# IMPLEMENTATION OF MULTIPLE ACCESS INTERFERENCE AND PAYLOAD NON-LINEARITY IN REAL TIME SATELLITE LINK EMULATION
# (EMPS2000)

**K.Narenthiran, H.M.Aziz, C.Valadon, R.Tafazolli and B.G.Evans**

***Mobile Communications Research Group, Center for Communication System Research,***
***University of Surrey, Guildford, Surrey GU2 7XH, UK***
***Email: K.Narenthiran@eim.surrey.ac.uk***

## ABSTRACT

A method of introducing multiple access interference and payload non-linearity in a real time satellite link emulation is proposed. The concept is to inject controlled Additive White Gaussian noise into the satellite communication link to represent the impact of interference and payload non-linearity. This paper explains how to determine the amount of noise contribution from the interference and payload non-linearity and how to integrate with propagation channel model.

## 1 INTRODUCTION

Mobile satellite communication link (MSCL) experiences multipath propagation, fading, pathloss, varying Doppler and varying time delay, multiple access interferences and payload non-linearity effects. These link impairments have impact on performance of the MSCL. Therefore there is a need for an laboratory equipment with the MSCL model to design system components of a mobile satellite system. Such type of equipment, called satellite channel emulator (SCE) was developed in the European ACTS SINUS/SUMO projects [1,2] to study the impact of link impairments on multimedia applications in terms of quality of service (QoS).

This paper describes the implementation of multiple access interference and payload non-linearity in a real time satellite link emulation by injecting controlled additive white Gaussian noise into the MSCL. The noise contribution from the interference is calculated based on the signal to interference ratio, which comes from the interference simulation with a specified satellite constellation and number of users scattered in the spotbeams. The noise power contribution from the payload non-linearity is based on the input back-off (IBO) of the HPA. The IBO is calculated using the users distribution under the particular footprint and the signal distribution of the individual users due to the environment changes with time. The hardware requirements for the implementation are noise generator, power level controller with controller PC.

## 2 MULIPLE ACCESS INTERFERENCE

The CDMA systems experience multiple access interference due to the cross correlation among the spreading sequences. When de-spreading the received signal, the unwanted signals become gaussian noise, since the different signature waveforms are never fully orthogonal. This interference will significantly impact on the link quality. Fig.1 presents the different sources of interference in the mobile satellite systems. The amount of multiple access interference received from each source will be estimated taking the following information into account.

- Satellite constellation
- Mobile terminal position
- Satellite spot beam/antenna pattern
- Mobile Antenna pattern
- Land mobile satellite channel
- Distribution of users

