EMULATION OF TRANSMISSION LINKS FOR FUTURE S-UMTS CONSTELLATIONS: THE SUMO TESTBED

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Abstract:
In order to evaluate the performance of future S-UMTS constellation, a satellite channel emulator is being developed within the ACTS-SUMO project. With the emulator and the control software developed by the Centre for Communication Systems Research, it is possible to emulate a wide range of satellite constellations (LEO, MEO and GEO) and propagation environments (open, urban, wooded ...). Moreover, since the channel bandwidth is equal to 10 MHZ, it is possible to use the emulator to evaluate the performance of different modulations, channel coding techniques and multiple access schemes.

1. INTRODUCTION

Universal Mobile Telecommunications System (UMTS) and International Mobile Telecommunications-2000 (IMT-2000) are aiming at providing high data rate services with a high quality of service. As the provision of a global coverage is to be one of the main achievements of such third generation multimedia systems, the satellite component is foreseen to be a key component in the network structure. Accurate and realistic simulation of satellite transmission links is often very complicated due to the large number of different processes to take into account (satellite movements, Doppler effects, payload non-linearities ...). This complexity is further increased when the access scheme is based on code division and the interference coming from different sources needs to be evaluated precisely to obtain relevant capacity estimates. In order to alleviate these limitations and evaluate in real-time the performance of future satellite constellations for UMTS, a Satellite Channel Emulator (SCE) is being developed by the Centre for Communication Systems Research (CCSR) within the ACTS-SUMO [1] (Satellite-UMTS Multimedia Service Trials Over Integrated Testbeds)✓ project.

✓ SUMO consortium: Alcatel Space Industries (F), Telenor (N), Media Mobil (D), Nera (UK), University of Bradford (UK), University of Surrey (UK), University of Bremen (D), Marac (GR)

2. SUMO SYSTEM OVERVIEW

The SUMO project is aimed at identifying and demonstrating generic approaches to service support and network control, focusing on the satellite segment of UMTS networks. The main issues adressed by the project are:

- Interoperability between complementary satellite systems as well as with terrestrial core networks
- Automatic selection of alternative access network resources in an integrated UMTS system depending on services requested and the mobile communication environment
- Validation of the URAN approach to the different network components [2]
- Bandwidth on Demand (BoD) flexibility of communication channels for application services.

In order to evaluate the above features, an advanced testbed is being developed within the SUMO project. This testbed, presented in Figure 1 [3], is based on the work performed by the ACTS-SINUS [4] and ACTS-TOMAS projects.

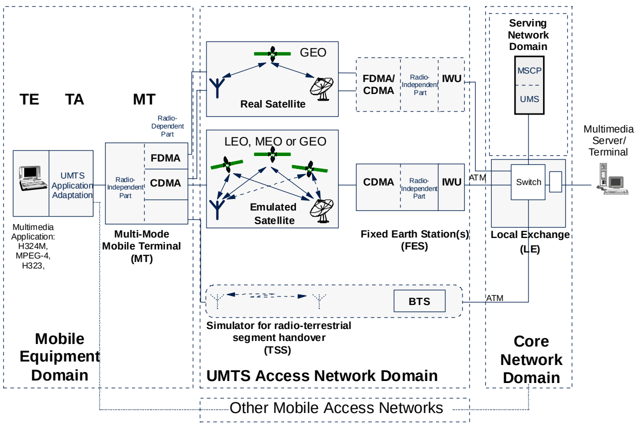

Figure 1: SUMO testbed

With the testbed, it will be possible to estimate the performance of different applications based on H324M and MPEG-4 as well as several protocol layers for different transmission environments (different satellite constellations, propagation environments, user terminals, ...).

3. SATELLITE CHANNEL EMULATOR

The SCE developed by CCSR at the University of Surrey allows the emulation of RF links for future S-UMTS constellations. The emulator is based on the NoiseCom platform and the control software has been completely developed by the CCSR. The SCE provides two full duplex links at an IF of 140 MHz. Thanks to the two full duplex links, the emulator can be used to evaluate the performance of transmission links with dual satellite diversity. It is also possible to perform hand-over tests (inter-spotbeam handover, inter-satellite handover and inter-segment handover). Since the SCE is a wideband channel emulator with a bandwidth of 10 MHz, it is possible to emulate transmission links with different modulations, coding techniques and multiple access schemes. Figure 2 presents the different functions that are implemented in the SCE and which will be presented in the next sections. The white boxes present the functions developed within the ACTS-SINUS project and the grey boxes identify the enhancements being implemented by the ACTS-SUMO project.

