DEMONSTRATION WITH FIELD TRIALS OF A SATELLITE-TERRESTRIAL SYNERGISTIC APPROACH FOR DIGITAL MULTIMEDIA BROADCASTING TO MOBILE USERS

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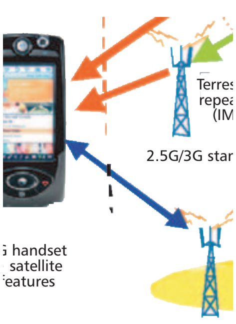

The synergy between a satellite system and terrestrial mobile cellular networks for cost-efficient content delivery to the mobile users lies at the core of the SDMB system concept.

ABSTRACT

The close synergy between a satellite system and terrestrial mobile cellular networks for cost-efficient content delivery to mobile users lies at the core of the satellite digital multimedia broadcasting system concept. Having already rich research and design work behind it, much of which has been carried out in the framework of European R&D projects, the system has recently seen the end of its first field trials, which relied on an experimental platform representing the future operational system. The article reports the outcomes of these trials that confirmed the technical feasibility of the system concept and provided valuable hints for the subsequent system design stages.

INTRODUCTION

The deployment of satellite systems as an overlay multicast/broadcast layer complementing mobile terrestrial networks in delivering point-to-multipoint services is a concept that has attracted strong interest within the satellite community in recent years. The inherent broadcast capabilities of satellites render them an attractive platform for the delivery of multimedia broadcast and multicast services (MBMS), in particular those featuring large and widely distributed audiences.

Satellite digital multimedia broadcasting (SDMB) implements a satellite-based broadcast/multicast layer, which is complementary to the third-generation (3G) mobile networks and increases their content delivery capacity [1]. The satellite component is designed to reuse as much as possible the cellular network architecture standardized within the 3G Partnership Project (3GPP). This way, the development of new products and technology is minimized, and via integration of maintenance, billing, and security operations within the overall cellular management system, the cellular company's operational efficiency is exploited. The satellite component enables immediate full coverage service provision and low transmission cost for point-to-multipoint applications addressing a large number of geographically dispersed terminals. On the other hand, the terrestrial cellular component is best suited for point-to-point applications and also point-to-multipoint applications with high geographical selectivity.

The first validation of the SDMB innovative system concept with field trials has been the *raison d'être* of the European Commission's R&D project Mobile Digital Broadcast Satellite (MoDiS) [2]. In the context of MoDiS an experimental platform representative of the integrated satellite and terrestrial cellular network system architecture of SDMB was developed. The platform has been used for extensive field trials that gave the opportunity to demonstrate the innovative service delivery proposal made by SDMB in close synergy with terrestrial cellular networks.

We first provide a brief introduction to the

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SDMB system architecture, before describing the testbed developed in the project for the demonstration and validation of the concept. The main part of the article focuses on the trials performed and the hints drawn from them rergarding system performance and possible directions for its enhancement. We conclude outlining the positioning of SDMB within digital multimedia broadcasting and the next steps that constitute the continuation of MoDiS.

THE MODIS TESTBED: A REPRESENTATIVE PLATFORM FOR THE SDMB SYSTEM

The SDMB architecture (Fig. 1a) combines bent-pipe geostationary satellites with terrestrial repeaters, also called intermediate module repeaters (IMRs), to form a large point-to-multipoint content delivery network (CDN) toward mobile users [1]. The satellite component operates in the IMT2000 mobile satellite systems (MSS) frequency band, which is adjacent to the band employed by the respective mobile terrestrial systems. SDMB provides a unidirectional distribution link toward mobile terminals and adopts the standard wideband code-division multiple access (WCDMA) air interface [3] used in 3G terrestrial cellular networks, enabling maximum reuse of terrestrial Universal Mobile Telecommunications System (T-UMTS) technology and cost-effective terminals [4].

The SDMB hub hosts the functional equivalents of the 3GPP Node B and radio network controller (RNC) nodes. A return link via the terrestrial mobile network, which may be 2.5G or 3G, enables access to all the standard interactive services of the terrestrial cellular network as well as functions related to the transfer of point-to-multipoint services over the satellite component, such as security-related transactions and application-level retransmissions of corrupted or lost content. The system makes use of an enhanced version of the 3GPP broadcast multicast service center (BM-SC), which, on top of its standard functionality [5], routes user and signaling data toward the satellite component and ensures normal execution/termination of the relevant protocol procedures.

The validation of this system architecture has been the main objective of the trials carried out in the context of the MoDiS project. The experiment consisted of setting up a representative platform of the SDMB system in Monaco, one of the most challenging — if not hostile — satellite signal propagation environments in Europe.