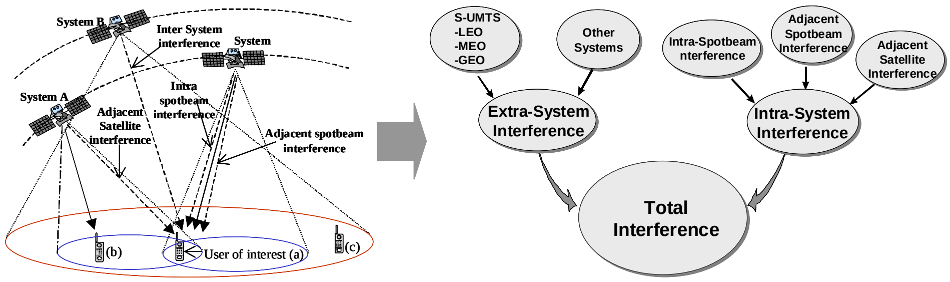


Fig.1: Sources of interference

### *2.1 Forward and return links implementation differences*

The interference calculations are performed following the same approach for both the forward and the return links. However, two differences have to be considered. Firstly, in the forward link, users in the same spotbeam as the user of interest have synchronous transmission. Hence, by using low cross-correlation spreading codes within one beam, the intra-spotbeam interference can be significantly reduced. This is not the case in the return link where the different users transmit independently from one another. Therefore intra-spotbeam interference is considered in the return link and not considered in the forward link. Secondly, in the forward link, the user of interest will see interference from the adjacent satellite as well as the satellite in the other constellation. Since there is only one source for the interfering signals (all the signals come together from the satellite), the user of interest will suffer from the interference from all the user traffic carried by the adjacent satellite as well as that of the satellite in the other constellation. However, in the return link, since the interfering sources are spread over the different coverage areas and thanks to the directivity of the satellite antenna (high spotbeam isolation), the interference from users (b) and (c) can be considered null.

### *2.2 Interference simulation model*

Interference occurrence with different terrestrial landmarks, are shown in Fig.2. Interference level depends on the type of environment (Urban, suburban ect.). Basic simulation model (Fig.3) for interferences has been developed to represent the environmental obstacles as shown in Fig.2 with the help of different environmental channel models ($Fad_{FLk}$ & $Fad_{RLk}$). Equations (1,2 and 3) represent $C/(N_0+I_0)$ in three noise injection points (Inj=1, 2 , 3) shown in Fig.12.

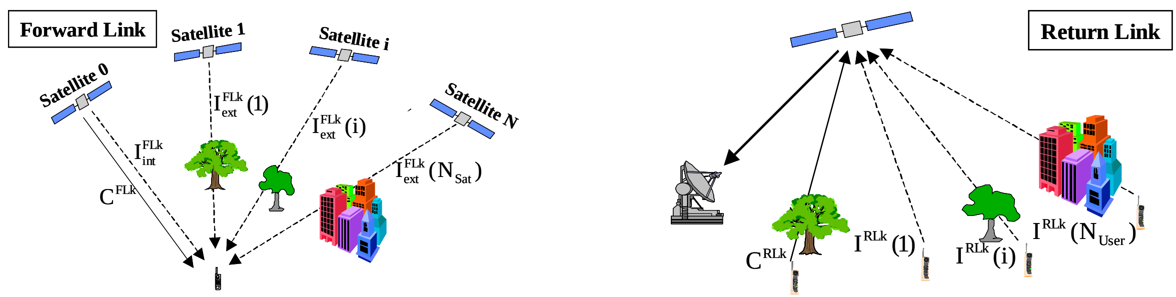


Fig.2 : Channel condition with the signal and interferences

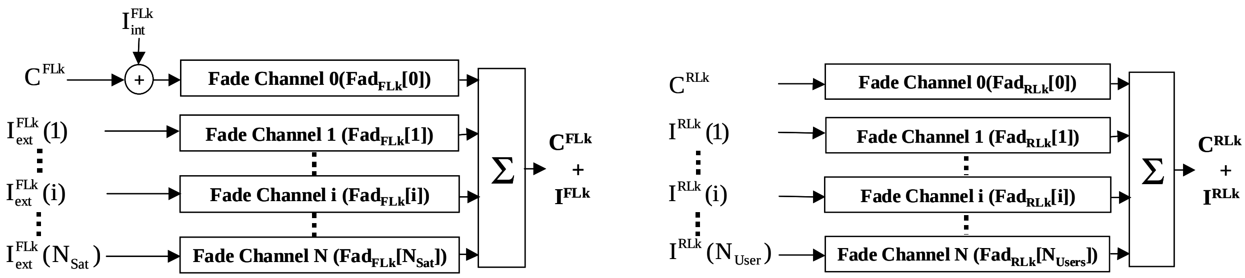


Fig.3 : Interference simulation model

$$\left[C/(N_0+I_0)\right]_{\text{Inj}=1} = C_{\text{FLk}} / I_{\text{int}}^{\text{FLk}} = C_1 / I_0^1 \tag{1}$$

