COMMUNICATION PERFORMANCE SIMULATION FOR THE ASIA CELLULAR SATELLITE SYSTEM

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ABSTRACT

Mobile Satellite Systems (MSS) are offering a solution to increased demand for cellular communications in developing areas of the world. The Asia Cellular Satellite System (ACeS) is a regional MSS being developed by Lockheed Martin Corporation (LMC) to provide such communication to Asia. Based on one geostationary satellite, the ACeS System has a variety of communication services for which System Engineering & Test (SE&T) at LMC's Management & Data Systems (M&DS) Division is responsible for ensuring adequate performance. These services carry such information as speech signals, data signals, and control signals. This paper describes the methodology and the communication simulation tools which SE&T engineers have developed and are using to ensure adequate performance.

INTRODUCTION

In the past several years, the market for cellular communications has dramatically increased. In developing areas of the world like, Southeast Asia, however, terrestrial expansion of cellular systems has not been sufficient to meet the demand. Satellite-based cellular systems offer a possible solution to this demand. The Asia Cellular Satellite System (ACeS) is one such system.

ACeS, a GSM-based geostationary satellite system for providing mobile voice and data telecommunications in the Asian region, is currently being developed by the Lockheed Martin Corporation (LMC). ACeS has the advantage of springboarding from the well-established GSM cellular interface standard, while providing some additional features. It provides for operation with GSM networks to support inter-network roaming. It incorporates several high penetration signals to support handsets in disadvantaged environments for both broadcasting information and paging.

The multi-faceted system involves the transmission of speech signals, data/fax signals, and control signals from a Mobile Handset across a geosynchronous satellite to a Gateway Station / Network Control Center or from a Gateway Station / Network Control Center across a geosynchronous satellite to a Mobile Handset. The Gateway Stations interface with the public telephone network. The system also supports handset-to-handset calls via a single satellite hop to minimize long-haul routing charges. The gateway to handset direction is referred to as the forward link; the handset to gateway direction is referred to as the return link. The radio links between the gateway and the satellite are at C-Band; the links between the handset and the satellite are at L-band. An overview of the ACeS System is provided in Figure 1.

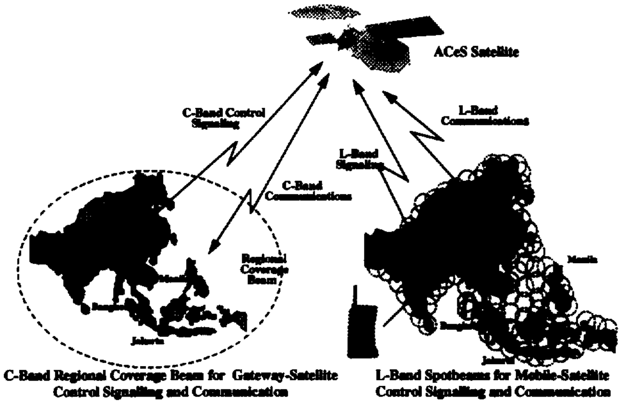

Figure 1: Overview of the ACeS System

System Engineering at LMC's M&DS is responsible for ensuring adequate communication performance of the many communication services associated with the ACeS System. The end-to-end communication signals are enumerated in Table 1. Note that FWD implies a forward link and RTN implies a return link. Table 2 illustrates the performance metrics used for these services, where MOS refers to Mean Opinion Score, BER refers to Bit Error Rate, and FER refers to Frame Error Rate. Lockheed Martin Commercial Communications Analysis Team has developed a methodology consistent with the ACeS System Specification for assessing the end-to-end performance of these services. To facilitate the performance analysis efforts, the Team has additionally generated a library of communication models and architectures which have already been used to assess end-to-end performance of many of the services in a variety of fading/interference scenarios.

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Service	Naming Convention	Links
Basic Speech	TCH/QBS	FWD/RTN
Robust Speech	TCH/HRS	FWD/RTN
Basic Data/Fax	TCH/Q2.4	FWD/RTN
Dedicated Control	SACCH / SDCCH / FACCH	FWD/RTN
Broadcast/Common Control	BCCH / AGCH / PCH	FWD
Broadcast Control	SCH	FWD
High Margin Control	HMSCH / HBCCH / HPACH	FWD
Common Control	RACH	RTN

Table 1: Communication Services for ACeS System

Service	Performance Measure
Basic Speech	MOS
Basic Data/Fax	BER
Broadcast Control	FER
High Margin Control	FER
Common Control	FER

Table 2: Communication Performance for ACeS System

METHODOLOGY

System, segment, and interface specifications formulate the basis for the assessment of end-to-end link performance. In the performance methodology, consistent with M&DS SE&T methodology, the communication specification parameters are flowed into an assessment of the power-side of end-to-end link performance and an assessment of the distortion-side of end-to-end link performance. A flow diagram of the methodology is illustrated in Figure 2.