The platform is depicted in Fig. 1b, and its relevance to the SDMB architecture is outlined below:

- Due to the lack of an existing satellite able to provide enough power and bandwidth in the L/S frequency bands, satellite transmission was emulated by placing a UMTS Node B at a high-altitude location in Monaco. A helix antenna giving a circular polarization of the UMTS waveform was used. The transmit power of the Node B was set to yield the same reception levels at the input of the MoDiS terminal as those corresponding to satellite transmission in the predefined test area. For the trials only, transmission was performed in the terrestrial IMT2000 frequency band.
- The SDMB hub was replaced by the combination of a 3GPP Node B and an RNC emulator. The baseband functions of the SDMB hub were enabled via adaptations of the two pieces of UMTS-compliant equipment to enable support of MBMS radio bearer services [6] and adapt to the MoDiS platform constraints.
- Terrestrial repeaters are *on-channel*; that is, they amplify the satellite signal at the same frequency and using the same scrambling code as the signal coming from the hub network emulator rather than performing frequency conversion and transmission with a different scrambling code (frequency conversion repeaters). Two on-channel repeaters, with a signal processing delay of 7 μs, were used during the trials with the MoDiS testbed.
- The interactive link is provided by a precommercial 3G network.
- The MoDiS terminal is not an integrated handset, as envisaged by the SDMB system, but merely an assembly of several pieces of equipment: a prototype SDMB receiver, a laptop, a 2.5G/3G handheld device, and a Global Positioning System (GPS) receiver. The MoDiS terminal was installed in a car.
- The MoDiS data server features only a subset of the enhanced BM-SC functions required for SDMB operation.

In order to accelerate the testbed development and validation procedures, the MoDiS platform was split into two distinct (sub)testbeds, the application testbed and the transmission testbed; the former dealing with the integration of the network, transport, and application layers, and the latter with the radio access layers of the MoDiS platform. The respective testbed operations are mostly independent of each other, permitting most of their features to be developed and validated separately before deploying the full platform for the trials.

TRANSMISSION TESTBED

The transmission testbed brings together the RNC emulator, the Node B and the transmission parts of the MoDiS terminal, the prototype SDMB receiver being their main entity.

RNC Emulator and Node B — The access layer features implemented in the RNC emulator include the radio link control (RLC), medium access control (MAC), and packet data compression protocol (PDCP) sublayers as well as limited functionality of the radio resource control (RRC) sublayer. The RLC works in unacknowledged mode: retransmissions are not feasible, and only one service data flow is transmitted at a time over the radio interface, rendering multiplexing and scheduling at the MAC sublayer irrelevant. The Node B is driven by the RNC simulator via its standard Iub interface. At the receive side the SDMB receiver and a PC capture the incoming data. This PC is also used to monitor the transport block error rate (BLER), which reflects the link quality.

SDMB Receiver — The MoDiS prototype SDMB receiver is made of three different blocks: a

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radio part, a baseband part that may be divided into the chip rate processing module (inner modem) and the symbol rate processing module (outer modem), and a simple protocol stack for interfacing with the monitoring equipment and the application testbed. The radio part is used to downconvert the signals of the satellite emulator and the terrestrial repeaters from RF (2.1225 GHz) to 4 MHz in two stages. The inner modem first performs a digital downconversion to baseband and then acquires the phase of the spreading code, the code group, and the frame edge in successive steps. The RAKE module performs despreading and descrambling on each of its