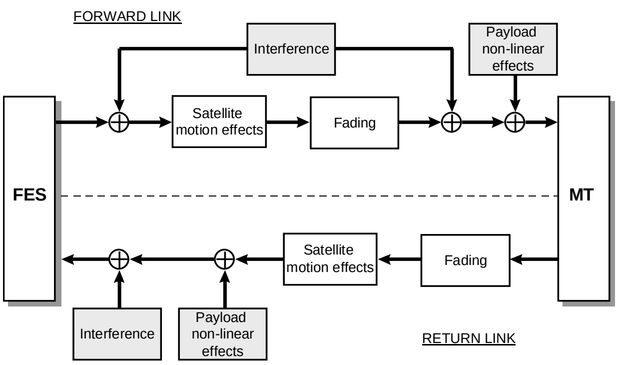

Figure 2: SCE architecture

3.1 Satellite motion effects

The dynamics of the satellite constellation will result in Doppler effect as well as variations in the path loss and transmission delay. Table 1 presents the Doppler and delay specifications for the SCE.

The maximum transmission delay being equal to 250 ms, it is possible to emulate with the SCE a large range of constellations from LEO orbits up to GEO orbits. Similarly the maximum Doppler values is high enough to simulate LEO constellation with carrier frequency values higher than 10 GHz.

Parameter	Performance
Delay range	2-250 ms
Delay resolution	16.7 ns
Delay accuracy	0.625 μs/msec
Doppler range	± 500 kHz
Doppler slew rate	1 kHz
Doppler accuracy	0.1 Hz

Table 1: SCE Doppler and delay specifications

3.2 Fading

In land mobile satellite systems, the variations of the received signal power induced by the propagation medium depend on a number of parameters such as the operational environment (open, urban, wooded, ...), the elevation angle as well as the azimuth angle. Nevertheless, in the modelisation of the channel, two separate processes, namely multipath fading and shadowing, are generally considered [5].

The shadowing process, due to the obstruction of the line of sight signal by building or trees, is modelled as a random variable with a lognormal distribution. The values of the mean and variance characterising the first order statistics of the shadowing process are calculated by the control software and then fed to the emulator. These parameters have been estimated for a wide range of propagation environments using the data collected by the CCSR [6]. The second order statistics of the shadowing characterise the time variation of the random process. Through the analysis of the available data, shadow models for the S-UMTS environment have been developed [7] and incorporated in the control software of the SCE.

Multipath fading is due to the combination at the receiver of the direct line of sight component (usually present in the satellite environment) with the diffuse paths resulting from reflections of the transmitted signals on surrounding objects. A wideband channel model, with a maximum number of three taps, has been implemented in the SCE to represent the multipath fading. The characterisation of the different paths in the multipath channel is performed using the approach presented in [8].

Table 2 presents the fading specifications for the SCE.

Parameter	Performance
Path loss range	0 to 40 dB
Flat fading range	0 to 40 dB
Attenuation resolution	0.5 dB
Attenuation accuracy	± 0.25 dB
Attenuation slew rate	50 dB/ms
Multipath delay spread	0-100 µs
Number of paths	3
Fading bandwidth	0-200 Hz
Ricean *K* factor	0-12 dB
Ricean *K* factor resolution	1 dB

Table 2: SCE fading specifications

When more than one satellite is visible from the mobile terminal, it is possible to receive replicas of the transmitted signal through different propagation paths. This technique, presented in Figure 3 and referred to as satellite diversity, helps combat the effect of both shadowing and multipath fading.

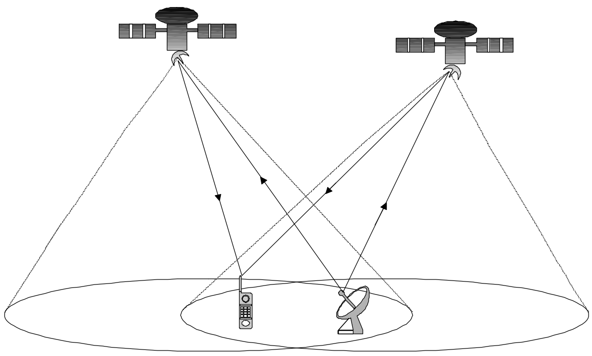

Figure 3: Dual satellite diversity scenario

As the mobile terminal moves from one location to another, the environmental properties change. However, although the channel characteristics vary over large areas, propagation experiments have shown that channel characteristics remain constant over areas with identical environmental features. Therefore, a land mobile satellite channel can be modelled with constant parameters over these areas. The channel characteristics over a large area of interest can be modelled by a finite state Markov model. Particular channel states are modelled as Ricean fading with different values of the *K* factor or as a combination of Rayleigh and lognormal fading. For the dual satellite diversity case, a four state Markov model is used as proposed in [9] (see Figure 4).

