).

FIGURE 8

Proposed integration scenario

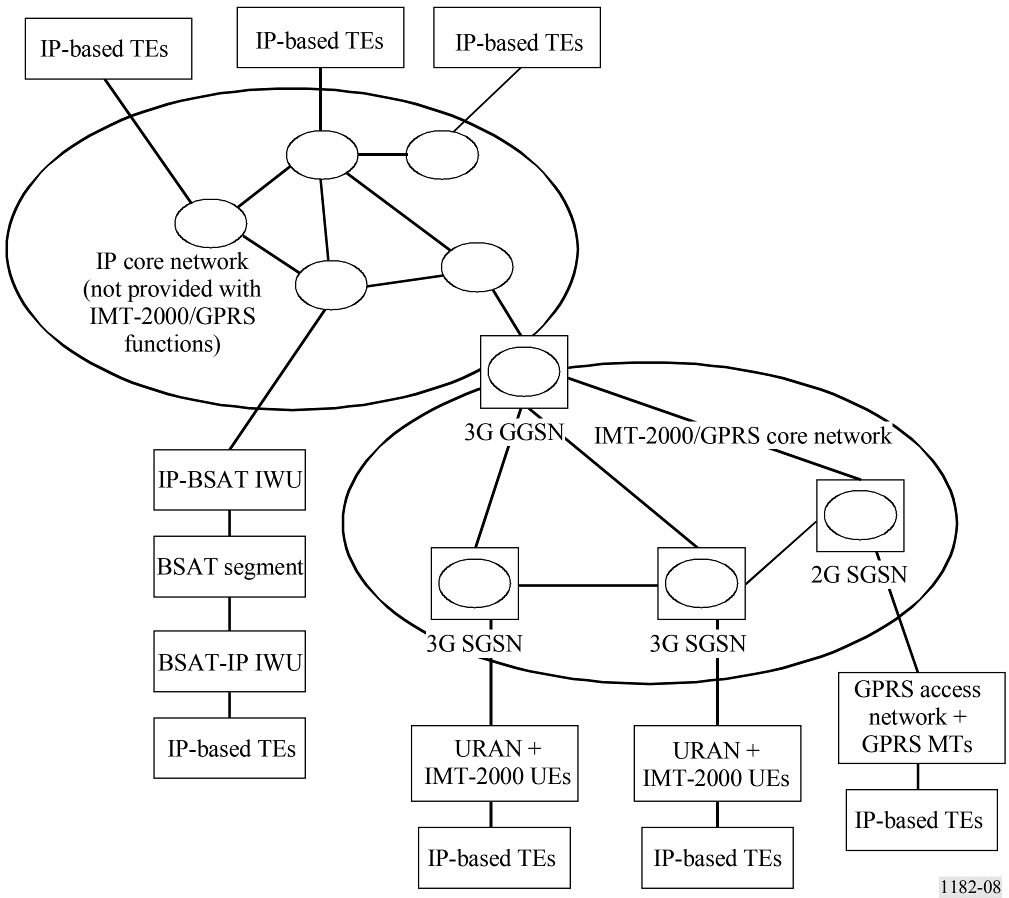


Figure 8, as an example, shows the following access networks: two IMT-2000 access networks (the so-called IMT-2000 radio access network (URAN)), one GPRS access network, one satellite access network (BSAT segment). Finally, Fig. 8 shows some IP-based TEs either directly linked to IP routers, or linked to some access networks. The TEs are standard hosts (i.e. they can be simple personal computers).

As shown in Fig. 8, the BSAT segment is seen as an access network linked to the IP core network. In particular, the presence of an IP-BSAT IWU on the network side and of a BSAT-IP IWU on the terminal side are needed in order to provide a proper interfacing with the IP core network. For instance, the IP-BSAT IWU has to behave on the IP core network side, as an IP router, while, on the satellite segment side has to interwork with the satellite-specific protocols.

Figure 8 considers an advanced GPRS/IMT-2000 scenario in which only the packet switching SGSN/GGSN (and no circuit switched equipment) are present. It is assumed that each SGSN can interface, at the maximum, one access network.

We have assumed that mobile IPv4 is present. Nevertheless, the explained concepts can be extended even to the case in which the mobile IPv6 is present.