$$\left[C/(N_0+I_0)\right]_{\text{Inj}=2} = C_{\text{FLk}} \times \text{Fad}_{\text{FLk}}[0] / \left( \sum_{i=1}^{N_{\text{Sat}}} I_{\text{ext}}^{\text{FLk}}(i) \times \text{Fad}_{\text{FLk}}[i] \right) = C_2 / \left(I_0^2 + N_0\right) \tag{2}$$

$$\left[C/(N_0+I_0)\right]_{\text{Inj}=3} = C_{\text{FLk}} \times \text{Fad}_{\text{RLk}}[0] / \left( \sum_{i=1}^{N_{\text{User}}} I_{\text{RLk}}(i) \times \text{Fad}_{\text{RLk}}[i] \right) = C_3 / \left(I_0^3 + N_0\right) \tag{3}$$

Using the above simulation models, the $C/(N_0+I_0)$ is calculated for different constellations (LEO, MEO and GEO). LEO-48 simulation result is shown in Fig.4 for equation (2) with time. Full detail about the interference calculations is available in [3].

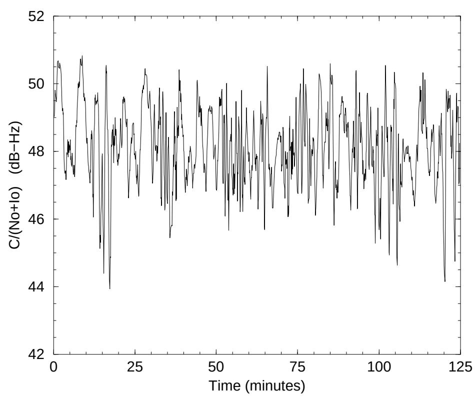


Fig.4 : Carrier to interference ratio

## 3 PAYLOAD NON-LINEARITY

Since the signal from different users are added and transmitted through high power amplifier (HPA), the HPA reaches the saturation region in the event of overload. This leads to the amplitude and phase distortion of the signal transmitted through the HPA (Fig.5). This is called payload non-linearity effect. HPA generally exhibits two kinds of nonlinearities. First, there is a nonlinear input against output power (AM/AM) relationship. Secondly, a nonlinear output phase against input power (AM/PM) relationship can be observed. This effect is high in CDMA access techniques compare to TDMA or FDMA, since the user signals are added together and transmitted on the same time-frequency medium. Fig.6 shows the situation where the operating point of the HPA is pushed into the saturation region.

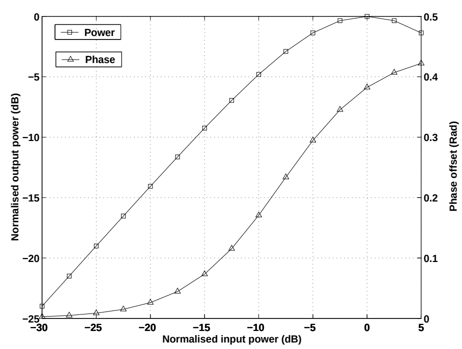


Fig.5 : HPA Characteristics

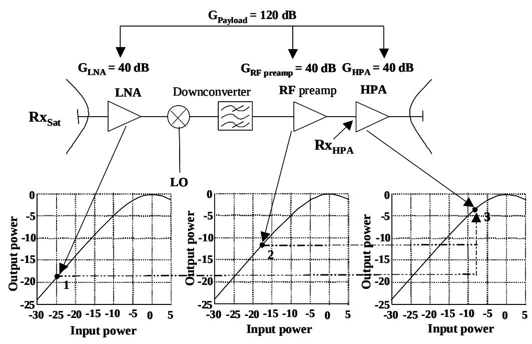


Fig.6 : Repeater architecture

### 3.1 Selection of High Power Amplifier Model

The assessment of the payload nonlinearities on the transmission quality calls for a HPA mathematical models. Due to the simplicity and good accuracy compares to other models [5,6], Saleh model [4] based on polynomials is selected. The input and output signal can be expressed by the equations (4) and (5) respectively.

