Link-level and system-level simulators for the SDMB system evaluation

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ABSTRACT

The paper describes the link-level and system-level simulators that have been developed for the study of the Satellite Digital Multimedia Broadcasting (S-DMB) system. The development of the simulators has been largely carried out in the Mobile Digital Broadcasting Satellite (MoDiS) project, which is partially funded by the European Union in the context of the 5th research framework program and aims at the demonstration of the S-DMB concept. The two-fold role of simulations with respect to the hardware test bed developed in MoDiS is explained: simulations both *support* and *complement* the hardware test bed experiments. The simulators' modules are introduced and the differences with regard to typical Wideband CDMA (WCDMA) link-level and system-level simulators are outlined. We enumerate the planned simulation scenarios and present sample results from the ongoing simulation campaign.

Keywords – S-DMB, Satellite UMTS, Wideband CDMA, MBMS

I INTRODUCTION

Multimedia broadcast multicast services (MBMS) are currently under standardization within the Third Generation Partnership Project (3GPP) [1]. The provision of services that are of interest to multiple users in multicast/broadcast mode alleviates significantly the capacity requirements imposed on the terrestrial radio access network. On the other hand, there is strong belief in the worldwide satellite community that satellites offer a competitive solution for the delivery of point-to-multipoint services due to their inherent broadcasting capabilities. In Europe, this belief has been strongly expressed in the design and development of the Satellite Digital Multimedia Broadcast (S-DMB) system [2]. S-DMB provides effectively an overlay multicast/broadcast layer on top of the terrestrial mobile networks. The S-DMB concept has been central for several European Union (EU) and European Space Agency (ESA) projects (for example, see [4]); the main mission of the Mobile Digital Broadcast Satellite (MoDiS) project is the validation and demonstration of the S-DMB concept in an experimental test bed.

The MoDiS test bed is a simplified, scaled-down version of the real system (Figure 1). A Hub emulator replaces the satellite gateway, whereas a terrestrial Node B on top of a hill will be used instead of real satellite. The Intermediate Module Repeaters (IMRs), which are envisaged in the S-DMB system architecture for enabling the signal reception indoor and in heavily built urban areas, are replaced by commercial repeater modules. Finally, a couple of prototype terminals substitute the S-DMB handheld devices.

Our paper describes the simulation test bed that has been developed as part of MoDiS activities. Its main objective is to support and complement the experimental hardware test bed, thus contributing to a comprehensive demonstration of the S-DMB concept. The next section elaborates the main technical challenges related to the implementation of the S-DMB system, around which the experimentation with the hardware and the software test beds evolves. In section III, the two-fold role of simulation in the project is explained, whereas the following section is devoted to the description of the simulation test bed. The simulation modules of both the link-level and the system-level simulators are briefly presented along with the interface between the two. In section V we list the planned scenarios for the simulation campaign and present preliminary simulation results. Section VI summarizes our paper.

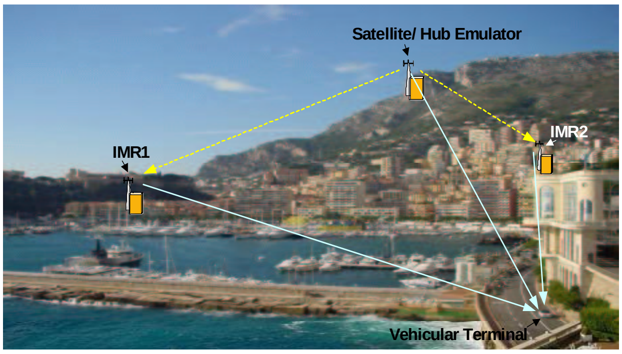

Figure 1: Sample of the MoDiS Experimental Platform

II TECHNICAL CHALLENGES FOR THE S-DMB SYSTEM

In the following, we elaborate on the technical challenges that are related to the S-DMB system implementation. Most of them are a direct consequence of the system nature and architecture, which are briefly summarized below. We present them following a bottom-up approach: firstly, we discuss the particular propagation conditions the S-DMB signal has to encounter, we then proceed with physical layer considerations and finally, we identify the implications at the system level, with emphasis on the transport layer.

A. S-DMB system features and architecture

The main features of the S-DMB system, as envisaged today, are listed below:

a) It is fully integrated with the terrestrial mobile network, with a satellite radio interface that features maximum similarities with the WCDMA interface of the terrestrial UMTS (T-UMTS). Therefore, the terminal should have the capability to handle both satellite and terrestrial signal reception.

b) It is a unidirectional content delivery system, which features only forward link via satellite and a return link via terrestrial network. Limited rate return link may expand the system use when mobile terminals are out of terrestrial network coverage.

c) The satellite system delivers only point-to-multipoint services that constitute a full set or a subset of MBMS services as currently defined within 3GPP [1]

d) Intermediate module repeaters (IMR) are deployed to ensure adequate signal reception in urban environments and inside buildings.