As far as the relationships between IP mobility and IMT-2000 (3G) mobility is concerned, three phases are being planned:

– During the first phase, an IMT-2000/GPRS mobile user is permanently assigned his reference GGSN (i.e. the GGSN through which all the traffic directed to the user is routed); this means that, wherever the mobile user is roaming, the traffic directed to him will be, in any case, routed through the reference GGSN permanently assigned to the user. In this phase, a GMBS MT terminated connection is routed up to the reference GGSN permanently assigned to the GMBS MT by means of the mobile IP and then routed up to the SGSN serving the GMBS MT (hereinafter referred to as serving SGSN) by means of IMT-2000 mobility features.

– During the second phase, it will be possible, for an IMT-2000/GPRS mobile user, to vary (not in real time and not with a connection in progress) the reference GGSN. This will allow a mobile user to make use of the reference GGSN closest to the location where he is at that moment roaming. In this phase an GMBS MT terminated connection is routed up to the reference GGSN currently assigned to the GMBS MT by means of the mobile IP and then routed up to the SGSN serving the GMBS MT (hereinafter referred to as serving SGSN) by means of IMT-2000 mobility features.

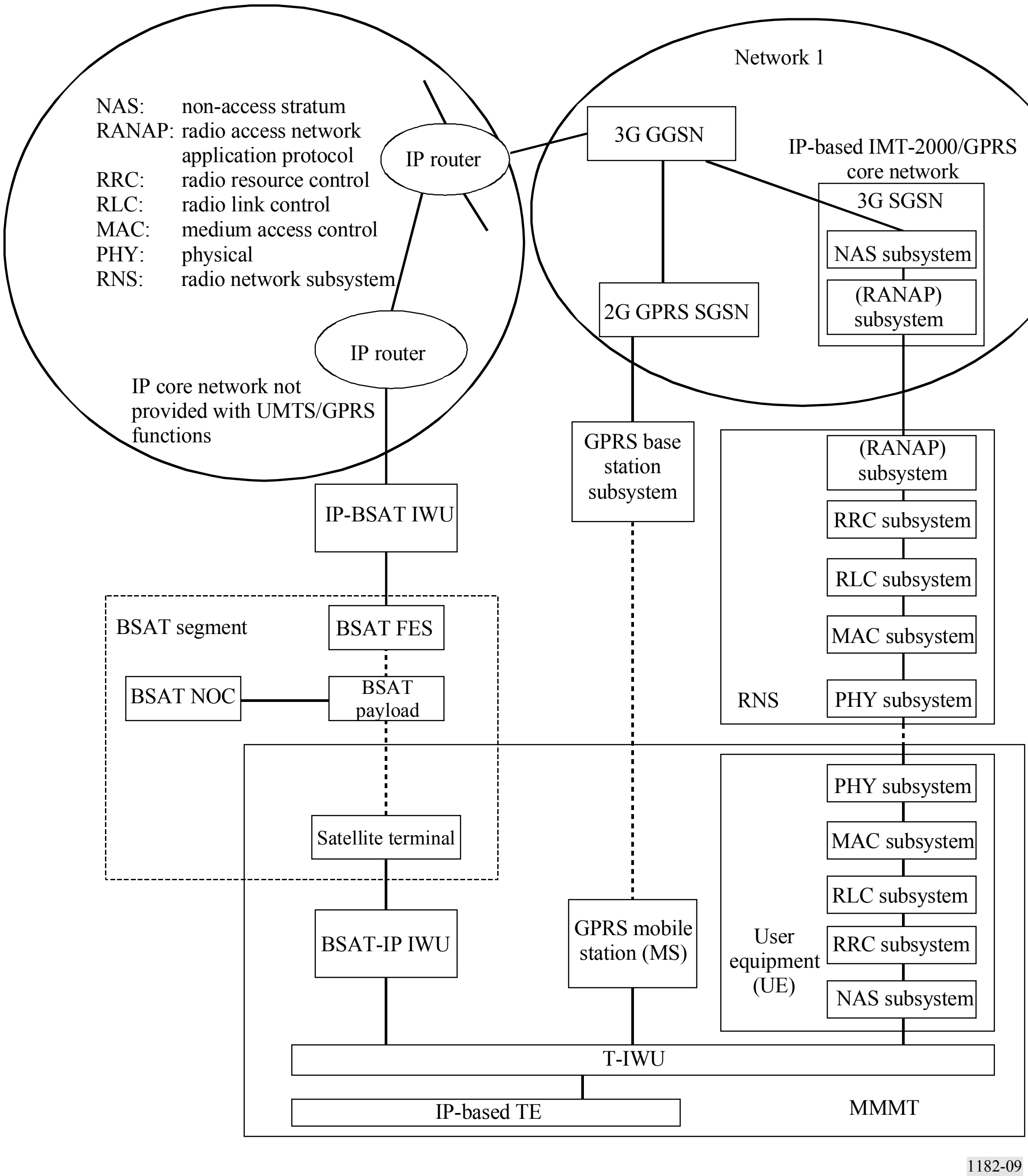
– During the third phase, the GGSN and the SSGN are expected to merge into a single entity. In this phase a GMBS MT terminated connection is directly routed up to the serving SGSN currently assigned to the GMBS MT by means of the mobile IP.