$$x(t) = r(t)\cos(\omega_0 t + \psi(t)) \tag{4}$$

$$y(t) = A[r(t)]\cos(\omega_0 t + \psi(t) + \phi[r(t)]) \tag{5}$$

$\omega_0$ is the carrier frequency and $r(t)$ and $\psi(t)$ are the modulated envelope and phase, respectively. $A(r)$ is an odd function of $r$, with a linear leading term representing the AM/AM conversion, and $\phi(r)$ is an even function of $r$, with a quadratic leading term representing the AM/PM conversion. The Saleh model represents these two quantities given by the equations (6) and (7) respectively:

$$A(r) = \alpha_a r/(1+\beta_a r^2) \tag{6}$$

$$\phi(r) = \alpha_\phi r^2/(1+\beta_\phi r^2) \tag{7}$$

Table 1 presents the parameters of the Saleh model corresponding to the Hughes 261-H tube model.

Table 1: Hughes 261-H tube model

| Parameter | $\alpha_a$ | $\beta_a$ | $\alpha_\phi$ | $\beta_\phi$ |
|---|---|---|---|---|
| Value | $1.6623\times 10^3$ | $5.52\times 10^4$ | $1.533\times 10^5$ | $3.456\times 10^5$ |

### 3.2 Payload non-linearity simulation model

Fig.7 shows the simulation model for the payload non-linearity. The HPA parameters in Table 1 were used for simulation. In order to see the bit error performance of the payload non-linearity, BER with payload non-linearity for different value of IBOs, without payload non-linearity and theoretical values were calculated. The results are shown in Fig.8 (a). The simulation model is validated by comparing the simulation result with theoretical result for thermal noise only. The rest of the curves shown in the Fig.8 are like BER performance of the modulation scheme with noise only. This observation leads to the concept of injecting additional noise into the communication signal, in order to introduce the payload non-linearity effect in the satellite link. The additional noise required to represent the payload non-linearity is given by equation (8).

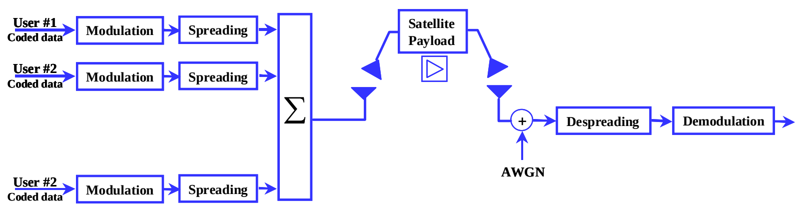


Fig.7 : Payload Non-Linearity Simulation model

$$N_{amp}[\text{dBm}] = N_0[\text{dBm}] - (E_b/N_{amp})_{Payload\ non\text{-}linearity}/(E_b/N_0)_{Noise\ only}[\text{dB}] \tag{8}$$

Using the BER performance of the payload non-linearity (Fig.8), the second element in the right hand side of the equation (8) has been found for different BER and IBO. The result is given in Fig.9. According to the variation of the number of users in a particular footprint and the payload architecture (Fig.6), the total signal to HPA can be calculated assuming that the signals from unblocked users experience only pathloss and the signals from blocked users experience pathloss and lognormal fading. Then the additional noise required for payload non-linearity can be calculated using the data from Fig.9 and equation (8).