B. Propagation Environments

The propagation environment is different than standard mobile channels due to the existence of the IMRs: the signal components that reach the terminal via the IMRs experience additional delay. The existence of more than one IMR gives rise to *artificial multipath.* This phenomenon is quite different from the multipath experienced in terrestrial UMTS.

Mobile users within the coverage a single spot beam encounter different propagation environments. With respect to their study by means of simulation, we have identified four scenarios:

SC I: Open/ remote environment, where only satellite reception is possible.

SC II: Highway/ rural environment, where the mobile terminal can receive the signal from both the satellite and the terrestrial Node B.

SC III: Urban environments where again both satellite and Node B signals can reach the terminal.

SC IV: Indoor environments. The assumption is that the satellite signal is too weak to be considered.

C: Satellite radio interface aspects

One of the requirements on the terminal side due to the hybrid system nature is that the terminal has to switch reception mode (satellite vs. terrestrial) regularly, in order to carry out basic functions relevant to the terrestrial mobile network (e.g. receive the paging channel to check if there is an incoming point-to-point call). During this period, data sent via the satellite will be lost. The satellite interface provides two ways to address the increased data loss:

- Recover data via retransmission of lost segments. This would necessitate real-time user-feedback, which is not feasible due to the absence of a satellite return link.
- Increase the interleaving depth in the first interleaver of the physical layer chain, in order to reduce the amount of data lost during these radio frames. The advantage of this countermeasure is that it does not require additional radio resources.

D: Transport/ System Level Aspects

Various mechanisms are envisaged above the link layer to increase the reliability of the content delivery over the S-DMB network, such as packet level forward error correction FEC and packet level interleaving. Moreover, within the context of the MoDiS project, we experiment with an additional layer in the Satellite Radio Access Network (SRAN), called subsequently Reliable MBMS Transport Protocol Layer (RMTP). This layer performs similar functions (packet level FEC and interleaving), this time at the access layer rather than end-to-end (Application-Level FEC-ALFEC).

Both FEC implementations add redundant (or parity) packets for every FEC group (set of higher layer original packets) by using an erasure code. At the receiver side, the FEC layer can tolerate certain number of packet losses within each FEC group, this number mainly depending on the redundancy level applied by the sender for each FEC group and the type of erasure code. Although the primary functions of both FEC implementations are similar, the flexibility in the selection of FEC-related parameters is different. In ALFEC, the data server will determine the FEC related parameters before the initial content transfer, and those parameters are chosen based on the session requirements (Quality of Service - QoS) and the satellite network radio resources. In general, the selected parameters will be unchanged during the session. Hence the satellite network will have to reserve the required resources during the session according to a fixed FEC capacity overhead due to redundant data. The instantaneous variability of radio resource consumption is not known to the FEC agent and cannot be exploited. To overcome this, S-RNC based FEC (RMTP) is considered in MoDiS.

The initial FEC parameters for the RMTP layer are also chosen before the content transfer but during the session the parameters can be dynamically changed in response to variable traffic characteristics . In this ways, the RMTP layer allows the S-RNC to utilise the available resources while providing best possible reliability to the content.

III TEST-BED LIMITATIONS AND ROLE OF SIMULATION PLATFORM

It has already been noted that the test-bed implementation is a simplified replica of the actual system it intends to demonstrate in a number of ways and it is impossible to develop as test-bed including all the system features, such as RRM for example.

Regarding diversity, for example, in the real S-DMB system, the satellite signal may reach the receiver from more than the 2 IMRs accounted for in the MoDiS test bed. Signal reception from IMRs depends on the elevation angle of the satellite. The elevation angle from place to place (different cities in Europe) will vary. This cannot be represented in the test bed since it uses a terrestrial transmitter. Moreover, the angle of satellite signal reception, which is very important for the reception of the direct line-of-sight component of the satellite signal, cannot be achieved by the terrestrial transmitter.

Simulations can address some of the system functions that are simplified or even omitted (e.g. RRM) from the test-bed implementation; furthermore it can provide results for a wider range of scenarios than the ones that will be evaluated at the test-bed, taking again advantage of the higher flexibility of simulation in “what-if” scenarios.

On the other hand, it is very difficult to come up with precise simulation models, which represent unpredictable radio channel conditions and all the related hardware component behaviour (RF receiver and transmitter including antenna, etc). Therefore there is a mutual relationship between simulation platform and physical test bed that can be exploited towards a thorough system validation.