In the proposed integration scenario, we consider the second phase; as a matter of fact, the first phase may be too short-sighted, while the third phase entails modifications of several IMT-2000 mechanisms (e.g. GPRS tunnelling protocol (GTP) tunnels) which are not yet defined. In this second phase, all the 3G GGSNs are assumed to be provided with mobile IPv4 foreign agent (FA) functions; thus, the 3G GGSNs will be at an extreme of the tunnel which the mobile IPv4 procedures establish between the home agent (HA) and the FA. Moreover, the 3G GGSN will also be at the extreme of another tunnel, the so-called GTP tunnel, that the IMT-2000 procedures establish between the reference GGSN and the serving SGSN.

Figure 9 can be considered as a part of Fig. 8 which includes the BSAT, GPRS and IMT-2000 access networks. In addition, Fig. 9 considers a multi-mode mobile terminal (MMMT) as able to access BSAT, IMT-2000 and GPRS segments.

FIGURE 9

Architecture of an MMMT (three-mode: GPRS, IMT-2000, BSAT) with the relevant access networks



This Figure highlights that the satellite system and the IMT-2000/GPRS network have independent accesses to the IP core network.

MMMT (three-mode: BSAT, GPRS, IMT-2000) such as the one shown in Fig. 9 is provided with three segment-specific mobile terminals (namely, a GPRS MS, an IMT-2000 UE, a satellite terminal), with a T-IWU in charge of the interworking of the three segments and of a single TE. The segment-specific MTs are the standard terminals belonging to the GPRS, IMT-2000 and satellite segments, respectively; the T-IWU is an appropriate equipment which allows the interworking among the three segments; the TE is a standard IP-based host.

A key issue is that the IP-based TE linked to the MMMT is regarded from the IP network as a single mobile user, i.e. it can be reached by means of a single IP address regardless of the segment which is presently serving it. In this respect, the proposed integration scenario foresees an efficient interaction between the mobile IP procedures and the segment-specific mobility procedures.

The T-IWU has a key role in the MMMT since it carries out all the inter-segment mobility procedures. It is in charge of selecting the most convenient access network (out of the three). For instance, if at time *t*, the T-IWU shown in Fig. 9 selects the IMT-2000 access network, this means that, at time *t*, all the data directed to the MMMT are routed through the SGSN network 1 (see Fig. 9). In other words, at a certain time *t*, the IP core network "sees" the TE attached to the MMMT as a TE associated to just a single access network, namely the one selected, at time *t*, by the T-IWU. Moreover, the T-IWU has a key role in the inter-segment handover procedure (i.e. the passage of a connection in progress from a segment to another).

A possible evolution of the scenario outlined in this section is a scenario fully based on IMT-2000 in which the satellite access network (the BSAT segment) is seen as an access network directly linked to the IMT-2000/GPRS core network; this means that, in this scenario, the IP-BSAT-IWU is linked to a 3G-SGSN. Nevertheless, such a scenario could be actually implemented only when the IMT-2000 will be fully deployed. The basic advantage and motivation behind this advanced scenario is that it should allow the BSAT segment to take advantage of the mobility features already planned for IMT-2000. Therefore, this scenario aims at allowing the BSAT segment to exploit (in a "free" manner) the IMT-2000 mobility features.