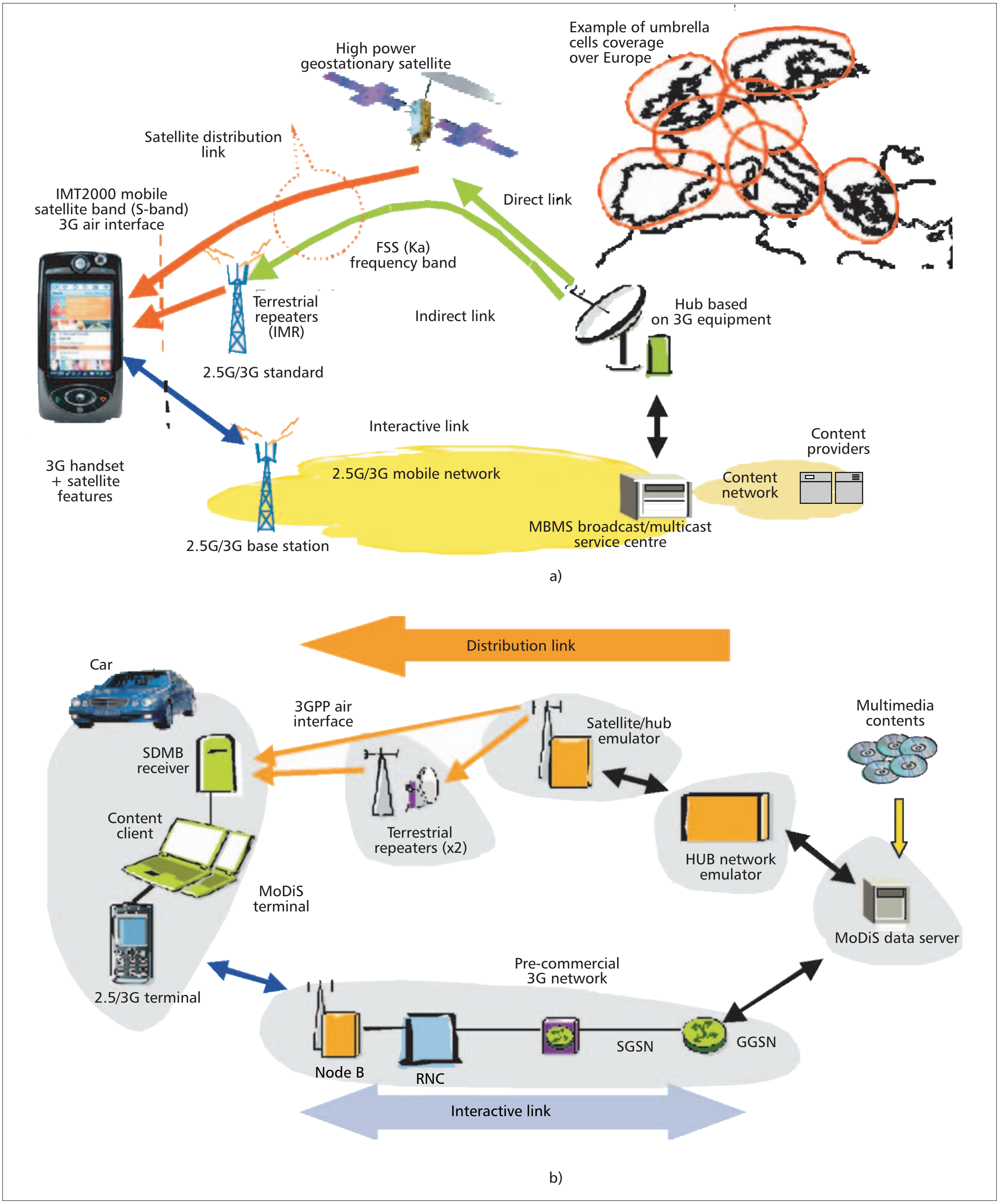


Figure 1. *The MoDiS testsbed as an abstraction of the SDMB architecture: a) SDMB system architecture; b) the MoDiS testbed.*

eight fingers and then a weighted coherent combination of maximum eight chip streams into one. The resulting symbol stream is fed into the outer modem, which is responsible for the main receive-side functions of the WCDMA physical layer chain [3]: outer (interframe) deinterleaving, rate matching, decoding with a turbo 1/3 decoder or a Viterbi-1/2 or 1/3 decoder with constraint length 9, and, finally, transport block error detection based on cyclic redundancy check (CRC) of 0, 8, 12, 16, or 24 bits.

APPLICATION TESTBED

The application testbed includes the MoDiS data server and part of the distributed MoDiS terminal, the MoDiS terminal application part. It enables the integration and demonstration of several transport, application, and service-level MoDiS features:

- Content description: provided generally by the producer of the content using Extended Markup Language (XML) technology. The resulting descriptor is known as the content delivery descriptor (CDD).
- Content filtering at the server side: The data server classifies the content according to the CDD, in order to provide some quality of service (QoS) at the transport layer taking into account the instant resource availability. QoS at this layer is provided via exercising scheduling disciplines and buffer management schemes on multiple queues, each aggregating data flows with similar service requirements.
- Content filtering at the terminal side: Comparing the content identifier list, which is manually loaded at the SDMB receiver, with the content identifier of the current transfer placed in the CDD, content is filtered and stored at the terminal only when it is likely to be of interest to the user.
- Cache management: involves the storage of content according to priority and user profiling. The user profile is continuously updated by analysis of user behavior regarding content stored on his/her terminal. The mechanism that implements this updating mechanism is called active cache.

The tested applications make use of two service delivery modes: streaming, where the content is played out at the terminal on the fly through a small playout buffer, and push-and-store, whereby content is fully stored at the terminal to be accessed later by the user. Four different MoDiS user services (application types) make use of these two service delivery modes:

- Push-and-store applications: involve content filtering based on the CDD, terminal type, and user profiles
- Emergency notifications: make use of the push-and-store delivery mode combined with prioritization at the data server
- Streaming applications: feature direct access to content (audio and video mainly) via the streaming delivery mode
- Peer-to-peer[1] (P2P) or groupcast applications: by which mobile users send content through the cellular network to the MoDiS data server, which processes it and then pushes it toward other group members via SDMB

The application testbed functionality is distributed between the MoDiS data server and the MoDiS terminal.

