INTERNATIONAL JOURNAL OF SATELLITE COMMUNICATIONS AND NETWORKING
Int. J. Satell. Commun. Network. 2004; **22**:87–111 (DOI: 10.1002/sat.776)

S-UMTS access network for broadcast and multicast service delivery: the SATIN approach

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SUMMARY

This paper proposes a complete satellite access network solution for multimedia broadcast multicast service (MBMS) delivery based on T-UMTS standards. First, the benefits of MBMS delivery via satellite (SAT-MBMS) for both S/T-UMTS network operators are shown with market and business analysis. A new integrated S/T-UMTS architecture for MBMS delivery is proposed featuring an intermediate module repeater (IMR) for coverage of urban areas. The architectural options of IMR and terminals are discussed considering the relevant cost and complexity. The IMR propagation channel conditions are investigated and a new propagation channel model is proposed. The potential of advanced coding schemes such as the layered coding technique to tackle the channel variations in broadcast/multicast environment is outlined. The functional and protocol architecture are defined along with the interface between the satellite access network and the UMTS core network. Required modifications on the terrestrial access scheme sub-layers to support MBMS data are investigated and the relevant logical, transport and physical channels are selected. Based on the channel selection and the point-to-multipoint service nature, we define a generic radio resource management (RRM) strategy that takes into account both QoS and GoS requirements. The efficiency of the proposed solutions is evaluated in the presented simulation results, advocating the feasibility of the overall approach. Copyright © 2004 John Wiley & Sons, Ltd.

KEY WORDS: satellite UMTS; MBMS; S-DMB; market-business analysis; intermediate module repeater; streaming; push and store; radio access network; core network

1. INTRODUCTION

The success story of second-generation (2G) terrestrial mobile systems (GSM) and the relative demise of 2G mobile satellite systems (MSS) such as Iridium and Globalstar will

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influence the future of MSS. These two distinct but interrelated events demonstrate the importance of proper market and business strategies for the success of the future mobile satellite industry.

On the terrestrial network side, there is increased evidence of demand for multimedia (MM) services over the air in the near future. The provision of MM services in broadcast/multicast (BC/MC) mode has been regarded as a key to the efficient use of the precious wireless resources and are currently under standardization within the 3GPP Multimedia Broadcast Multicast Services (MBMS) [1] framework. However serious concerns are expressed as to whether T-UMTS can cope with the additional requirements of MBMS delivery on top of the other point-to-point T-UMTS services due to the spectrum limitations and very limited means to improve the spectrum efficiency. On the other hand, satellites are a promising platform for MBMS delivery due to their unique wide area coverage capabilities. The closer co-operation between MSS and terrestrial systems and their integration—at service—, network—and/or terminal-level—promises benefits for both the satellite and the terrestrial system operators. The IST SATIN (Satellite UMTS IP based network) project has addressed this system concept from both technical and marketing point of view, focusing mainly on the definition of a satellite air interface that drives the integration of the satellite and the terrestrial networks to these ends.

In the next section, two approaches for the synergy of T/S-UMTS at service level are presented along with three relevant evolution scenarios. Then addressable satellite markets are assessed including results of a business case built for a satellite operator and a comparative study for MBMS deployment addressing the terrestrial mobile operator. The system architecture that can support this business case in a cost-efficient manner is described in Section 3. The intermediate module repeater (IMR) concept, central to this architecture, and its implications are also discussed in detail in this section. Section 4 addresses the core project objective, namely the adaptation of the T-UMTS radio interface to the system architecture. A subset of the T-UMTS air interface channels (logical, transport and physical) are retained along with the respective signalling procedures. Section 5 deals with the physical layer adaptation. In particular we investigate non-standard coding and modulation schemes to tackle the particular propagation conditions of satellite environments and to improve spectral efficiency for MBMS delivery. The UMTS and ETSI SW-CDMA cell search procedures are then compared and the RACH channel (adopted for limited data transfer on the return link) is addressed. Section 6 outlines the involvement of broadcast/multicast control (BMC) in MBMS service delivery procedures and the required adaptations of radio link control (RLC) and medium access control (MAC) to support the selected channels for data transfer. A generic radio resource management (RRM) strategy, suited to the services under consideration and catering for the constraints related to the specific air interface, is defined in Section 7. Capacity analysis is invoked in Section 8 to show the feasibility of the proposed SAT-MBMS system. In Section 9 we give a brief overview of ongoing and forthcoming activities in this new system approach and in Section 10 we present the overall conclusions.

2. S-UMTS MARKET AND BUSINESS ASSESSMENT

The principal question traditionally posed for MSS is whether they should address a mass/consumer market, or target specific limited size niche markets. The niche market is already served by players such as Inmarsat and Eutelsat and hence there is high competition for S-UMTS in entering such a market (estimated at about 500 000 users). S-UMTS is however positioned, as a potential player in a much wider market (Figure 1(a)), addressing segments covered by terrestrial broadband systems, or targeted by the forth-coming fixed/mobile satellite services systems (SES Global BBI and Inmarsat B-GAN) as well as those segments served by existing MSSs. However, experience with 2G MSS has shown that satellite systems cannot capture the predominant voice market and furthermore acquire a position in the mass market as stand-alone systems; thus integration with terrestrial systems emerges as a critical issue for the future of the satellite communications industry. From a service perspective two roles were identified for S-UMTS regarding synergy with its terrestrial analogue:

Geographical complement: Expansion of coverage areas (not adequately covered by T-UMTS), including disaster-proof availability and absorption of excessive terrestrial traffic.

Service complement or close co-operative: Provision of only MBMS for the benefit of the end-users with low cost innovative services and the S/T-UMTS operators in terms of shared infrastructure investment.

Regarding the future S-UMTS market growth we derived with three evolution hypotheses:

Average hypothesis: It is assumed that the highly sensitive issues (cost of terminal, technical feasibility, mobile MM penetration, etc.) will not experience remarkable evolution in the short term.

Pessimistic hypothesis: (10% of average case) Operators are reluctant/unable to produce low-cost MM handsets and 3G value-added services are not sufficiently developed. S-UMTS no longer correlated with market demands, suffers a major setback.

Optimistic hypothesis: (2–3 times the average case) Fast inter/intra-nets evolution, new satellite-capable handsets with display capabilities, user-friendly interfaces, and robust satellite reception.

For the sake of the financial analysis we categorized S-UMTS potential users into three groups as shown in Figure 1(b).

Our hypothesis is that the S-UMTS operator will probably operate on one hand in cooperation with T-UMTS operators, but on the other hand in competition with other MSSs or other regional/global systems offering a 'similar' set of services (DVB/DVB-RCS). Based on this complex and highly competitive market landscape, a share of 33–62% of the addressable global

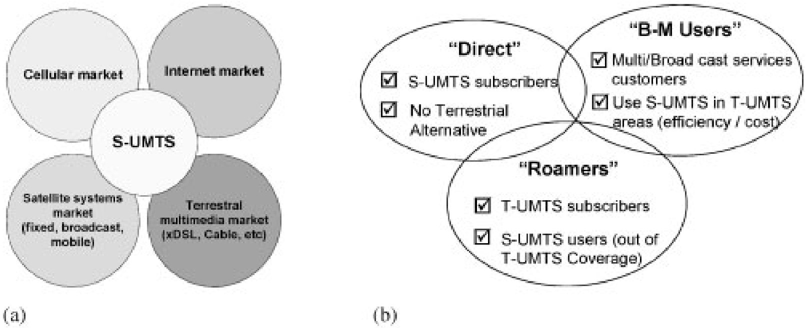


Figure 1. S-UMTS market and subscriber coverage. (a) S-UMTS Market. (b) S-UMTS user categorization.

market [2] is assumed for S-UMTS, allowing all reasonable error margins and unpredicted fluctuations. Figure 2(a) depicts the assumed evolution of the subscriber base time-wise (launch year at 2004–2005).

To conclude the market aspects study, a Business Case was built focusing on a sensitivity analysis of the financial aspects for the deployment of a global S-UMTS system. A GEO constellation based system was considered, providing global coverage and comprising five basic plus two spare satellites of 15 years life expectancy and up to 20 Gateways in the ground segment. System development cost and working capital for covering pre-operational expenses such as salaries or interest expenses up to launch were considered. An 800 employees organization was assumed, with sales/marketing & financial operations partly undertaken by terrestrial value chain partners i.e. considering a 'close co-operative' approach. The assumed figures for operating costs per annum and accumulated system costs, were in the order of 95 and 2665 M€, respectively. Regarding revenues, direct users' average revenue per user (ARPU) were assumed in the range of €1450-1400 per annum with a low cost of revenue (ACRPU) between 10 and 20% of the ARPU. Roamers' and B–M users' ARPUs were significantly lower (€400–600 aver.) but with a high ACRPU (40–60%). The B–M user generates revenue from airtime subscription, advertizing and transactions while using his 'home' network, while Roamers will normally generate revenues from airtime when visiting S-UMTS. The average projected difference in revenues between these two categories is in the order of €340 (2nd op. Yr) to €240 (6th op. Yr), i.e. a range of €28 to €20 per month. This amount is considered as a 'realistic' difference, users would be willing to pay for receiving added value to their standard 3G services.