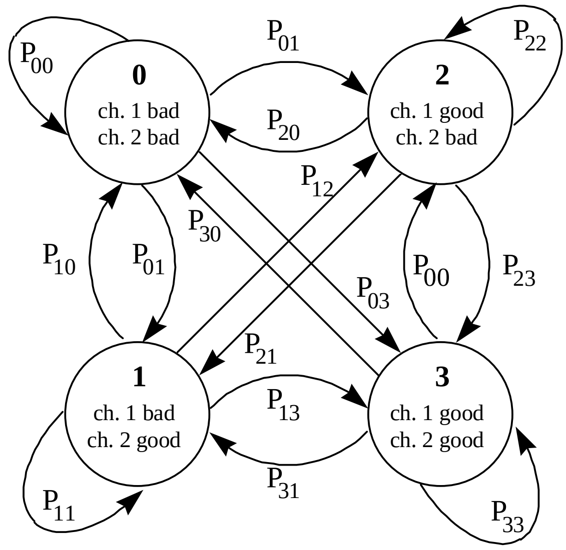

Figure 4: Four state Markov model

The performance improvement that can be achieved with dual satellite diversity depends on the correlation between the two propagation channels. If the probability of both links to be blocked at the same time is high, the use of satellite diversity will not significantly ease the system dimensioning. In order to measure this effect, the azimuth correlation of the shadowing has been calculated for different environments. These values are then used to define the transition probabilities of the Markov chain and implemented in the control software of the SCE.

3.3 Payload non-linear effects

One of the main functions of the satellite payload is the amplification of the signal power level. The input-output characteristics of an ideal amplifier is merely a coefficient of proportionality. In practice however, the output voltage does not vary in proportion to the amplitude of the input signal. High Power Amplifiers (HPA) generally exhibit two kinds of nonlinearities. First, there is a nonlinear input-against-ouput power relationship. Secondly, a nonlinear output-phase-against-input-power relationship can be observed. These payload nonlinearities will distort the transmitted signal and hence result in a performance degradation. The SCE models the impact of the payload nonlinearities on the transmitted signal by lowering the effective signal to noise ratio. Using the analytical model presented in [10], the performance degradation caused by the non-linear effects is estimated for different multirate spreading techniques [11] and different Input Back Off (IBO)-Output Back Off

(OBO) values. It is then possible to derive the optimum operation point of the HPA and the corresponding increase in power requirements over the pure AWGN channel. This result is then used by the control software to modify the carrier level in the SCE.

4. INTERFERENCE EMULATION

For CDMA systems, the different users share the same time and frequency medium. Every user is assigned a particular waveform to modulate the information data. Since the different signature waveforms are never fully orthogonal, CDMA systems will suffer from interference caused by the users present in the system. The interference will significantly impact on the transmission and needs to be taken into account when evaluating the link quality. Figure 5 presents the different sources of interference implemented in the SCE.

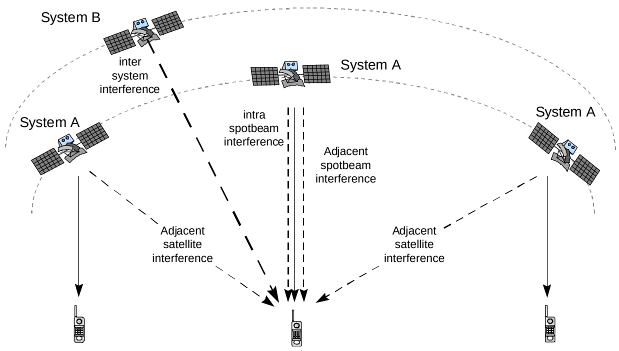

Figure 5: Sources of interference

The intra-spotbeam interference is caused by the users transmitting in the same beam as the user of interest. In the forward link, the inter-spotbeam originates from a single source (the FES) and the signals of the different users are therefore synchronised. Hence, by using spreading sequences with low cross-correlation properties, it is possible to keep the forward link intra-spotbeam interference to a minimum. On the other hand, in the return link, the different users are scattered all over the spotbeam coverage area and alignment of the different signals is usually very difficult to achieve. Hence, the intra-spotbeam interference can not be neglected in the return link.