IV SIMULATION ARCHITECTURE

A. Link-layer simulation model

The link layer simulator for MoDiS (Figure 2) is developed inline with 3GPP specification [11] and the S-DMB related channel multiplexing scenarios [9].

1/3 rate Turbo coding for FACH channel and 1/2 rate convolutional coding for the Paging Channel (PCH) channel are used. For the simulation, multipath components due to IMRs, that are below -15dB are disregarded and the assumed Rake window size is 80 chips duration (20.8 μs). The assumed values for processing delay (T-Addit) in IMRs are 0, 5, 10, 15 μs. TTI values up to 320 ms are considered. For the initial simulations the I_{or}/I_{oc} value assumed as –1dB. However the real value in S-DMB case will be determined later in the simulation activities.

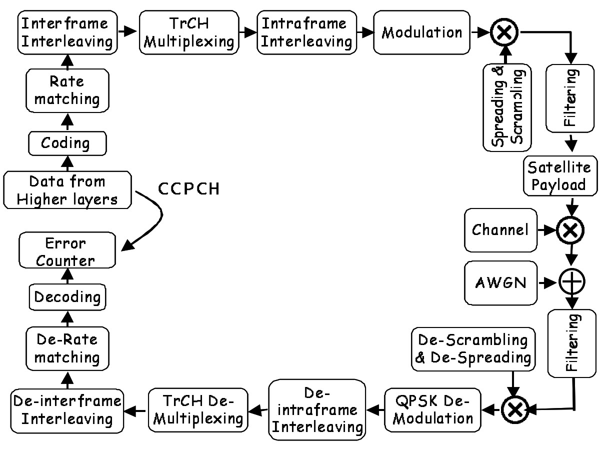

Figure 2: Physical layer Simulator

For the system level simulations, the received signal from the IMR in urban environments is modelled by correlated log-normal distribution [4]. The satellite component of the received signal is modelled based on the Markov on/off (good/ bad state) model [6] with correlated shadowing process for the bad state [8][9]. Parameters of the system components such as the IMR cell layout and gain, interference characteristics, satellite antenna gain and user position are also input to the link-level simulations.

C: Radio interface/RRM Simulation Model

The radio interface and the RRM simulation modules are developed on top of the mainstream network simulator version 2.26 (NS2) platform. The WCDMA-based interface [5] is developed inline with 3GPP specifications, and it consists of the WCDMA MAC and RLC functions such as segmentation and reassembly of packets into/from access layer TBs and concatenation of TBs. They also include the packet-scheduling block, described in [8].

The pedestrian and vehicular mobility models from [5] are used for modelling the user mobility.

D: Reliable multicast transport model

In the MoDiS test-bed, the ALFEC reliable multicast mechanism is performed by the UDPush engine, developed by UDCast, The physical test-bed will only account for two users therefore the performance obtained from ALFEC cannot be generalised for a larger audience. The system-level simulator will allows to simulate larger number of users experiencing different propagation conditions, and the optimum FEC parameters obtained from simulation can be validated from the test-bed. The following reliable multicast modules have been developed on top of NS2: Application level FEC and RMTP layer FEC.

In both modules the standard FEC mechanism; for every *k* number of original packets *h* number of redundant packets will be generated is implemented. However in ALFEC, the FEC grouping is different from (RMTP). In ALFEC the whole transmission will be segmented into Application Data Units (ADU) and then those ADU’s are segmented into transmission packets. Those packets are then grouped into Application level FEC groups (AFG) and then using an erasure code, an encoder will generate redundant packets using the original packets within the AFG. In contrast, the RMTP layer generates the redundant packets as soon it has received enough number of original packets (*k*) from the higher layers, the *k* value dynamically varying as mentioned in section II. After generating the required number of redundant packets both FEC implementations will add a new FEC header before passing the encoded packets to the lower layer and this header will consist of FEC-related parameters for decoding purposes at receiver side.

On the receiver side, the FEC agent will perform standard FEC decoding processing; for each FEC group the decoder has to receive at least *k* encoded packets in order to correctly decode the original packets. If this does not happen; the decoder may forward only the correctly received original packets, if the used code is systematic [14] or nothing at all in the opposite case.

Another difference between ALFEC and RMTP layer FEC has to do with the way the packet loss is calculated. In ALFEC, if the receiver does not receive all AFGs belonging to an ADU, then all the packets within that ADU are considered lost. On the contrary, in the RMTP, if the decoder does not receive all the original packets belonging to a given FEC group, then the number of lost packets is equal to [*k* - number of correctly received original packets]. Figure 3 shows the basic system-level reliable multicast transport simulator models and their relation to the other system-level modules.