Analysis was conducted, on the basis of the discount cash flow (DCF) method (at a compound discount rate of 14%). Thirteen different scenarios were evaluated based on different assumptions on number of users and evolution hypothesis. The overall study period was 18 years from investment decision, while the first satellite is launched in the third year and two satellites every 2 years up to the ninth year. In this respect, financial analysis covers 15 complete years of commercial operation. Furthermore, we assume that the number of users and ARPUs

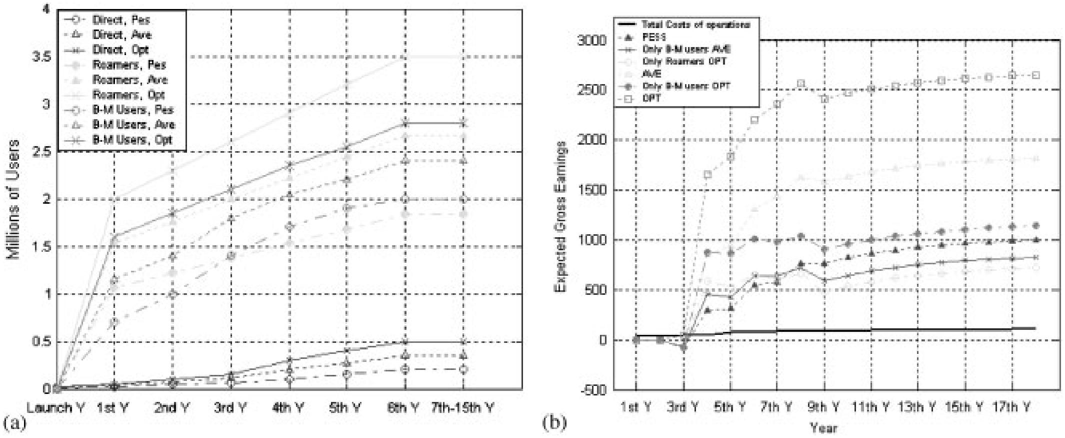


Figure 2. Subscriber prediction and expected gross earning. (a) S-UMTS subscriber base evolution. (b) Break-even point & gross earning (k€).

remain constant at the levels achieved in the 10th year from investment decision. Summing up financial projections, the following are concluded:

- S-UMTS venture is not viable assuming only ‘direct’ users. An approach focusing only on ‘roamers’ produces financially healthy results if their number exceeds 2 millions from the very beginning, which is highly unlikely. If the portfolio of services includes B–M services, the investment is viable if the operator attracts a number of users in the order of 1.15 million. This appears to be feasible, considering that B–M users are normally urban/sub-urban inhabitants seeking in S-UMTS a cost efficient ‘alternative’ to T-UMTS.
- To achieve high profitability, S-UMTS should address a mixed population of users with varying needs. MBMS should be the basis of the potential services portfolio, to minimize spectrum implications and secure higher ARPUs.
- All the scenarios producing positive net present values (NPV) (Figure 2(b)) assume a considerable population of users (in the order of millions) from the very beginning of commercial operation. This imposes a close ‘co-operative’ approach for deploying the system, with terrestrial operators ensuring that the initial user population of S-UMTS will be sought from among their numerous ‘home’ users and not occasional ‘roamers’.

In addition to the above, a separate comparison study between combined S/T-UMTS and standalone T-UMTS deployment of MBMS was undertaken. Three techno-economic scenarios were considered:

- ‘*High*’: An average monthly ARPU of about 18 euros at 2010 for infotainment services and ‘fast’ user subscriptions’ evolution according to revised projections of UMTS Report 17 [2].
- ‘*Medium*’: A moderate monthly ARPU (€12 in 2010) from infotainment and normal evolution of subscriptions growth.
- ‘*Low*’: A low monthly ARPU for ‘push and store’ type of services (in the order of €3–4).

The results of the financial evaluation, which considered as a test case the deployment of T-MBMS or S-MBMS by an incumbent mobile operator (MNO) in a major metropolitan area, are summarized in Figure 3, depicting NPVs for the six scenarios under study. If the ARPU is of the order of 17 $\sim$ 12€ both MED cases (S- and T-UMTS) are attractive. In the ‘High’ scenario, the terrestrial case increases its distance from the satellite one. Overall, lowering ARPU at the levels of €10 seems to favour MNOs sharing revenues with the satellite operator and makes T-MBMS standalone too risky. Therefore if the market is sufficient to charge MBMS services at such levels, and considering the assumptions taken in this case, cooperation with a Satellite

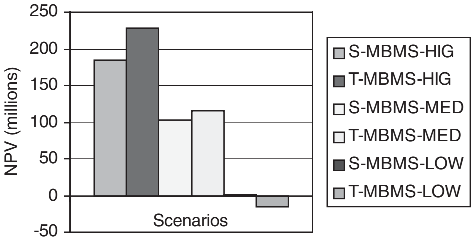


Figure 3. Comparative study scenarios’ NPVs for 2006–2012 period.

Operator becomes appealing for the MNO, the risk is divided, and the survivability of the venture increases.

3. SYSTEM ARCHITECTURE

Having shown that the market potential of MBMS for S-UMTS, we propose two architectures, a baseline and an optional, that feature close S/T-UMTS integration and are shown in Figure 4.

Baseline: this is based on the close co-operative approach where the terminal is satellite-receive only. The signal reception can be directly from satellite (called direct access—DA) or via an IMR (called indirect access—IDA). In IDA case, the return link is provided via the terrestrial system. This scenario is mainly based on a mass–market scenario.

Optional: This is based on the geographical complement approach where transmission from the terminal is directly to the satellite (niche market) with limited return link capacity (3–8 kbps). This scenario allows the user to move outside T-UMTS coverage while retaining a basic service.

Considering the above system architecture, terminal requirements (cost and complexity), network complexity, deployment time, investment risk, step-by-step coverage expansion, inter-beam and inter-carrier connectivity, current payload technology, QoS issues and the worldwide licenses issues, GEO satellites with multi-beam on board transparent digital processing payload was selected for space segment. The satellite gateway (GW) includes both Node B and RNC functionalities so that it can be connected to the UMTS core network via the standard Iu interface as shown in Figure 6. The IMR and terminal aspects are discussed in more detail below.

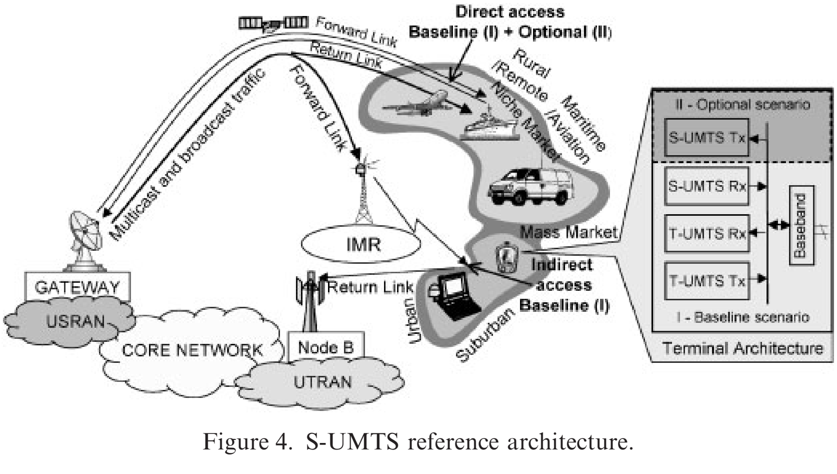


Figure 4. S-UMTS reference architecture.

3.1. Intermediate module repeater (IMR)

Four different IMR environments (urban, vehicular, UMTS islands and ships/planes) were considered along with three different functional architectures (simple IMR-like booster, IMR with Node B functionalities and IMR with Node B and RNC functionalities.). The simple

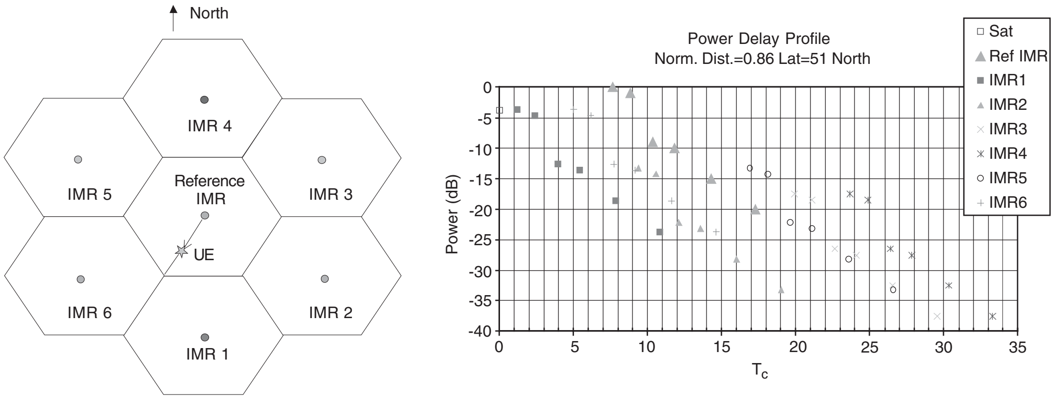


Figure 5. IMR layout and power delay profile for low power IMR (Vehicular model, $1/T_c = 3.84$ Mchip/s).

repeater option featuring booster-only (*low power*) or combined booster and frequency converter (*high power*) capabilities, was retained for SATIN based on the complexity and cost of IMR and the modifications needed in the standard WCDMA interface and the link between satellite and IMR. The MBMS signal will be transmitted in the contiguous MSS frequency band.