The spreading/despreading operations improve the resistance of CDMA signals to interference and make it possible to reuse the same frequency carriers in adjacent spotbeams. The adjacent spotbeam interference therefore corresponds to the signals of the users that are communicating with the reference satellite. The level of adjacent spotbeam interference mainly depends on the satellite antenna gain pattern.

When non-GEO satellites are considered and in order to support inter-satellite hand-over, the coverage area of the different satellites in the constellation will overlap. This results in adjacent satellite interference.

Since spread spectrum signals are more resistant to interference, it is also possible for CDMA systems to operate within the same frequency bandwidth [12]. Hence, the SCE also takes into account the possibility of different constellations sharing the same frequency resource by incorporating inter-system interference calculations.

Because of the dynamics of the satellite constellations, the interference level varies with time. Figure 6 plots the *C/(N+I)* ratio for a typical LEO system over a thirty minute run.

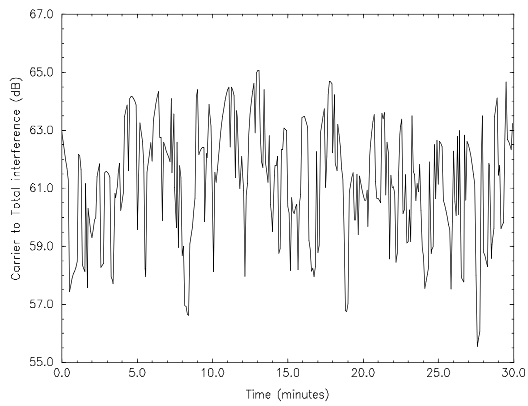

Figure 6: C/(N+I) time series

It can be seen from Figure 6 that the dynamic range of the *C/(N+I)* is of the order of 10 dB. These large variations of the signal to noise ratio will affect the performance of all the different tracking algorithms, such as power control, and therefore need to be implemented in real-time in the SCE. The chosen approach is presented in Figure 7.

The whole SCE is controlled by a Pentium PC where all the simulation software resides. Using a TCP/IP connection, the control PC provides in real-time the Satellite Link Emulator (SLE) with the parameters characterising the transmission delay, the Doppler effect and the path loss. The Multi-Path

(MP) units emulates both the shadowing and the multipath fading. The parameters characterising the statistics of these processes (mean and variance for the lognormal fading, power and *K* factor of the different fast fading paths ...) are calculated by the control software and fed to the MP via GPIB. A noise source is used to represent both the noise and the interference. Both interference and thermal noise are generated with the same noise generator but they are injected at different points of the emulator. The level of the noise at the different insertion points is changed dynamically according to the *C/I* variations through step attenuators controlled through GPIB by the PC.

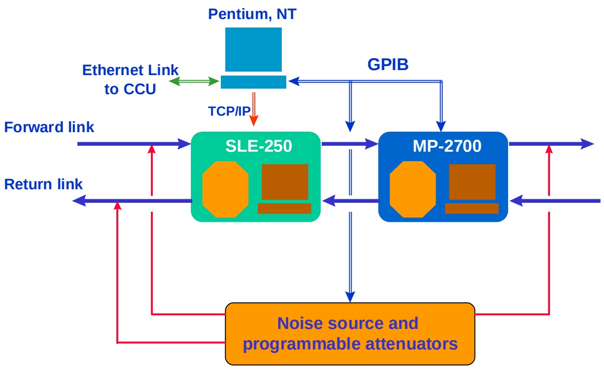

Figure 7: SCE Hardware

5. Summary and Conclusions

The specifications of the SCE developed by the CCSR for the ACTS-SUMO project have been presented in this paper. The SCE includes all the phenomenon impairing satellite links (path loss, delay, Doppler, fading, payload nonlinearities, interference, ...) and is capable of emulating any S-UMTS constellation.

In the ACTS-SUMO project, the SCE will be used to evaluate the performance of different multimedia applications. It is also interesting to note that *live* trials using the EMS payload have also been planned. It will therefore be possible to compare the results obtained with both the emulator and the real satellite and validate the testbed.

6. References

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