MoDiS Data Server — The mission of the MoDiS data server is multifold. First, it gathers multimedia contents from content providers. Then it packages these contents, adding content metadata (CDD insertion) that enable the cache management function. The server also has to schedule the various contents to support the SDMB bearer services provided to users. It encompasses the server part of the reliable transport layer and the server part of the aforementioned MoDiS applications. Finally, it includes a routing unit that lets it route traffic over the physical connection to the transmission testbed. In terms of discrete modules, the MoDiS data server encompasses the file server, application server, and a third module comprising the scheduler and routing unit, whose implementation is tightly coupled and constitutes the MoDiS push engine server part.

MoDiS Terminal Application Part — The MoDiS terminal application part consists mainly of the push client, cache manager, and user application. The push client processes incoming content. It first filters the incoming traffic, passing the content of interest to the cache manager for further processing using an ad hoc protocol. Once the content has been correctly received, the SDMB receiver is turned off. The push client also manages the content identifier list, which involves functions such as initialization and updates of the list stored at the SDMB receiver, filtering of incoming traffic when the SDMB receiver is turned on, and removal of the content identifier of content that has been correctly received. Finally, incoming data is deciphered according to prestored keys. The cache manager, on the other hand, is responsible for the implementation of the active cache mechanism. Contents are filtered on the basis of the continuously updated user interests profile; an auto-adaptive process allows the user profile to be built strictly based on what the user likes to get and what he/she is not interested in. This process is fully implicit without requiring any programming effort from the user and can cope with dynamic changes of this profile.