In order to reduce the deployment costs, IMRs are proposed to be co-located with the UMTS node B, giving rise to an IMR layout which mimics that of a terrestrial cellular cluster (Figure 5). The propagation conditions between a UE and a single IMR will therefore be characterized by multipath propagation typical of mobile terrestrial channels, e.g. those reported in the ITU-R specification for the 3G mobile systems. However, unlike the T-UMTS case, the surrounding IMRs transmit the same version of the signal. These replicas will reach the UE with different delays and powers depending on the UE position within the IMR cluster, and on the different propagation path lengths between the satellite and the receiving IMR, which are functions of the latitude and longitude of the IMR cluster itself. In conclusion, as shown in Figure 5, the propagation channel will be characterized by a large number of multipath components and a wide delay spread (e.g. up to 25 chip period). These completely new channel characteristics have to be dealt with by the terminal's RAKE receiver in order to exploit multipath diversity.

3.2. Terminal

Two service coexistence scenarios are specified in order to outline different terminal configurations:

Concurrent scenario: in this scenario the user terminal supports the simultaneous delivery of both basic UMTS services and MBMS. In this scenario it would be possible to receive MBMS as background processes while making e.g. a phone call. Taking the aforementioned assumptions into account, the following rules apply:

- A parallel receiver architecture is necessary to receive simultaneously a terrestrial and a satellite link. Hence, no significant reuse of receiver hardware is possible.
- Paging or interactivity to support MBMS can be provided through the terrestrial access.

Time exclusive scenario: in this scenario the user terminal does not support the simultaneous delivery of both basic UMTS services and MBMS. Taking the aforementioned assumptions into account, the following rules apply:

- A reconfigurable receiver architecture capable of switching between terrestrial and satellite mode can be used.
- Paging should be provided through the satellite access network when a terminal is in MBMS mode, but in the absence of the complementary satellite transmitter, the terminal lacks interactivity with the network.

3.3. *Logical architecture and protocol architecture*

Figure 6 shows the position of the satellite component within the 3GPP MBMS architecture [1]. Node B and RNC are assumed to be part of gateway (GW). The interfaces Iu and Iub are similar to those in the terrestrial case. The differences are related to the interfaces Sf, Sui and Sii. The feeder link Sf can be at Ku band. The air interface Sui between IMR-UE and SAT-UE is WCDMA. If the interfaces between UE-IMR and IMR-SAT are the same (Sui), then the IMR has to be a '*low power*' version to avoid electromagnetic coupling effects between its transmitting and receiving parts.

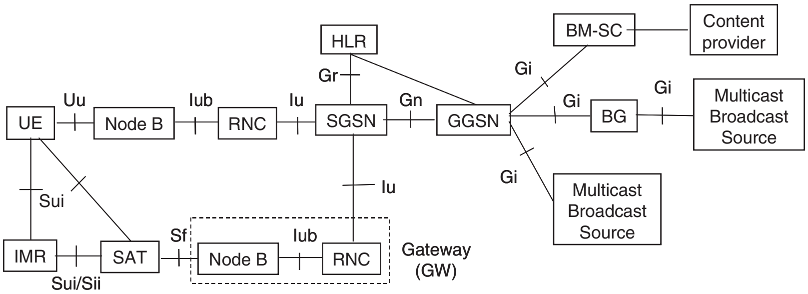


Figure 6. Possible satellite components in logical architecture of MBMS.

If the interfaces are different (i.e. different frequency of operation), then the IMR may be a '*high power*' version. The additional functional entity introduced in MBMS, with respect to the conventional unicast case, is the broadcast multicast service centre (BM-SC). As BC/MC data transfer should be operated in the packet switched domain and not in the broadcast domain, it is assumed that the future MBMS radio access bearer (RAB) is compatible with the point-to-multipoint (p-t-m) radio bearer (RB) provided by BMC/RLC.

4. SATELLITE RADIO INTERFACE

Adaptation of the T-UMTS packet mode to the satellite environment for MBMS delivery was investigated based on the 3GPP MBMS [3] and ETSI SW-CDMA [4]. The possible forward and return link scenarios are given below:

- *Forward link*: MBMS direct/indirect to terminal, with multi-path signals from the satellite and from the IMR components combined at baseband.
- *Return link*: T-UMTS is the baseline case while direct satellite access is envisaged for the optional architectural scenario, namely two-way communications are provided via satellite.

The main features of the interface with respect to the two architectural scenarios are:

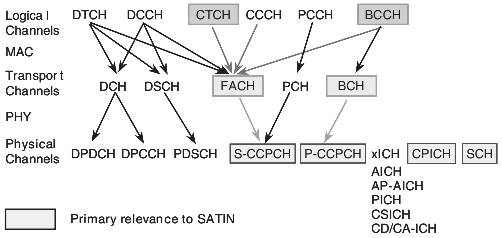
4.1. *Baseline case*

- No connection over the air as regards the satellite radio interface and no packet data protocol (PDP) messaging between UE and GW.
- No real time interaction is possible between UEs and GW.
- No feedback/loop mechanisms such as power control or ARQ are supported.
- Use of unidirectional signalling from GW to UEs for the control of common traffic RBs. The service notification and radio resource set-up for a set of common traffic channels builds upon Cell Broadcast mechanisms, namely in-band signalling, complementary to system information messages, is carried on the 'system master CTCH/FACH' channel that remains available for reception to all UEs in the cell.

4.2. *Optional case*

In this scenario, the MAC mechanisms supporting packet data on RACH and CPCH (access preambles, collision detection preamble, power control preamble) in terrestrial networks are not efficient in the satellite case, again due to the high round-trip delay.

Considering the above issues, the forward access channel (FACH) was selected as the transport channel for data transfer, mapped onto the S-CCPCH physical channel (with spreading factor down to 8). Compared to DCH and DSCH, it necessitates the least changes in the standard UTRA FDD interface. For the MM data transport, there is one-to-one correspondence between services and logical channels (common traffic channel—CTCH). The logical channels are mapped one-to-one onto transport channels. The channels of relevance to SAT-MBMS are shown in Figure 7. Based on traffic mix scenarios (Appendix A—Tables A3 and A4), four multiplexing scenarios (Figure 7) are considered to cover the possible data rates. A multiplexing scenario example is shown in Figure 8.



FACH Number	Multiplexing Scenarios and Data rate (kbps)			
	A	B	C	O
1	8	16	32	8
2	48	100	64	48
3	228	192	80	80
4	-	-	128	-

Figure 7. SAT-MBMS common channel mapping and transport channel multiplexing scenarios.

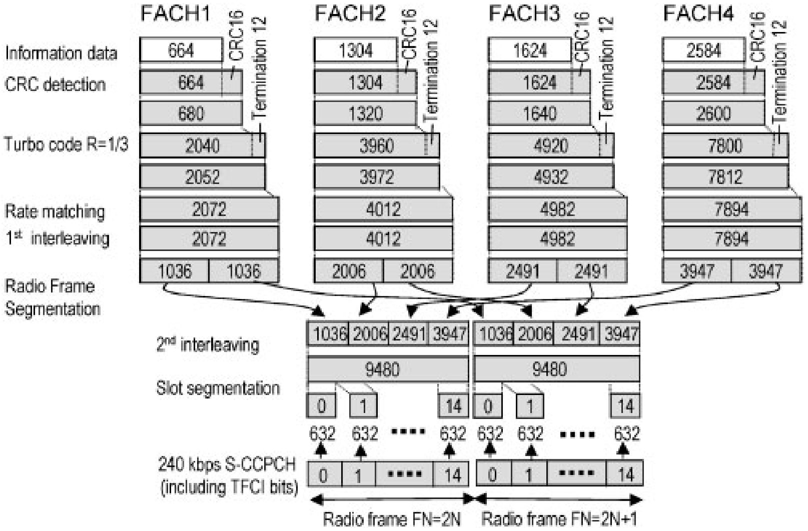


Figure 8. Transport channel multiplexing (scenario C).