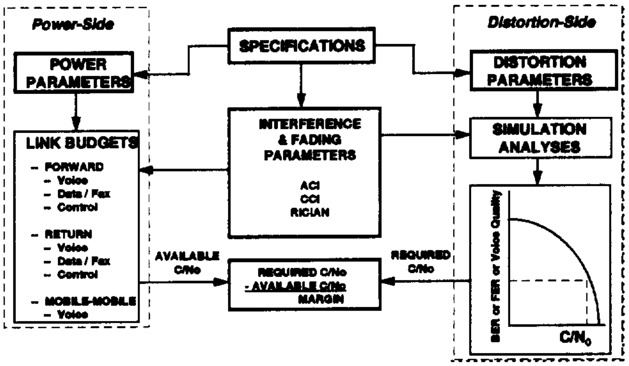

Figure 2. End-to-End Performance Methodology

The power-side assessment handles specifications which affect the strength of the overall signal-to-noise ratio, like EIRP, G/T, noise figure, propagation loss, etc. Analysis of the power-side is normally performed with a link budget, which is used to determine the overall signal-to noise ratio (C/No) of the end-to-end link that is available with the specified communication parameters.

The distortion-side assessment handles specifications which affect the characteristics of the signal that is transmitted, like the modulation scheme, filter responses, phase noise, and accuracy of phase/time recovery. Analysis of the distortion-side is normally performed with a Monte Carlo simulation of the end-to-end link, in which the signal and any elements of the specification/design which may have a deleterious effect on the signal are modeled. These simulations are used to generate performance curves for BER in the case of speech and data, or FER in the case of control signals, as a function of C/No. Since specifications normally provide a required operating point for BER or FER, the performance curves are used to indicate the C/No that is required to meet this operating point.

SIMULATION MODELING OVERVIEW

To handle the multitude of links produced among forward/return scenarios, different communication services, different fading environments, and different interference environments, a number of simulation models have been developed to aid in the distortion-side analysis. The Cadence Design Group tool referred to as the Signal Processing Workbench (SPW) has been used as the basis for communication simulation work to date. The purpose of these models is to simulate each of the services/links described in Table 1.

As such, there are two basic architectures for the simulation models: a forward architecture and a return architecture. The variety of simulation models needed to support the eight services listed in Table 1 have been obtained by customizing the front- and back-end encoding/interleaving/ burst-formatting and burst de-formatting/deinterleaving/ decoding schemes of the basic forward/return architectures for each service. Figures 3 and 4 depict the basic architectures used to formulate the simulation models.

The forward architecture consists of a gateway transmitter which produces a modulated signal with a burst rate that is the same as the GSM burst rate. This burst rate corresponds to 156.25 bits being transmitted every 0.577 msec. This C-Band FDMA/ TDMA-bursted signal passes through a spacecraft segment channelizer which routes it to the appropriate L-band frequency channel. Before it is received by the L-band handset, this signal may be impaired with a Rician fading environment and adjacent/co-channel interference.

The return architecture consists of a handset transmitter which produces a modulated signal with a burst rate that is a fraction of the forward link. The forward/return link

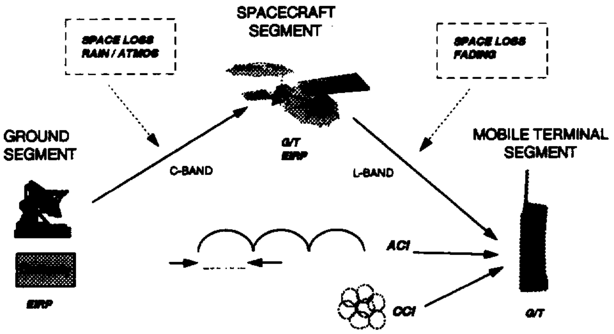

Figure 3. Forward Link Architecture

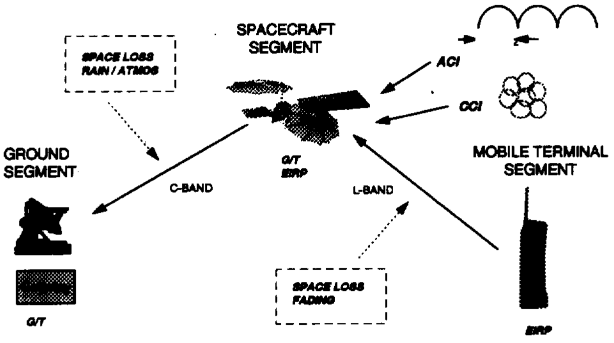

Figure 4. Return Link Architecture

asymmetry helps in prolonging the handset's battery life, as well as maintaining the power emissions within environmentally-acceptable human limits. This FDMA/ TDMA-bursted signal may be impaired by the Rician-fading and adjacent/co-channel interference on its L-band link to the satellite. It similarly passes thru the satellite channelizer for routing to the appropriate C-band channel, and is finally received at C-band by the gateway. Note that in the forward/return FDMA/TDMA structure, although the timeslots for the return structure are longer than those of the forward structure, the return architecture is designed to provide for multiple frequency subchannels for each forward frequency channel. This ensures that the forward and return structures are capable of servicing the same number of FDMA/TDMA users, while providing the benefit of a reduced burst rate to the handset for minimizing peak-to-average power ratios.