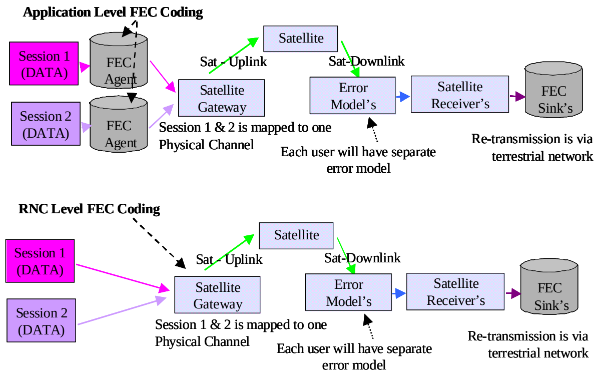

Figure 3: System level Simulator

E. Interface between the link--level and the system-level simulators

The existence of an accurate interface between the link- and system-level simulators is considered as very important in a CDMA system in comparison witha TDMA-based system [10] due to the soft capacity concept of the CDMA system and the related power control (fast, closed-loop [13]) mechanism. Two approaches [12] for this interface were discussed within the engineering communities working for UMTS (*Average Value Interface and Actual Value Interface*), which introduce a trade off between accuracy and simulation run time.

In the expected S-DMB system air-interface, there is no power control, hence the channel condition does not influence the capacity in short term, whereas it has an impact on the mechanism going to be deployed for reliable multicasting (ALFEC). The packet scheduling is done based on the long-term statistics. Therefore the average value interface is used for the simulations in MoDiS, based on the logic presented in Figure 4.

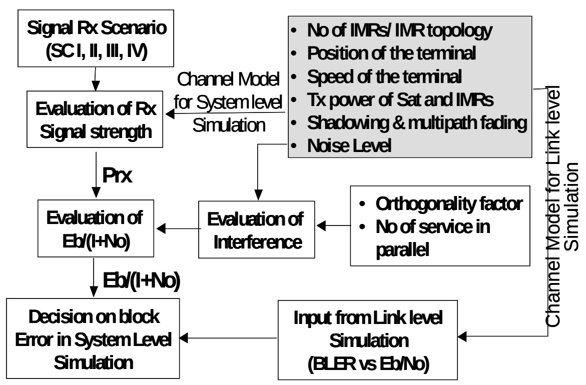

Figure 4: Interface between the link/ system level

For the urban and indoor environment, where the mobility levels related to pedestrian and slow-moving vehicle are lower, the correlated channel characteristics are handled by a two-dimensional data structure [13], which represents the geographical points inside the IMR coverage area. Outside the IMR coverage area, it is considered that mobile users are in high-speed vehicles (i.e. the users will not return to the same point again and again). Therefore the distance traversed by the users is used to produce the correlated shadowing values.

V SIMULATION SCENARIOS AND RESULTS

Regarding the propagation scenarios, propagation scenario I is not considered for the simulation since it provides perfect reception. On the contrary, propagation scenarios III and IV are the main scenarios in the simulations' scope.

A: Link-level Simulation

The physical layer simulator is built based on the following objectives.

- Implement the test-bed arrangement alone and full IMR environment in the simulation platform
- Implement the 1st interleaver with higher interleaving depth to see the performance of the UE receiver when it switches to T-UMTS to receive the signalling information.
- Evaluate the performance degradation due the processing delay in IMR
- Derive the BER & BLER with different channel multiplexing scenarios and MBMS traffic mixes to feed to system/ transport level simulators.
- Evaluate the performance with different payload non-linearity models.

For the physical layer simulation, different scenarios are considered based on the objectives in section IV.

Initial results from the simulation model are shown in Figure 5 and Figure 6 for the cases with and without processing delay in IMR. From the first figure, we can clearly see the difference between the 7 IMRs case and 1 or 2 IMRs case: it is clearly shown that gathering more multipath components using RAKE does not necessarily improve the performance. This phenomenon will further be investigated to see how this multipath environment can be tackled to get better performance.