5. PHYSICAL LAYER ADAPTATION

In order to allow exploitation of economy of scale in the production of mobile terminals for the proposed T/S integrated architecture, the 3GPP UMTS FDD air interface (i.e. WCDMA) has been considered as a reference for the SATIN physical layer specifications definition. Modifications have been introduced only when the satellite peculiarities have necessitated them. In particular, performance evaluation has demonstrated that the WCDMA forward link specifications were suitable for direct application to the proposed architecture. In Figure 9, bit error rate and frame error rate of the turbo coding scheme defined in the 3GPP WCDMA specifications are reported for two typical SATIN situations: the Ricean satellite channel, and the wideband IMR channel. Notably the Ricean channel is representative of rural or suburban environment, where higher speed, i.e. 200 km/h, are more likely, whereas, the wideband channel deriving from the IMR coverage is more representative of an urban scenario where terminal speeds are limited, i.e. 50 km/h. In both cases, the desired QoS, e.g. $\mathrm{BER} = 10^{-6}$, can be achieved with acceptable E_b/N_o values.

As far as the return link is concerned, in the baseline scenario, where the return link is provided via the T-UMTS network, the application of the 3GPP WCDMA specifications is straightforward, whereas in the optional scenario, the satellite link characteristics call for a modification of the random access procedure (RACH procedure). The method of preamble power ramping with fast acquisition foreseen in WCDMA is in fact not suitable for the long propagation delays typical of the satellite links (e.g. 500 ms for a GEO satellite). To overcome this hurdle, the RACH procedure proposed in the ETSI framework for S-WCDMA, i.e. one-shot acquisition with a longer preamble, has been adopted in the SATIN scenario. A novel acquisition procedure, based on a differential post detection integrator scheme was also proposed in order to obtain good performance and reduced system complexity [5, 6].

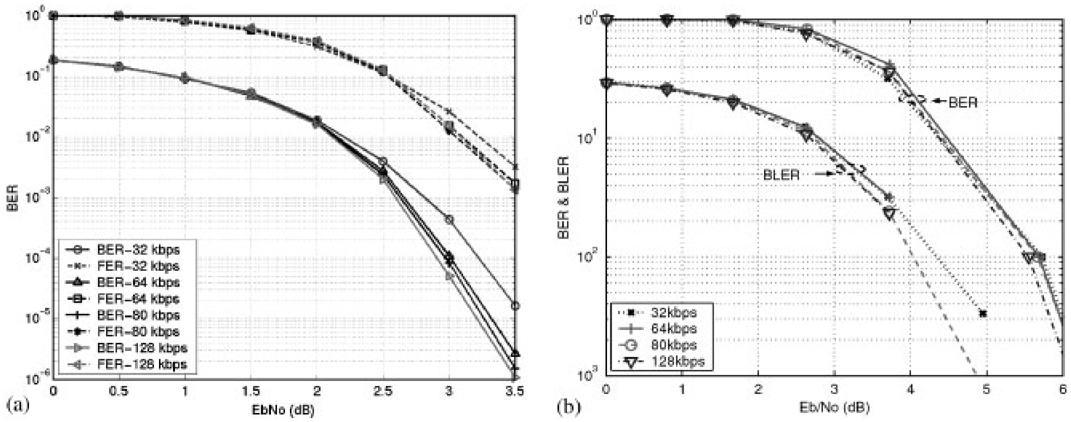


Figure 9. FACH performance. (a) Ricean channel (turbo coding, QPSK and 200 km/h). (b) SAT-IMR wideband channel (turbo coding, QPSK, 50 km/h).

Table I. Cell search procedure performance.

	Minimum time to acquisition time		Receiver complexity (correlators required)	
	WCDMA	SW-CDMA	W-CDMA	SW-CDMA
First step	$M*$Tslot	$M*$Tslot	1 (Hierarchical)	
Second step	15∗Tslot	15∗Tframe	16	$K-(1)$
Third step	$N*$Tslot	2∗Tframe	8	$K*15-(2)$

Note: M-post detection integration length, N-number of slots considered in the third step, K-number of scrambling codes considered (512).

Physical layer procedures dedicated to power control and cell search have also been analysed (Table I).

As far as power control is concerned, the absence of dedicated links hinders the application of standard techniques. Group power control algorithms based on worst-case approach or on statistic measurements can be used instead, but they have not been investigated during the project lifetime.

The ESA S-WCDMA beam search and the WCDMA cell search procedures have been thoroughly analysed and compared from both performance and complexity points of view [7]. Results have shown that, although comparable from the performance point of view, the WCDMA complexity is lower than that of the S-WCDMA (Table II). For this reason, the WCDMA cell search procedure has been retained in the SATIN specifications. Notably, this choice has been confirmed by the adoption of the WCDMA cell search procedure within ETSI, for the S-UMTS specifications.

In addition to the evaluation of the standard WCDMA air interface characteristics, and with the aim of increasing the spectral efficiency of the system under consideration, enhanced coding and modulation techniques have been investigated.

5.1. Coding

Standard UMTS convolutional and turbo coding schemes can be used in the satellite environment, however they have some shortcomings in the case of providing BC/MC services. An innovative layered coding scheme is proposed as an additional option that provides a soft trade-off between performance and complexity.

Layered Coding allows a user with a good channel to recover the information with low complexity, while a user with a bad channel will still be able to achieve an acceptable BER at the cost of increased computational complexity. It can be directly applied in the case of MBMS systems that are based in a 'one to many' unilateral communication without power control. The proposed layered coding scheme consists of an inner and an outer convolutional code that can be separated and can operate in two different ways. According to the required maximum BER and the received Eb/No, the user terminal can choose to operate either with the received symbols encoded using only the outer (UMTS) convolutional encoder (CC-high BER case), or with the symbols encoded using the serial concatenation of the UMTS outer encoder and an inner encoder (SCCC-low BER case). Two basic encoding structures; 'structure A' based on mapping onto 8PSK symbols and 'structure B' based on mapping onto QPSK symbols are considered and their performance is shown in Figure 10.

It has been demonstrated for both layered coding structures that as the channel conditions become worse, the gap between the SCCC and CC code performance increases. This performance gap allows users with high received Eb/No to use only the outer convolutional decoder and those with low received Eb/No to choose the more complex SCCC decoding. As the channel conditions get worse or the multiple access interference increases, more users have to resort to SCCC decoding, thus the coverage efficiency is maintained by increasing the average complexity of the system.

Comparing the layered coding structures, it has been shown that Structure B leads to better coverage efficiency due to its improved BER performance [8]. Structure A has worse performance than Structure B, but, due to its higher spectral efficiency, it can accommodate twice the throughput of Structure B. Therefore, the choice of the suitable layered coding structure is a trade-off between performance, throughput, complexity and coverage.

5.2. Higher order modulation (HOM)

Along with the standard QPSK constellation, 8-PSK and 16-QAM constellations have been investigated to get higher bandwidth efficiency and also strike a good match with the proposed layered coding approach. However, these constellations are more sensitive to channel conditions and payload non-linearity. In Figure 11(a), BER is reported for QPSK, 8-PSK, and 16-QAM under Ricean channel for different data rates. In Figure 11(b), the effect of HPA non-linearities are shown for 16-QAM and different input back off (IBO) values. Clearly, use of HOM within the proposed scenario calls for pre-distortion or/and equalization techniques to guarantee the desired QoS [9].

6. LINK LAYER ADAPTATION

6.1. BMC sub-layer specifications

The BMC sub-layer was adapted from the 3GPP specification [10]. It consists of one BMC protocol entity per MBMS. Each BMC entity requires a single CTCH, which is provided by the

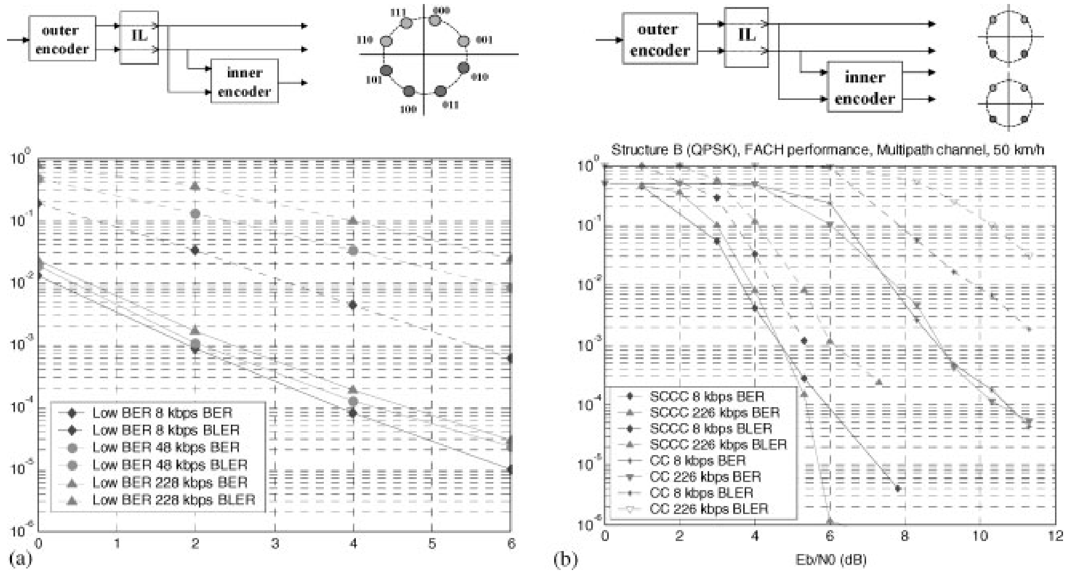


Figure 10. Layered coding performance. (a) Structure A (8PSK, Rice $K = 5$ dB, 200 km/h). (b) Structure B (QPSK, Lower power IMR, vehicular 50 km/h).