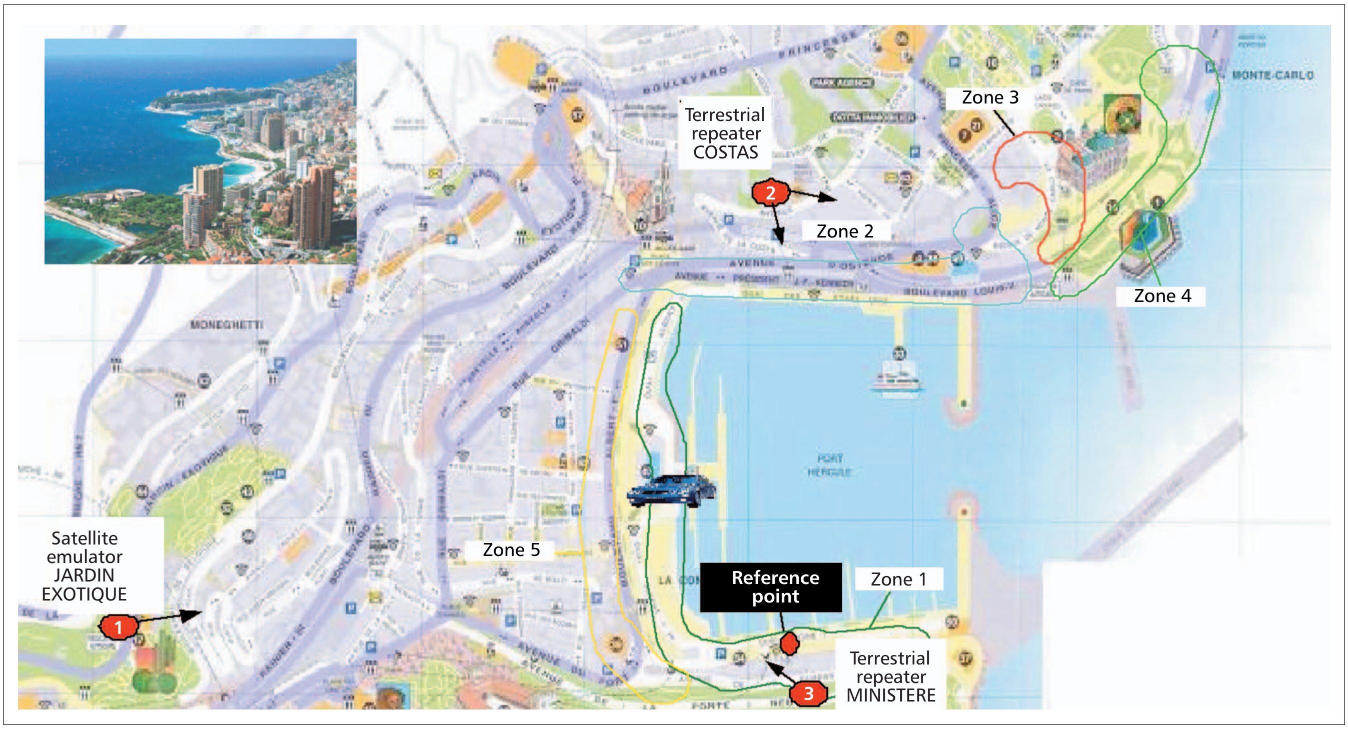
TRIAL DESCRIPTION AND METHODOLOGY

TRIAL SETUP

The field testbed was installed in the area of Monte Carlo (Fig. 2.) The position of the satellite emulator was fixed at one of the highest points of Monaco. The antenna was pointed to the harbor area, where line-of-sight (LOS) propagation conditions are not always possible. The first terrestrial repeater was set up close to an area where there was no satellite reception at all because of high buildings. The buildings also blocked the LOS to the IMR; however, reception was good due to reflections onto these buildings that created strong enough multipaths. The second repeater was placed on the other side of the harbor in an attempt to overcome the problem of bad reception due to the

The application testbed includes the MoDiS data server and part of the distributed MoDiS terminal, the MoDiS terminal application part. It enables the integration and demonstration of several transport, application, and service-level MoDiS features

[1] *The use of the term* peer-to-peer connectivity *in the context of MoDiS implies the possibility offered to individual mobile users to become the sources of content that is pushed toward the peer members of their group.*



■ **Figure 2.** *MoDiS platform setup in Monaco with location of satellite emulator, repeaters, and test zones along the car routes in Monte Carlo.*

blocking of the satellite signal at several places in this area. The existence of the two repeaters also meant that at those places where the satellite signal was not blocked by buildings, we could receive and combine both the satellite and repeater signals.

The power received by the different equipment was set to be equal to the power that would have been received from a real geostationary satellite. The signal reception level at the reference points and the reference points themselves, the test zones, and the IMR input powers were defined accordingly. The reference point is where the MoDiS receiver input power level from the satellite emulator was equal to what would have been received from the real satellite. The test zone was defined as the area where the received power is ±1.5 dB around the power received at the reference point. Five different test zones were defined, as depicted in Fig. 2. In zone 1 there is usually good LOS reception of the satellite signal, whereas the IMR signals are blocked or too weak to have great influence on the performance of the receiver. In zone 2 we have a combination of the satellite signal and the signal from an IMR. Reception is good, but can sometimes suffer from blocking. In zone 3, the casino area, the available signals are only faded multipaths coming from one IMR, and poor reception is expected. Zone 4, the tunnel, is the most difficult, with reception being almost impossible, whereas in zone 5 the reception of the satellite signal is again difficult due to high buildings surrounding the roads in this zone. The repeater placed below zone 5 increases the total received power by introducing a second signal path. Finally, the IMR input power coming from the satellite emulator is equal to the power that would have been received from the real satellite. The satellite emulator-reference point and the satellite emulator-IMR distances were equal to 1 km.

The SDMB receiver, a monitoring PC, and the application PC were installed in the boot of a car with built-in screens that were used to monitor the physical part of the receiver and examine the quality of the received data. During the trials, all measurements were logged onto the monitoring PC. Data from the RAKE receiver, the automatic gain control (AGC) block, and BLER measurement data and GPS data were saved for post-processing purposes. From the RAKE measurements one could extract the signal level per combiner finger, total signal power, and noise power, making it also possible to calculate the ratio E_b/N_t (energy per bit over total noise, including interference, density ratio). Four different transmission modes corresponding to four different WCDMA radio bearers at 12.2, 64, 128, and 384 kb/s were tested. The transmit power was set in such a way that the received antenna power at the reference point was between –85 and –95 dBm.

TRIALS' SCOPE

At a high level, the trials aimed at demonstrating the envisaged SDMB applications and features relevant to service delivery, such as cache management, user profile management, and conditional access. The primary concern in these experiments with streaming applications was to assess the possibility of streaming audio/video content at rates of 64, 128, and 384 kb/s. The operator schedules a transmission using the CDD, usually a Windows Media stream. The server then activates the multicast routing function and forwards the stream onto the hub network emulator. A session is announced

Service	Sat data rate (kb/s)	Sat power (dBm)				Quality
Streaming			Packets received	Packets recovered	Packets lost	%
89 kb/s max, 12 frames/s max	128	–95	18,000	136	1542	91
89 kb/s max, 12 frames/s max	128	–85	16,000	107	529	97
89 kb/s max, 12 frames/s max	384	–95	27,048	260	3500	87
89 kb/s max, 12 frames/s max	384	–85	29,031	220	2921	90
Push and Store			Contents announced	Contents received		%
Content size: 61,051 bytes	12.2	–90	8	8		100
Content size: 72,370 bytes	64	–85	44	42		95
Content size: 34,467 bytes	128	–85	85	80		94

Table 1. *Reception quality for different transmission modes as measured at the application layer.*

periodically to wake up terminals that want to receive the specific session.