Figures 5 and 6 provide block diagrams of the basic forward and return simulations. Because TDMA-structured communications is based upon transmitting packets of data in defined timeslots, data transmission and reception involves operating on blocks of information which fit onto these timeslots. As such initial blocks of information are encoded to fit onto an integer number of bursts or timeslots. The size of an initial information block and the number of bursts on which the final encoded information block is transmitted depend on the service.

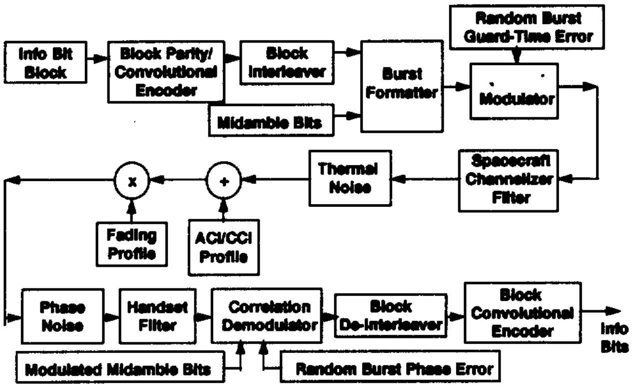

Figure 5. Forward Link Simulation Block Diagram

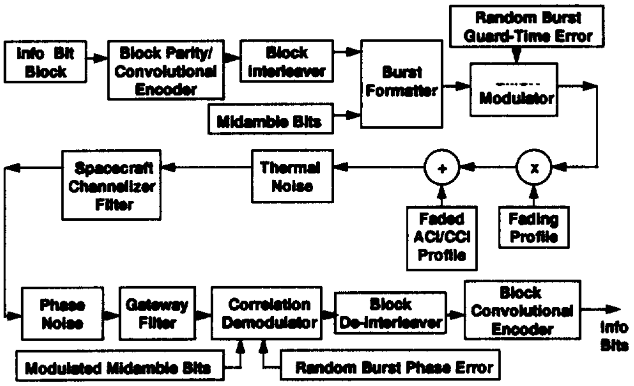

Figure 6. Return Link Simulation Block Diagram

The flow through the simulation architecture is as follows. An information block, composed of uniformly distributed 1's and 0's, is typically encoded with some form of a parity code (CRC or Fire) to flag message errors at the receiver, followed by a convolutional code to provide protection against errors introduced by thermal noise and intersymbol interference. The encoded message bits are then interleaved to combat against fading. Interleaving is typically of a block-diagonal form to increase the span. The interleaved bits are subsequently placed on the portions of the burst which are allocated for data. The basic formats of the bursts used for the ACeS services/ simulations are based on modified GSM burst formats. They consist of data-carrying bits and guard bits. The data-carrying bits include a midamble surrounded by information-carrying bits and tails bits. The midamble bits are used for demodulation, the information-carrying bits hold the encoded/interleaved data, and the tail bits serve as a pad to allow for power ramping. The burst formatting model also incorporates a uniformly-distributed error for placing the predefined bits within the guard bits. The burst-formatted information is then modulated to produce 4 complex samples per bit.

In the forward simulation, the modulated signal passes through a point data filter representing the channelizer of the spacecraft. The point data essentially models an FIR filter with a linear phase response. Thermal noise, in the form of additive white Gaussian noise, is then added to the signal based on a parameter-defined C/No setting. The noise is incorporated after the channelizer filter, which represents the L-band portion of the architecture or the limiting link. After the addition of noise, a pre-defined file of adjacent and co-channel interferers (ACI/CCI) may also be added to the signal. The interference profiles are simulated outside of the basic architectures to reduce simulation runtime. The resulting signal is then AM-modulated with a fading profile. The fading profile represents the effects of the handset's L-band propagation environment. The fading profile is generated outside of the basic architectures, so that it may be slotted to correspond to the ACeS TDMA structure; this technique allows the simulation to operate with a continuous burst structure, and also improves runtime. The Rician fading profile is produced by adding a direct path to a Rayleigh-faded profile which is 9 dB from the direct path. At this point, the signal enters the receiver.