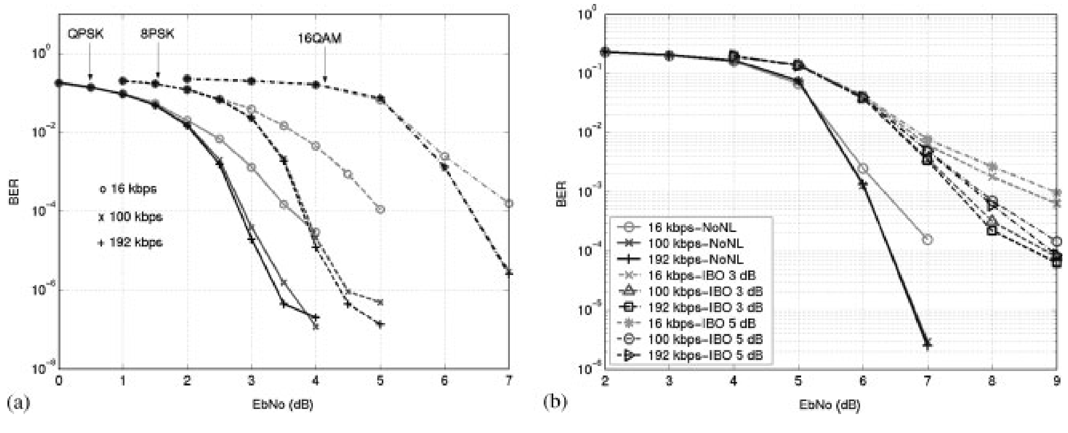


Figure 11. Higher order modulation performance. (a) Rice channel, $K = 5$ dB, 200 km/h. (b) 16 QAM, rice channel, $K = 5$ dB, 200 km/h.

MAC sub-layer, through the RLC sub-layer. The BMC requests the Unacknowledged Mode service of the RLC.

A BMC protocol entity serves those messages of the respective MBMS at BMC-SAP that are to be broadcast into a spotbeam (towards all users or a certain group).

The functions supported by the BMC sub-layer encompass: storage of BMC SDUs (cell broadcast messages extended to MBMS packet bursts), traffic volume monitoring and radio resource request for BC/MC services, scheduling of BMC messages, transmission of BMC messages to UE, delivery of BMC SDUs (cell multicast/broadcast messages) to upper layer.

Further and similar to BMC schedule message, two new types of BMC message from GW (RNC) to UEs are proposed:

Notification message: it consists of all service notification information elements for the cell/spotbeam: service-to-channel mapping, Level 1 scheduling parameters associated to each CTCH/S-CCPCH. It is generated/processed by the BMC peer-entities operating the global service control and notification (also referred to as system master CTCH/FACH) and further processed by UEs RRC.

Notification change message: it informs the BMC peer-entity (and further the UE RRC) operating a given MBMS service of the forthcoming change of the associated notification information, and indicates which parameter(s) are updated and their respective new value(s) (new service-to-channel mapping and/or new Level 1 scheduling parameters) and the time for their applicability (System Frame Number).

6.2. *RLC sub-layer specifications*

The SAT-MBMS RLC sub-layer features [11] a subset of the full RLC functionality described in 3GPP [11]. Two types of entities are envisaged: Transparent Mode (TM) and Unacknowledged Mode (UM) entities. In general, the TM and UM entities can be configured to act as transmitting or receiving entities, in which case the entities transmit/receive RLC PDUs to/from lower layers respectively.

For the satellite case, transmitting entities only reside at the GW side, while at the UE side, the TM- and UM-RLC entities act as receivers.

There is one transmitting and one receiving RLC entity for each TM and UM service. Each UM and TM entity exchanges data PDUs via use of logical channels.

6.3. *MAC sub-layer specifications*

The MAC entities retained are a subset of the full set of entities defined in 3GPP [12] and their functionality is different depending on whether they are at the user (UE) or the GW side.

MAC-b entity: This is the entity responsible for the broadcast channel (BCH). There is one MAC-b entity in each UE and one in the GW side for each satellite spotbeam.

MAC-c entity: This is a subset of the full MAC-c/sh entity defined in T-UMTS and within SAT-MBMS controls access to the FACH transport channel.

For the optional case, everything in the baseline described above is retained, but with added functions so as to enable the use of a direct return link over the satellite through the RACH. The use of logical channels of dedicated type introduces the need for the MAC-d entity and additional functions related to the MAC-sh entity.

7. RADIO RESOURCE MANAGEMENT (RRM) STRATEGY

The main function of RRM is to allocate physical radio resources for p-t-m services when requested by the radio resource control (RRC) layer. Two features are the main types of services, or rather service delivery modes, envisaged in the system. *Data streaming* services make use of a playout buffer, where they are inserted before being played out by the UE streaming application. They introduce packet-level requirements, related to the delay jitter experienced at the S-RNC, as well as rate requirements. The higher this variation, the larger the play-out buffers have to be in order to avoid starvation of the buffer. In the case of audio or video, the latter could degrade the end user experience. *Push & store* services, on the other hand, are buffered at the terminal, only to be accessed later by the user. There is no per-packet requirement in this case; the network should be able to provide some minimum rate to the whole stream of items (broadcast schedule) carried over the air (see Section 7.3).

In the SAT-MBMS service scenario, the main RRM entities are the admission control (AC), load control (LC), and the packet scheduler (PS), the broadcast scheduler (BS) and the radio bearer allocation and mapping (RBAM) module. The p-t-m service delivery mode and the absence of return link, in the baseline scenario, make power control irrelevant, while hand-over control become less significant due to the broad spot-beam coverage. All RRM functions are located in the GW (RNC).

Two modes of operation are possible:

RRM mode A: The RBAM provides the RB configuration (i.e. channel mappings and transport format combination set/physical channel) that remains static for some time interval, over which the traffic mix remains the same (for example in the order of 1 h). The AC functions within the constraints imposed from this mapping.

RRM mode B: the RB mapping is drawn in an ad-hoc manner by the AC. In this case the AC decides on the acceptance of the service request and then (re)-configures the bearer appropriately. This allows higher flexibility in the resource utilization at the expense of extra interlayer- and over the air-signalling (re)-configuration messages towards the group users.

7.1. Radio Bearer Allocation and Mapping (RBAM)

The aim of the RBAM block is to dimension the system for data streaming services. This is equivalent to providing an appropriate configuration of the bearers (number of FACHs, rates and mapping to S-CCPCHs). This task relies on some prediction of the traffic that is expected over subsequent time intervals, which may be based on historical measured data, and is suitable for content delivery type of systems.

The dimensioning task is executed separately per beam. The steps relevant are:

7.1.1. Estimation of required FACHs. The assumption is that there is some adequate description of the traffic mix in terms of—at least—arrival rate (λ_i), duration (μ_i) and requested rate ($\Re_i$) for each type of service. On the basis of this characterization, user group profiles and statistics related to the geographic scope and audience of each service, the RBAM estimates the beam-level load per service. It then makes use of classical queueing models such as the multi-server loss model (M/M/c/c) and its extension for multi-service networks (see, for example, Reference [13]) to estimate the required number of FACHs that can guarantee a given blocking probability per service.

7.1.2. Mapping of the FACHs on S-CCPCHs. The objective of this function is to map the derived FACHs onto the available S-CCPCHs. The number of available S-CCPCHs, M, and their maximum capacity *C*, or a rough estimation, is assumed to be known *a priori* (i.e. from link budget exercises and link-level simulation input). Two options for this mapping exist. Both of them have been formulated as particular instances of the bin-packing problems [14].

The pure *bin-packing* approach consists in packing the services in a way that minimizes the total required number of physical channels. This should allow a higher number of code channels to be fully devoted to the support of broadcast schedules carrying push & store services.

The *power-aware mapping*, on the other hand, performs the mapping of FACHs in such a way that minimizes the power consumption. It tends to *pack* services (CTCH/FACH) of similar E_b/N_o requirements into the same S-CCPCH, since all services multiplexed on a certain S-CCPCH will be eventually transmitted with the same power.

7.1.3. Derivation of TCFS for each S-CCPCH. Contrary to the previous steps, an analytical formulation of this task is not easy. The TFCS introduces a trade-off between actual system utilization, power efficiency and framing overheads (headers, padding). Smaller transport block sizes allow higher flexibility in utilizing the available bandwidth but lead to broader TFCS in order to cover the whole range of the short term rate variation of the flows. This increases the processing requirements on the terminal side. Smaller TBs also lead to increased power requirements (Figure 9).