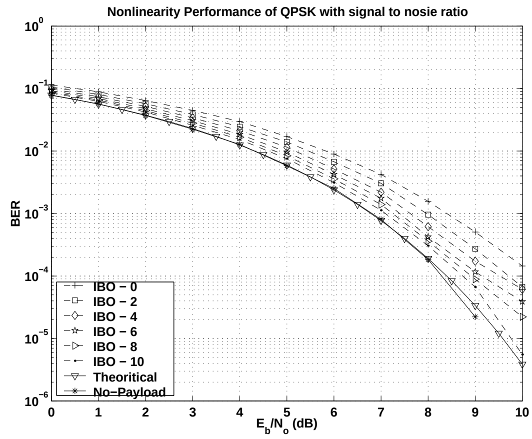


Fig.8 : Non-linearity performance of QPSK

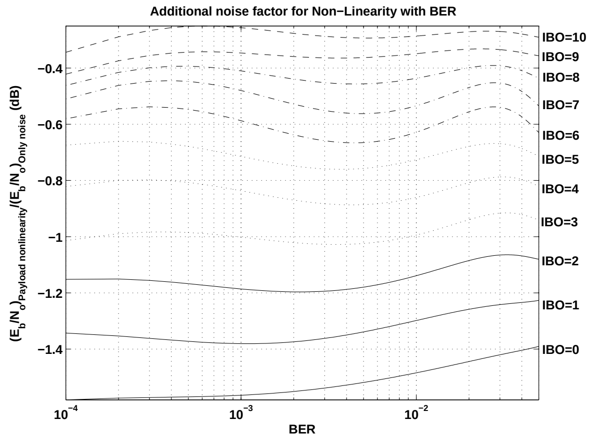


Fig.9 : Additional noise factor for non-linearity

## 4 IMPLEMENTATION

As explained in the previous two sections, the software calculates the noise level for the multiple access interference and the payload non-linearity effects. The whole process is explained in Fig.10. With the input parameters shown in Fig.10, the interference simulation model finds the addition of interference and noise $\left(I_0^1, I_0^2 + N_0, I_0^3 + N_0\right)$ at the three noise injection points (Inj=1,2,3) and the payload non-linearity simulation model computes the noise contribution $N_{amp}$ from the payload at two noise injection points (Inj=2,3). It has been assumed that traffic load is equal through forward and backward HPAs. Combination of interference contribution, payload contribution and thermal noise gives the total noise required at each noise injection points in the test-bed (Fig.11). These noise values are finally converted into control digital signals of the noise controller. The hardware arrangement is shown in Fig.12. Here, the noise controller is controlled by a controller PC. Controller PC has the combined software of channel simulator, Interference simulator and payload non-linearity simulator.

## 5 CALIBRATION

After the whole test-bed is arranged as shown in Fig.11, the communication signal power at each noise injection points (Inj=1,2,3) have to be measured using the power meter or spectrum analyzer (say $C_1$, $C_2$, $C_3$). Using these measured values and equations (1,2,3) the actual noise required at three noise injection points ($N_1$, $N_2$, $N_3$) can be calculated. The values are given in equations (9,10,11). Where “W” is communication signal bandwidth.