Regarding push-and-store applications, the requirement was to exploit the active cache features for pushing large amounts of multimedia content from the data server into the cache memory of user terminals. Likewise, in the case of emergency announcements, the interest was in testing the ability of the system to prioritize them and push them promptly to the users. In groupcast applications, a more advanced service paradigm was tested: two users make use of 2.5G/3G handsets and send data to the MoDiS data server making use of the point-to-point connection through the 2.5G/3G network. There the content is processed and pushed to the MoDiS terminal using the push-and-store delivery mechanism. The users are engaged in a location-based collaborative session, where they are able to use video messaging and chat, as well as a location mapping application that allows users to be aware of each other's position.

Therefore, the trials inevitably focused on a series of issues that have a severe impact on application performance and, eventually, the end user experience of the system.

Signal Quality — The quality of the signal is monitored while the testbed is configured in four different transmission modes. Parameters like data rate, spreading length, and transport block size (TBS) are different in these modes and cover all possible settings of the forward access channel (FACH), the WCDMA transport channel used for the support of MBMS radio bearer services.

Macro-diversity — Equally important was to analyze the propagation conditions in the emulated satellite-IMR environment for different configurations and evaluate the impact on reception performance using the MoDiS prototype SDMB receiver. The macrodiversity requirements were first tested in a laboratory environment with a channel simulation tool in a wired setup, where the delays between the different paths can be adjusted to known values. The field trials gave a chance to repeat the tests in an uncontrollable but realistic wireless environment. The delay between the paths and the power of each transmitter were monitored and logged by the RAKE Visualizer, a tool with the capability to display the position and strength of each RAKE finger.

Reliable Transport — The use of reliable transport protocols over SDMB bearers was another mechanism to validate. Tools were used for monitoring reception quality at the client side at the terminal. Relevant state machines were developed for this purpose. The collected statistics at each receiver may drive the fine-grained tuning of transport layer parameterization, such as packet forward error correction (FEC) redundancy, and interleaving depth.

Outcomes of the Trials and Hints for the System

Overall, the complete system performed according to our expectations. The transmission performance was good up to 128 kb/s, whereas for 384 kb/s the results were less satisfactory, as depicted in Table 1 and Fig. 3. The four types of SDMB applications were all successfully demonstrated.

The main conclusions derived from the various sets of trials are presented below.

SDMB Receiver and Radio Transmission — The need for a larger RAKE window and more RAKE fingers for the SDMB receiver was one of the main outcomes of the trials. In general, the RAKE window size has to be twice the maximum delay difference between the channel resolved paths. The first detected path must be set in the middle of the RAKE window because other paths can occur before or after it, so the path with maximum difference in delay can appear before or after this first path. The maximum delay difference during MoDiS trials was 11 µs, significantly higher than that usually met in T-UMTS cells. The combination of the IMR signals with the direct signal coming from the satellite results in a multipath signal, with much wider delay spread and a higher number of resolvable components than when only terrestrial transmission occurs [7]. With the standard RAKE window size of 20 µs, this "artificial multipath" due to the existence of on-channel IMRs could not be combined constructively, thus generating additional interference. The receiver performance improved significantly when the RAKE window size was increased to 33 µs, since this allowed more signal components to be combined, at the same time reducing the interference levels. The wider spread of the multipath, and hence the need to increase the RAKE window, was also due to the processing delay of 7 µs introduced by the on-channel repeaters. This problem would have been avoided with frequency conversion repeaters. Notably, all four transmission modes tested in the trials featured a transmission time interval (TTI) of 10 ms, limiting the reception quality gain to outer (interframe) interleaving.

The trials also showed that the use of IMRs not only imposes additional requirements on the SDMB receiver, but also requires their correct placement and transmit power setting. When the IMR power was too high, other signals could not come through; when it was too low, on the other hand, it generated extra interference because the receiver was not able to recombine the signal. Simulations using a radio planning tool were deemed necessary for the testbed deployment and configuration. These simulations took into account the performance of the Node B, repeaters, and SDMB receiver, as well as the location of the MoDiS equipment and the Monaco Telecom UMTS network. More investigation regarding the satellite angle must be done in the future in order to better understand its impact on coverage, scattering, and indoor penetration.