7.2. Admission and preventive load control

AC is the set of actions taken by the satellite network during the phase of service establishment or service re-negotiation to decide whether to accept or to reject a user group service request. A new user group service request can be accepted only when there are adequate network resources available to guarantee the QoS of all existing and the requesting services.

AC first checks the allowable TFCs by applying the QoS and power constraints. In the case of the fixed mapping it then checks whether there are available FACHs with allowable information rate greater than the requested rate for the incoming service request. AC provides the allowable combinations, from which the corresponding TFCS are derived (it is possible that the resulting TFCS is a reduced set following the application of additional constraints).

If the AC criteria is satisfied then preventive LC [15] takes over and checks what would have been the total load for each Transport Format Combination (TFC) available at the specific S-CCPCH if the new session were accepted. If this load criterion is also satisfied then the session is accepted and the selected TFCS is available to PS via RBAM. The above process reduces the probability of congestion depending on how conservative or optimistic the selection of the load threshold value is and partially makes up for the inability of the unidirectional system to react to congestion events. The performance of the proposed AC strategy has been examined using system level simulations. Evaluation for a number of different scenarios has been carried out, mainly covering both modes (A&B) of operation, different mapping strategies (i.e. power-aware and bin-packing), sensitivity analysis for various system parameter values (orthogonality factor, antenna leakage, load threshold), $\text{BLER} = f(E_b/N_o)$ for different channel conditions, and different traffic mixes of the SAT-MBMS service portfolio.

Figure 12(a) shows the performance comparison between the two mapping strategies. There are regions where ‘Power-aware’ mapping outperforms the ‘RT/NRT’ (bin-packing) mapping and *vice versa*. Particularly, from Figures 12(b) and 12(c) we observe that both location based services (LBS), audio streaming (32 and 64 kbps) and video streaming (128 kbps) benefit from the power-saving technique. What is interesting to note is that the highest QoS class (video 256 kbps) does not benefit from the 'Power-aware' approach. Far from it, this service experiences an extremely high blocking probability 'wasting' (especially for normalized offered load less than 2) the capacity gain obtained using the 'power-aware' mapping.

The impact of preventive LC on the system's performance is shown in Figure 12(d). The figure demonstrates that the combined AC-LC Algorithm for a given load threshold setting leads to higher blocking probabilities compared to the case where the preventive LC criterion is not considered. The system's throughput is also decreased under the strict combined AC-Preventive LC Algorithm. However the added benefit that the preventive LC brings is that it guarantees the network's stability, hence a trade off between network's stability and blocking probability for new services exist.

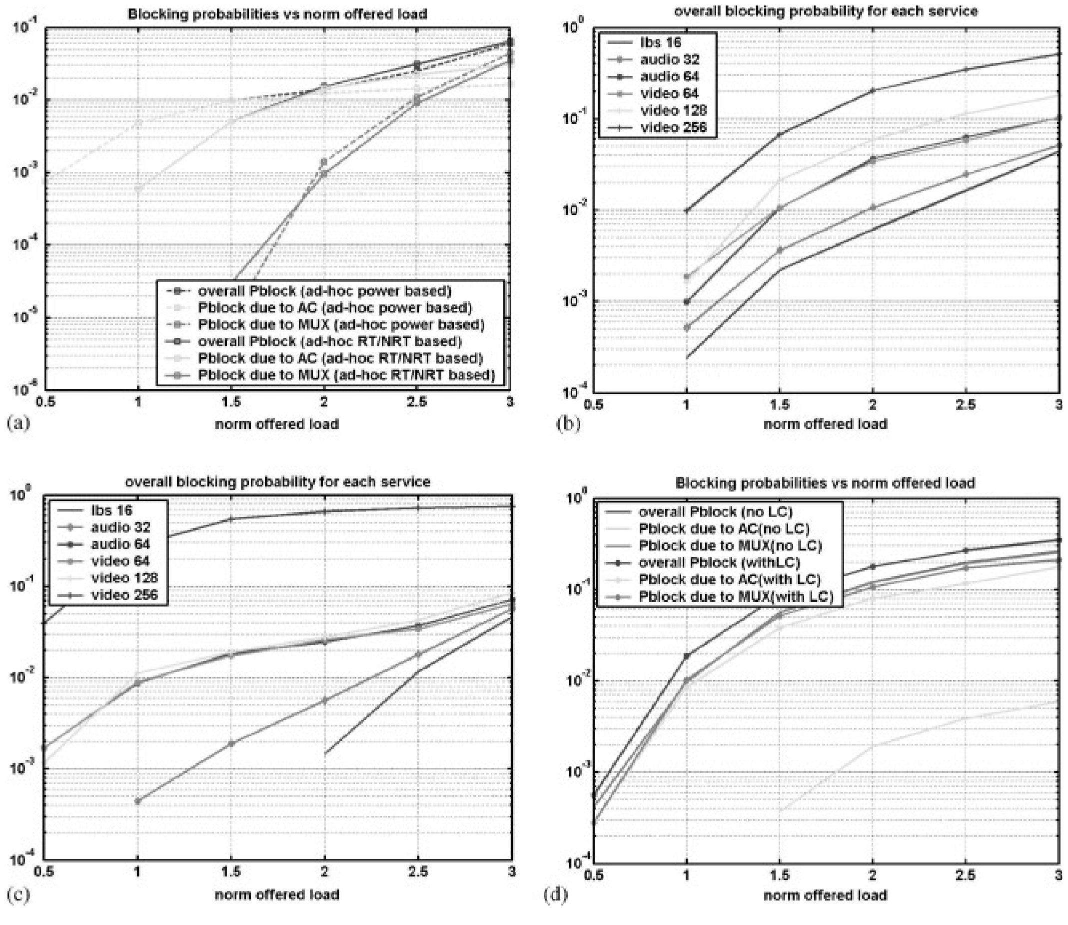


Figure 12. Impact of admission control on system blocking probability (GoS). (a) 'Power-based multiplexing vs RT/NRT multiplexing. (b) *Ad hoc* 'RT/NRT' based multiplexing. (c) *Ad hoc* 'power-based' multiplexing. (d) Impact of preventive load control.

7.3. Broadcast scheduling

This entity is effectively the RBAM analogue for push & store services. Spare capacity after the RBAM dimensioning task in RRM mode A or pre-reserved capacity in RRM mode B is considered for the dimensioning of broadcast schedules. This consists in the estimation of the number of *items* (e.g. web pages, video/audio clips) that can be loaded on the remaining FACHs, under the requirement for a given *average response time*. This is defined as the time elapsing from the moment a user decides to access some content till the moment this content appears over the air within the broadcast stream so that the terminal can acquire it and store it in its cache.

The design of these broadcast schedules (cycles) has been discussed in scientific literature for almost twenty years, though initially within a different context [16]. The proposed algorithms derive the order and frequency of appearance of the individual items within the broadcast stream, for a target response time bound, considering the interest in each item and its size. More popular items appear more frequently in the broadcast cycle. Cache management algorithms can further reduce this time. In SATIN three priority classes are defined with respect to the achieved response time, namely high, normal and low (background), in line with the definition of priorities in the cell broadcast service framework. These priorities may be related to service types, individual items or user groups. The last case implies the repetition of the same content over two different broadcast cycles at different speeds. Tables II and III list the number of items that can be carried in the schedule for different CTCH/FACH rates and target response time values for services under the high and normal priority respectively (Appendix A—Table A1). The assumption behind these numbers is that the interest in individual items is inversely proportional to their size (i.e. Zipf demand probability distribution).

7.4. Packet scheduling (PS)

In T-UMTS the PS allocates the radio resource in short-term having as a significant criterion for its allocations the state of the individual links (channel state). In the SAT-MBMS access scheme,

Table II. Dimensioning of broadcast schedules for rich audio/video messages.

	Target response time					
FACH capacity (kbps)	1 min	2 min	3 min	5 min	10 min	15 min
32	8	17	28	49	110	175
144	44	97	155	278	614	973
176	55	121	195	350	772	1221

Table III. Dimensioning of broadcast schedules for webcast and software download.

	Target response time				
FACH capacity (kbps)	5 min	10 min	15 min	20 min	30 min
32	9	18	28	38	61
144	44	98	155	220	355
176	55	124	199	277	447

information regarding channel state is not available at the scheduler—in any case such information would have to be exploited in a manner accounting for the p-t-m nature of services; decisions about the scheduling of a single service (flow) should consider the state of several links corresponding to the users of each group. Therefore the role of the PS is not equally important in determining the system throughput with respect to the terrestrial UMTS [17]. The throughput, in terms of number of flows and respective rates, is mainly determined by the AC function. Nevertheless the scheduler carries two important tasks.

First, it time-multiplexes flows with different QoS requirements into fixed SF physical channels, in a way that can satisfy these requirements. The latter have to do with the delay jitter and the guaranteed rate for the data-streaming services and the rate only for the broadcast schedules carrying push & store services. Increase of the delay jitter values calls for a respective increase of the buffer allocated for the playout of the stream at the mobile terminal.