$$N_1 = W\left(I_0^1\right) \tag{9}$$

$$N_2 = W\left(I_0^2 + N_0 + N_{amp}\right) \tag{10}$$

$$N_3 = W\left(I_0^3 + N_0 + N_{amp}\right) \tag{11}$$

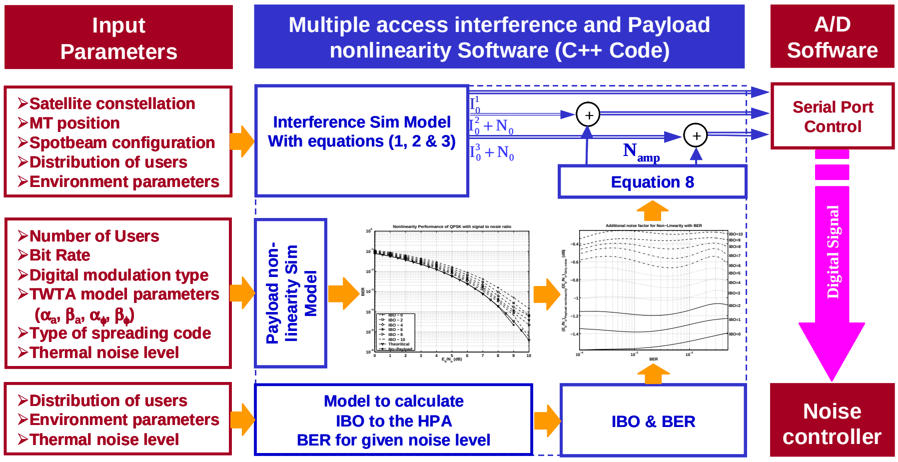


Fig.10 : Software Implementation

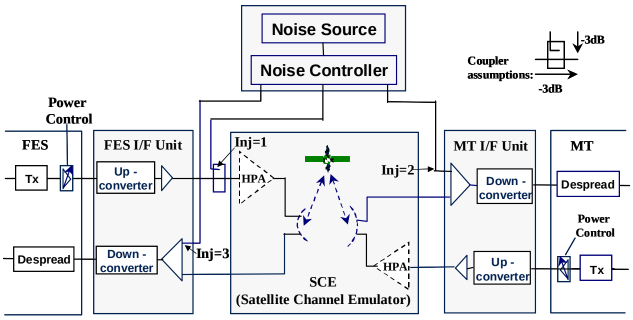


Fig.11 : SUMO test-bed arrangement

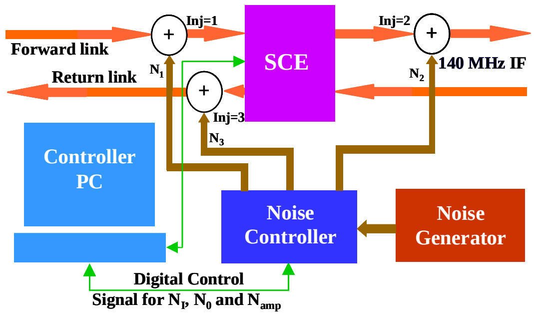


Fig.12 : SCE arrangement

## 6 SUMMARY

The concept of injecting additive white gaussin noise into satellite communication link to represent the interference and payload non-linearity effects was introduced. Implementation procedure of this concept in real time link emulation is also explained with simulation models and hardware arrangements. The Satellite Channel Emulator is the most comprehensive space segment emulation system capable of emulating dynamic real time land mobile satellite channel in a laboratory environment. Integration of the interference and payload non-linearity effects with SCE further enhances the capability of the equipment. Therefore the manufactures would be able to test and optimize performance of the User Terminal and Fixed Earth Station under more realistic conditions.

## REFERENCE


[1] P.Taaghol, H.M.Aziz, K.Narenthiran, R.Tafazolli and B.G.Evans; "A real-time dynamic space segment emulator", *IMSC-1999*, Hull Canada.

[2] H.M.Aziz, C.Valadon, K.Narenthiran, R.Tafazolli and B.G.Evans, "Emulation of transmission links for future S-UMTS constellations: the SUMO testbed", *IEEE VTC*, 1999-Fall Amsterdam.

[3] H M Aziz, R Tafazolli and B G Evans, "Band Sharing Between CDMA Based Non-GEO Satellite-PCNs", *IEE 5th Intl. Conf. Sat. for Mobile Com. and Navigation*, London, May 1996.

[4] A.A. Saleh, "Frequency-Independent and Frequency-Dependent Nonlinear Models of TWT Amplifiers", *IEEE Trans. Commun.*, vol. 29, no. 11, Nov. 1981.

[5] P. Hetrakul, D.P. Taylor, "Nonlinear Quadrature Model for a Travelling-Wave-Tube-Type Amplifier", *IEE Electronics Letters*, vol. 11, no. 2, Jan. 1975.

[6] S.Benedetto, E.Biglieri, R.Daffara, "Modeling of nonlinear satellite links-A Volterra series approach", *IEEE Trans. on Aerospace and Electronic Systems*, vol. 15, no. 4, July 1979.