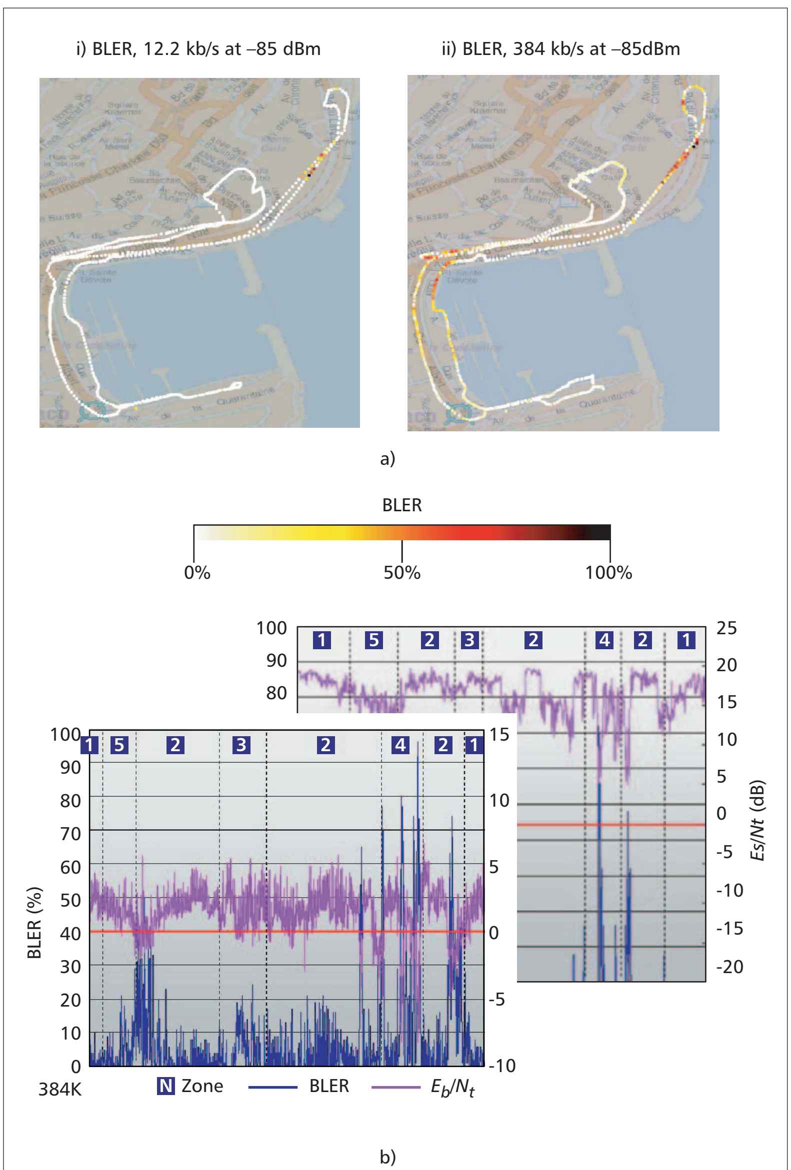


Figure 3. *BLER and* E_b/N_t *measurements along the route followed by the MoDiS car for reference point reception level equal to –85dBm: a) BLER performance at different date rates; b) BLER and* E_b/N_t *measurements for 12.2 kb/s (rear) and 384 kb/s at different test zones.*

Transport and Application Layers — The reliable transport layer implemented for the push-and-store service included packet-level FEC and interleaving. The conditional access mechanism was validated by sending encrypted content over the broadcast link that was decrypted by the user with the correct key.

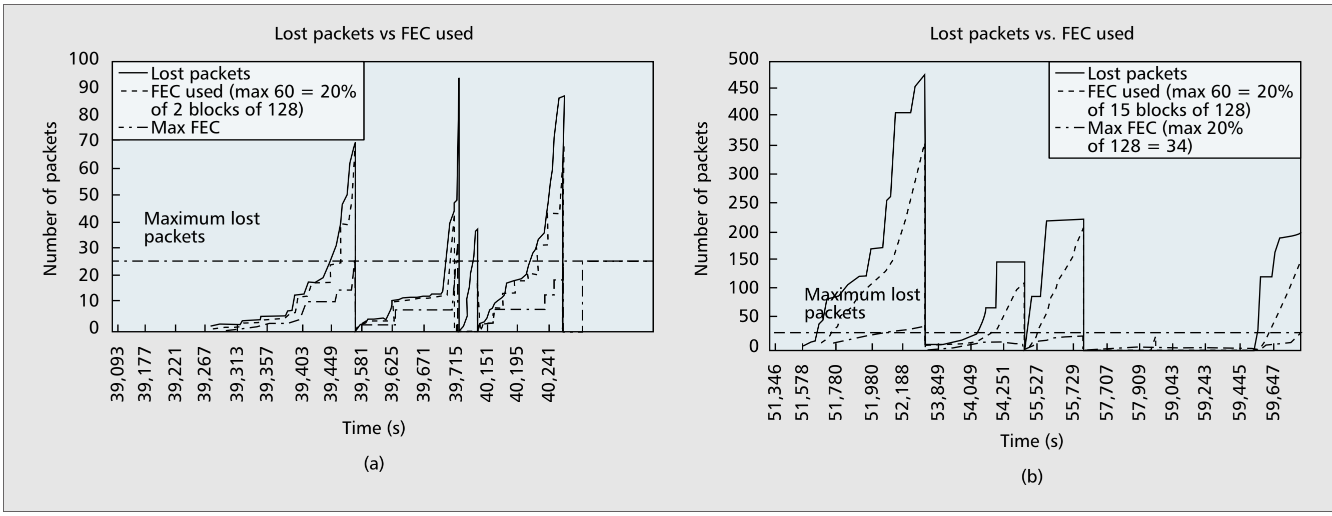
The results in Fig. 4 show that interleaving is of utmost importance in coping with data loss of up to 100 percent during intervals of complete signal outage on the order of 10 s (e.g., while the car was traversing the well-known Monte Carlo tunnel in zone 4). With 20 percent static FEC we were able to compensate for 10 s of complete blocking.