Secondly, it adjusts the transmit powers of the code channels, not on the basis of channel information but rather on the basis of the packet/transport block sizes to be served or knowledge of the expected audience distribution within the beam. This power adjustment is not of the same granularity of the power control mechanism but rather limited to a small set of values.

Within SATIN, two scheduling disciplines were tested, which draw on well-known algorithms used for years in wired networks: the multi-level priority queuing (MLPQ) and the weighted fair queuing schemes (WFQ). The evaluation of the two proposed packet schedulers (PS) confirmed the challenging task of determining optimized TF/TFCs, and more particularly the relevance of TBS size thresholds in meeting the rate requirements of all services and achieving high physical channel utilization, whilst preserving the power resources of system [18].

Regarding fairness between flows of the same QoS class or physical channel utilization it makes little difference for each PS scheme whether the mapping is power-aware or not, although the tuning of the TFCS appears to be easier in the pure bin-packing case with the MLPQ-based PS. The nature of the WFQ-based PS is controlled by the TFCS selection process and the packet-level dynamics of the flows in many multiplexing cases have not allowed the significant reduction of TF range, which may be foreseen with WFQ when compared to MLPQ.

Equally important is the impact of the TFCS on the power consumption of the system. On the contrary, the actual way to perform the mapping (power-aware or not) seems to be less significant. In short, irrespective of the PS scheme the optimization of the system capacity/throughput depends on the cautious trade-off between power saving and multiplexing effectiveness.

8. CAPACITY EVALUATION

In order to provide evidence for the feasibility of the proposed SAT-MBMS delivery approach, a capacity analysis, (i.e. achievable aggregate bit rate in the forward link), has been carried out considering the link budget, traffic mixes, and simulation results.

First, the computation of the available $E_C/(N_0+I_0)$ has been undertaken for both DA and IDA cases; secondly, considering five different traffic mix scenarios along with the two separate mapping strategies (Section 7), the $E_C/(N_0+I_0)$ required to achieve a BER of 10-6 (i.e. BLER approximately 10-3) for all the transport channels is computed. The following assumptions have been made: 20% of the link power is dedicated to pilot channels, signalling is provided by means of a 8 kbps channel with SF equal to 256, which corresponds to a worst case performance in terms of required BER, because of the limited efficacy of the turbo code internal interleaver; rate 1/3 turbo coding is considered for both data and signalling, along with QPSK modulation.

Table IV reports the link budget analysis and the available data plus signalling $E_C/(N_0 + I_0)$. Notably, thanks to the IMR power amplification, the received power in the IDA case is larger than that achievable in the DA case, confirming the efficacy of the IMR layout.

On the basis of these data, the results reported in Table V have been obtained. In particular, to take into account the presence of the pilot channel, an additional 0.97 dB has been subtracted from the overall $E_C/(N_0 + I_0)$, leading to the available $E_C/(N_0 + I_0)$ shown.

Notably, very satisfactory results were obtained in the multipath IMR case, with margins larger than 7 dB, are obtained by considering ideal combining, i.e. ideal channel estimation, synchronization, and path tracking. In actual conditions non-negligible performance deterioration is expected, however, this is completely acceptable due to the large power margin.

It is worthwhile concluding by observing that this study demonstrates the feasibility of the satellite BC/MC overlay network approach proposed and developed within SATIN, paving the way for its future development. The studies performed show in fact that the link budget can be closed with both the DA and the IDA scenarios achieving aggregate bit rates up to 1680 kbps in the base line case.

Table IV. Link budget parameters for both the direct and the indirect (through IMR) link.

	DA	IDA		DA	IDA
Frequency of operation (GHz)	2.5	2.5	Chip rate (Mchip/s)	3.84	3.84
Polarisation + pointing losses (dB)	1	1	Terminal antenna gain (dBi)	2	2
Thermal noise density (dBW/Hz)	−204	−202.6	Received power (dBW)	−134.5	−131
Data + signalling $E_C/(N_0 + I_0)$ (dB)	1.5	3.89	Overall $E_C/(N_0 + I_0)$ (dB)	2.47	4.86
SAT/IMR EIRP/traffic code (dBW)	57	−19	Interference density (dBW/Hz)	−209	−209
Free space losses @20° elevation or path loss ($d = 346$ m), ETSI model (dB)				192.5	113

Table V. Capacity analysis for the considered L2 traffic mixes.

		$E_C/(N_0 + I_0)/(\mathrm{dB})$								
		AWGN channel			Ricean channel			IMR multipath channel		
		Required mapping		Available	Required mapping		Available	Required mapping		Available
Traffic mix	Aggregate bit rate (kb/s)	Bin	Power		Bin	Power		Bin	Power	
1	1472	−0.86	−1.52	1.5	1.42	0.83	1.5	−3.17	−3.22	3.89
2	1424	−0.86	−1.53		1.42	0.83		−3.17	−3.24	
3	1344	−1.45	−1.64		1.16	0.76		−3.17	−3.22	
4	1600	—	−1.45		—	1.01		—	−3.20	
5	1680	—	−1.20		—	1.17		—	−3.18	

9. SATIN WITHIN THE S-DMB PERSPECTIVE

SATIN can be considered as the forerunner project to an eventual commercial system satellite digital multimedia broadcasting (S-DMB) [19] where the multimedia content is delivered to groups of customers via satellite in broadcast or multicast mode. This concept is the basis of next-generation mobile satellite systems and a series of ongoing European research activities—led by Alcatel Space with the support of the French Space Agency (CNES), the European Space Agency (ESA) and the European Commission (EC)—will build upon it.

Within the EC IST Research framework, the successor to SATIN is called MoDiS (Mobile Digital Broadcast Satellite) [20]. Its role in the S-DMB roadmap consists in the development of a first experimental platform to demonstrate and evaluate the system concept. The MoDiS testbed is a simplified version of the eventual S-DMB system. It relies on a satellite emulator rather than a real satellite in space. Only two terrestrial repeaters will be deployed and the signal will be received from a hub network functional emulator at the terrestrial IMT2000 rather than the MSS band. A prototype terminal will be used rather than an integrated handset, while the data server is a simplified version of the required S-DMB data server in a real system.

In the longer term, EU FP6 activities in the direction of S-DMB are expected to focus on both technical and non-technical aspects (i.e. standardization, regulation, marketing) related to the concept and aim at the implementation of a pilot network, as a step towards the deployment of a commercial system that is envisaged for 2008.

10. CONCLUSIONS

This paper has described a satellite system that is in close-cooperation with the mobile terrestrial networks, providing them with an overlay multicast/broadcast layer for the delivery of MBMS. It outlined a top-down approach that led to the design of the proposed satellite radio interface: market considerations and service requirements drove the system architecture definition and then the access scheme was derived so that it fulfilled the system- and service-specific requirements in the most efficient manner with respect to the complexity and cost of system components.

The market & business analysis considered different user groupings and made subscribers' evolution hypotheses, before concluding that a satellite venture only becomes viable if a considerable number of MBMS users are attracted. It thus imposed a close 'co-operative' integration approach for deploying the system, with terrestrial operators ensuring that the initial user population of S-UMTS will be sought amongst their numerous 'home' users. An additional case study showed that a low ARPU basis (€10/month) seems to favour terrestrial operators sharing revenues with the satellite operator and makes T-MBMS standalone too risky.

The architecture of the integrated satellite/terrestrial system features a multi-beam transparent digital processing GEO satellite and terrestrial repeaters, called intermediate module repeaters (IMRs), to assure adequate coverage indoors and in built-up areas. Use of the contiguous MSS bands re-broadcasting terrestrially leads to a simple and cheap terminal and minimal modifications to UMTS Node B for the IMR integration.

The UTRA FDD access scheme was taken as a reference for the definition of the satellite radio interface. Such an approach has a number of advantages for the terminal, allowing maximum reuse of hardware/software and reducing its complexity and cost. The adaptations were related to the particular requirements of the satellite environment and the p-t-m service nature: the WCDMA FDD physical layer procedures were adopted thoroughly for the baseline architecture scenario, where the terminal is satellite receive-only. The superiority of the WCDMA 3-step cell search procedure over the SW-CDMA alternative scheme with respect to efficiency and complexity was demonstrated. In parallel, layered coding and high order modulation were the two non-standardized features that were considered as means to enhance performance. Layered coding schemes trade-off complexity versus performance at the terminal level, and throughput versus coverage at the system level. High order modulation (8PSK & 16 QAM) can achieve 2-fold capacity improvement (with 16 QAM) in ideal channel conditions. However it is very sensitive to payload non-linear effects.

The proposed access scheme combines typical broadcasting elements with packet switched domain features. For the multimedia data transport, there is one-to-one correspondence between service and CTCH. The logical channels are then mapped, again in one-to-one mode, to FACHs that are multiplexed over secondary common control physical channels (S-CCPCHs). Signalling is carried by the broadcast control channel (BCCH) mapped to BCH at MAC level and a reserved low-rate 'system master CTCH/FACH' that remains available to all UEs in the beam. System information messages allow reception of in-band service signalling (relying on BMC messages) onto the master CTCH/FACH, which then provides service-to-channel mapping, hence allowing protocol stack configuration for reception of any other CTCH of interest.