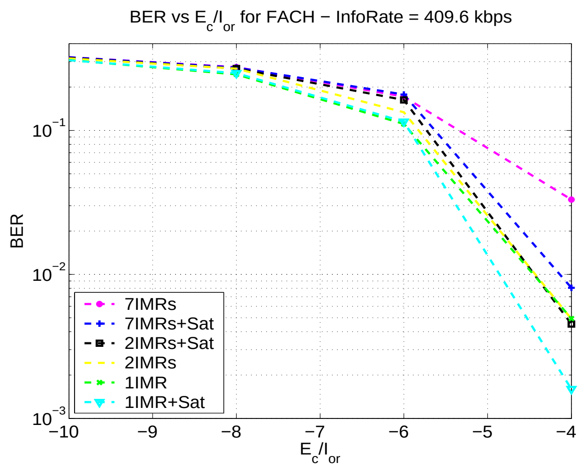

Figure 5: BER curves without processing delay in IMR

The second figure shows that the processing delay in IMRs is not that significant. The IMR signal is much stronger than the satellite signal, particularly in urban environment.

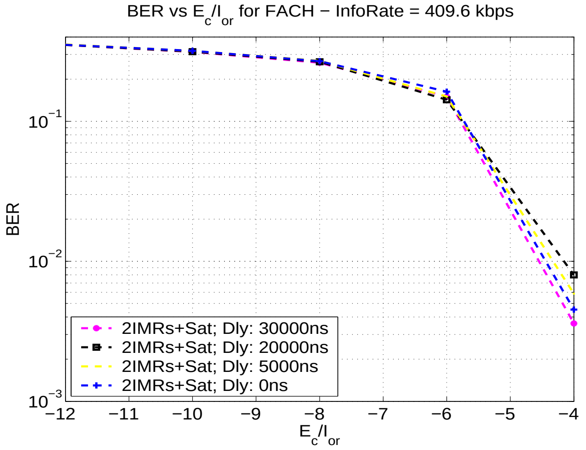

Figure 6: With processing delay in IMR

C: Transport/ System Level simulation

The main objective of the transport and system level simulations are to evaluate the FEC performance (user satisfaction) for different FEC parameter settings, such as ADG size, number of AFG's within a ADU, packet size, number of packets within a AFG, redundancy level for each AFG, and number of encoded packets within a FEC group ($h + k$). Likewise, for RMTP layer different FEC parameters will be evaluated in respect to different link level parameters settings, such as transmit power, interleaving depths and Transport Blocks (TB) sizes, when analysing the FEC performance. Within the simulations each set of FEC parameters corresponds to a simulation scenario.

The simulation results will be used to dynamically adopt the FEC parameters for S-RNC based FEC (RMTP) as a function of traffic characteristics and available radio resources.

Figure 7 demonstrates the performance gain achieved when we increase the FEC redundancy overhead ($R_o = h*100/k$). The number of satisfied users (S_U) increases, more quickly at low redundancy overhead levels and less quickly at higher R_o values. It is also highly dependent on the transmit power levels: increasing the transmit power overhead, the FEC gain varies within smaller ranges. $P_{tx-ref}\left(P_{txo}\right)$ is the reference transmit power value, which is considered in the forward link budget, and the other power overheads are measured in dBs with reference to P_{tx-ref} .

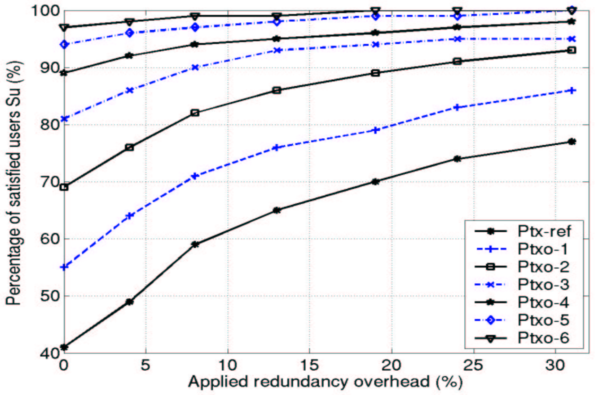

Figure 7: S_u variation with redundancy overhead for different transmit power levels; RMTP layer PLR 5%

VI SUMMARY AND FUTURE WORK

We have summarized the S-DMB system concept, the technical challenges faced in the system implementation and the role of the MoDiS project in this context. The focus of the paper was on the simulation platform that has been developed for the evaluation of the SDMB concept and the support of the MoDiS physical test bed.

We have described the individual components of this platform and the way they interface each other. The simulation objectives and scenarios were outlined and the initial results/ findings were presented.

The simulation activities will continue to see the completion of the simulation model development and investigate the system performance end-to-end, considering jointly the impact of reliable multicast protocol, RRM and outer interleaving depth, under different propagation environments. In the early experimentation phase with the physical test bed the simulation role will be supportive: the simulation outcomes will be compared with test-bed results and bi-directional calibration and validation will be done. From then on, the role of the simulations will become complementary: it will address system aspects that cannot be covered via experimentation with the physical test bed.

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