The trials also confirmed the importance of packet-level FEC in compensating for short-term errors. In particular, in fixed situations with good reception, 10 percent FEC can easily compensate for the less than 10 percent BLER that occurs sporadically. However, in situations with high BLER (more than 70–80 percent), particularly inside tunnels, 10 percent FEC cannot compensate for the errors, and sizing the FEC for this would lead to unrealistic values. In such conditions, large storage capacity associated with interleaving and carouseling appear to provide high added value.

More detailed analysis of the trials results is available at [2].

SDMB Positioning within Digital Multimedia Broadcasting

Several technologies are being developed by the industry in order to address the emerging market of digital multimedia broadcasting. The 3GPP MBMS framework [5] is one option implying sharing of mobile network operator resources between typical interactive and point-to-multi-



■ **Figure 4.** *Chronogram showing the FEC impact a) without and b) with interleaving.*

point services. The SDMB offering allows operators to devote network resources to more profitable interactive services, providing them with an additional platform for delivery of broadcast/multicast services.

On the other hand, the digital video broadcasting standard for handheld devices (DVB-H) [8] adds certain features to the DVB terrestrial (DVB-T) standard to address the power consumption and mobility constraints of handheld terminals. Whereas the standard allows the support of higher transmission rates (on the order of 10), the use of a different radio interface requires the use of an additional full reception chain on the mobile handheld to enable access to both types of services: the interactive ones provided by the mobile cellular network and the broadcast/multicast ones offered by DVB-H.

Between the two systems, from a capacity point of view, stands the terrestrial DMB (T-DMB) alternative, which is a modified version of the terrestrial digital audio broadcasting (T-DAB) standard and makes use of OFDM technology. The system raises similar concerns as DVB-H on the handheld side and is implemented at the very/ultra high frequency (VHF/UHF) bands, which may delay system deployment until these bands become available from a regulatory point of view.

The SDMB system stands as a complementary rather than purely competitive alternative to these options, in particular DVB-H. Its main advantage is reduced cost on the network and, in particular, on the handheld terminal side, thanks to close integration with the mobile terrestrial networks, high reuse of technology, and adoption of the WCDMA radio interface.

Conclusions and Further Work

The MoDiS experimental platform has demonstrated for the first time an innovative service delivery proposal for mobile users, relying on the synergy of mobile satellite and terrestrial networks. The successful demonstration of representative SDMB applications in a particularly challenging propagation environment reinforced the technical feasibility of the SDMB system concept, while allowing real-world experimentation with key system engineering issues.

The proof of concept demonstration in the context of the MoDiS project has been another step for the SDMB system toward the operational stage. The described testbed has brought together many of the findings in earlier R&D projects partially sponsored by the European Commission (EC), European Space Agency (ESA), and French Space Agency (CNES), whereas system studies are continued within the EC 6th Framework Programme (FP6) and ESA research programs.

The main expression of research effort on SDMB is currently the EC FP6 project MAESTRO, which addresses the whole range of issues pertinent to SDMB, from system design and demonstration to regulation and standardization [9]. With respect to system demonstration in particular, MAESTRO aims at enhancement of the MoDiS testbed, replacing the MoDiS data server with a representative SDMB-enhanced BM-SC, and the distributed MoDiS terminal with an SDMB-enhanced 3G handset. These additions will lead to a platform much closer to the envisaged commercial SDMB system and enable real-world experimentation with more design trade-offs, particularly on the user terminal side, many of which have been made clear during the MoDiS trials.

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