The coexistence of broadcasting and packet switched domain features into the access scheme is naturally reflected into the RRM functions. Two modes of operation are possible. Dimensioning is crucial task in Mode A; Mode B allows higher flexibility at the expense of additional interlayer and over-the-air signalling. The admission control is coupled with a preventive load control mechanism, while, given the transport channel choice (FACH), the time scheduling of the different FACHs that have been mapped to a single S-CCPCH is the major task of the packet scheduler. Push and store services, on the other hand are organized into broadcast schedules. These services are transmitted cyclically on FACH channels, the main objective in this case being the minimization of the mean response time. The proposed SATIN RRM strategy is generic in that it supports two service delivery mechanisms and considers both QoS and GoS requirements. The ultimate decision on the system capacity partitioning between these two mechanisms has to consider non-technical aspects as well (e.g. tariff policies) and is left upon the individual network operator.

Last but not least, the overall feasibility of the satellite BC/MC overlay network approach proposed and developed within SATIN was demonstrated via a capacity evaluation study, suggesting that satisfactory aggregate bit rates are achievable with this baseline interface and can be extended via improved modulation and coding.

APPENDIX A: TRAFFIC MODELLING

The services considered for RRM analysis are given in Table A1. Services under streaming category correspond to separate streams, mapped one-to-one to logical channels (CTCHs). Push & Store services are organized into broadcast schedules and are treated with lower priority.

The main problem regarding traffic modelling was the lack of models for streaming applications. Few studies are available in the literature mainly because of the proprietary protocols used for such applications and the limited insight to their code. To our knowledge, only one protocol has been proposed for streaming audio, the real audio model in Reference [21]. For our simulations, the exponential ON-OFF model with high activity factor (0.8) was retained as the reference model for audio streaming.

The channel mapping and the respective RB configuration are the outcome of an elaborate procedure that has as starting point the user profiles. On the basis of these profiles, estimations about the number of the system subscribers and their evolution as well as assumptions about the

Table A1. Services considered for simulations and their QoS characterization (class, traffic priority).

Service category	UMTS QOS class	Service type		Guaranteed rate (kbps)	Priority	Min item size max/min size ratio
Data streaming	Streaming	Audio streaming		32/64	1	N/A
	Streaming	Video streaming		64/128/256	1	N/A
	Interactive	Location based		16	2	N/A
Push & store services	Background	Webcasting		N/A	3/Normal	20 KB/50
		Rich audio/ video info		N/A	3/High	30 KB/5
		Pre-stored on demand	Movie	N/A	3/Low	10 MB/10
			Video	N/A	3/Low	3 MB/2
			Radio	N/A	3/Low	100 KB/20
			Music	N/A	3/Low	1 MB/5
		Software download		N/A	3/Normal	20 KB/50

Table A2. Traffic models.

Service	Traffic models	Packet size (bytes)	Model parameters/info
Audio streaming	Exponential on-off	500	Activity factor = 0.8 Mean off duration = 100 ms
Real audio	structural model-empirical CDFs		Idle intervals: multiple of 1.1 s
Video streaming	Video trace	500	H.263 files at 64/128/256 kbps target bit rate
LCS	CBR	120	—

Table A3. Power aware mapping for traffic mix.

S-CCPCH	1-2	3	4	5	6	7
SF	16	16	16	8	8	8
Data streaming	1 × 32, 4 × 16	1 × 64, 2 × 32	2 × 64	1 × 128, 2 × 64	2 × 128	1 × 256
Sum	96	128	128	256	256	256
Push & store	1 × 48	1 × 20	1 × 20	1 × 48	1 × 48	1 × 52

Table A4. Bin packing mapping for traffic mix 1.

S-CCPCH	1	2	3	4	5	6
SF	8	8	8	8	8	8
Data streaming	1 × 256, 1 × 32, 1 × 16	1 × 256, 1 × 32, 1 × 16	2 × 128, 1 × 32, 1 × 16	1 × 128, 2 × 64, 1 × 16	2 × 64, 2 × 16	1 × 64, 1 × 32, 2 × 16
DS sum	304	304	304	272	160	128
Push & store				1 × 32	1 × 144	1 × 176

audience (popularity) of individual services, accounting for the p-t-m nature of the services, the traffic load at the system level may be computed. Five different traffic mixes resulted from considering the system at different stages of its life (earlier/later featuring different subscriber numbers), in different hours of the day (morning/afternoon busy hours) and under different assumptions about the service offer in its early operational years. In the following we maintain the first traffic mix for demonstration purposes (Table A2). This traffic mix is input to the dimensioning procedure (RRM mode A) or directly to AC to provide the mappings depicted in Tables A3 and A4 for the bin packing based and power-aware packing based methods. These mappings have subsequently driven all RRM-related simulations and were used for the capacity evaluation (Section 8).

ACKNOWLEDGEMENTS

The authors would like to thank all colleagues that contributed to the SATIN project and directly or indirectly provided inputs to this paper.

REFERENCES

1. *Multimedia Broadcast/Multicast Service Architecture and Functional Description*. 3GPP TR 23.846
2. The future mobile market—global trends and developments with a focus on Western Europe. *Report No*. 8, UMTS Forum, March 1999.
3. *Multimedia Broadcast/Multicast Service*; *Stage 1*. 3GPP TS 22.146 v5.1.0.
4. Satellite Component of UMTS/IMT2000. *Analysis and Definition of the Packet Mode*. ETSI S-UMTS TR 101866 V1.1.1
5. Corazza GE, Salmi P, Vanelli-Coralli A, Villanti M. RACH acquisition in S-UMTS. In *Proceedings of 5th European Workshop on Mobile/Personal Satcoms (EMPS)*, 25–26 September 2002, Baveno-Stresa, Lake Maggiore, Italy.
6. Corazza GE, Salmi P, Vanelli-Coralli A, Villanti M. Differential and non-coherent post detection integration techniques for the return link of satellite W-CDMA systems. In *Proceedings of IEEE PIMRC 2002*, Lisbon, Portugal, September 15–18, 2002; 300–304.
7. Caini C, Castellan H, Corazza GE, Vanelli-Coralli A. Initial synchronization procedure in S-UMTS networks for multimedia broadcast multicast services. In *Proceedings of IEEE PIMRC 2002*, Lisbon, Portugal, September 2002; 295–299.
8. Levissianos A, Metaxa G, Dimitriou N, Polydoros A. Coding for satellite and terrestrial multipath correlated fading channels. *First ASMS-TF Conference*, Frascati, Italy, July 2003.
9. Salmi P, Neri M, Corazza GE, Vanelli-Coralli A. Non-linearity effects on FACH performance in a multicast/broadcast satellite network. In *Proceedings of Eighth International Workshop on Signal Processing for Space Communications*, Italy, September 2003.
10. *Broadcast/Multicast Control BMC*. 3GPP TS 25.321 V5.0.0 (2002-03), Release 5.
11. *Radio Link Control (RLC) Protocol*. 3GPP TS 25.322 V5.0.0 (2002-03), Release 5.
12. *MAC protocol Specification*. 3GPP TS 25.321 V5.0.0 (2002-03), Release 5.
13. Kaufman J. Blocking in a shared resource environment. *IEEE Transactions on Communications* **COM-29**, October 1981.

14. Karaliopoulos M, Angelou E, Andrikopoulos I, Henrio P, Evans BG. SATIN radio resource management strategy. In *Proceedings of IST Mobile & Wireless Communications Summit 2003*, Aveiro, Portugal, June 2003.
15. Angelou E, Koutsokeras N, Andrikopoulos I, Mertzanis I, Karaliopoulos M, Henrio P. Admission and preventive load control for delivery of multicast and broadcast services via S-UMTS. In *Proceedings of First International Conference on Advanced Satellite Mobile Systems*, Frascati, Italy, July 2003.
16. Ammar MH, Wong JW. The design of teletext broadcast cycles. *Performance Evaluation* 1985; **5**(4):235–242.
17. Holma H, Toskala A. *WCDMA for UMTS Radio Access for Third Generation Mobile Communications*. Wiley: Chichester; 2002.
18. Karaliopoulos M, Henrio P, Angelou E, Evans BG. Packet scheduling for the delivery of multicast/broadcast services via S-UMTS. In *Proceedings of First International Conference on Advanced Satellite Mobile Systems*, Frascati, Italy, July 2003.
19. Francon MG *et al*. S-DMB: A satellite based multicast architecture for multimedia services in 3G Mobile networks. In *Proceedings of EMPS*, Baveno, Italy, September 2002.
20. Narenthiran K *et al*. S-DMB system architecture and the MoDiS demo. In *Proceedings of IST Mobile Summit*, Aveiro, Portugal, June 2003.
21. Lan K-C, Heidemann J. *Structural Modelling of Real Audio Traffic* ISI-TR-544. September 2001.