In the return simulation, the modulated signal is first AM-modulated with a fading profile, since the handset's L-band link precedes the spacecraft. A profile of independently-faded ACI/CCI may also be added to the signal. Note that unlike the forward architecture, the interferers are independently faded. Thermal noise of a parameter-defined C/No is then injected onto the resulting signal. The signal passes through the channelizer filter (represented by point data, as discussed for the forward architecture) before entering the receiver.

The receiver architectures of the forward and return simulations are similar. Phase noise, correlated over the signal bandwidth, is introduced on the signal; the amount of phase noise induced represents the composite of the phase noise contributions from the handset, satellite, and gateway segments. The signal is subsequently filtered with a handset or gateway filter to limit ACI and reduce noise. The filtered signal is burst-demodulated with a correlation receiver which provides phase-recovery and time-alignment on a burst-by-burst basis via correlation of the received midamble sequence with an undistorted version of the modulated midamble sequence. The data bits are subsequently sampled, stripped from the burst format, deinterleaved, and finally decoded. With the decoding operation complete, the parity bits are checked for message or frame errors and the decoded bits are compared to the original sequence for bit errors. In this way, each forward and return simulation can be executed to provide a performance curve of BER or FER as a function of Burst C/No. To achieve this capability, well over 100 custom-coded simulation models and specialized architectures have been developed.

SIMULATION RESULTS

Figures 7 through 10 illustrate some performance curves which have been obtained from the various simulation architectures. These figures are intended to provide a sample of the types of information which can be obtained from the simulation. Figure 7 shows the channel error rate performance for the forward and return channels in both an AWGN and mobile fading environment, where 2 km/hr represents walking speed. With the same demodulator, the forward architecture outperforms the return. The fading environment has detrimental effects. Note that Burst C/No is determined by factoring burst rate into the Eb/No. Figure 8 indicates the performance of the data/fax service in a return architecture. In an AWGN environment, these curves indicate that a 3-dB Eb/No is needed to achieve a typical BER of 10^{-5}. At that performance level, approximately 1.5 to 8.0 dB of margin is needed for operation in a fading environment from 3.5 to 15 km/hr. As speed decreases, more margin is needed for fading, because the interleaver is less likely to combat the duration of the fade. Figure 9 provides the performance of the return SACCH/SDCCH/FACCH service. These curves indicate that approximately 5 additional dB of Eb/No is needed to maintain perfomance in a 9-dB Rician environment; more is necessary in a 6-dB Rician environment. Figure 10 finally illustrates the performance of the basic speech service in a return architecture. Within a speech frame, different bits receive different coding protection. The important Class I/II bits receive more coding than the Class III bits.

FUTURE WORK

The simulation capability for the Lockheed Martin Commercial Communications Analysis Team will continue to grow and develop. Future plans include the development of a burst receiver with Maximum Likelihood Sequence Estimator and other enhancements for demodulation. A plan is also underway to provide common documentation and configuration management of the current models and architectures. These models and architectures will continue to be used to support ACeS, and will also be modified, as well as embellished, to support other such initiatives in the telecommunications business area.

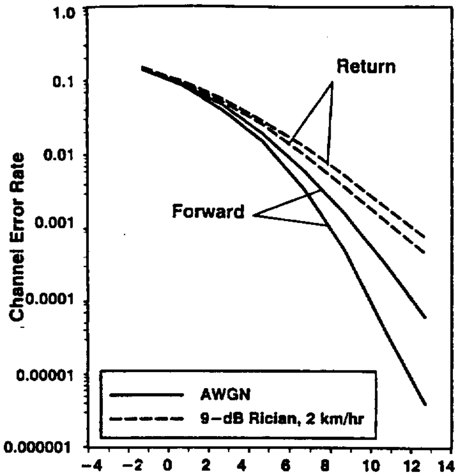

Figure 7. Pre-Decoder Performance w/o ACI/CCI

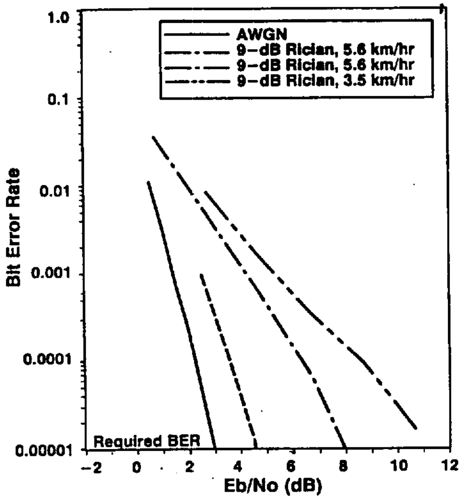

Figure 8. Data/Fax Performance w/o ACI/CCI

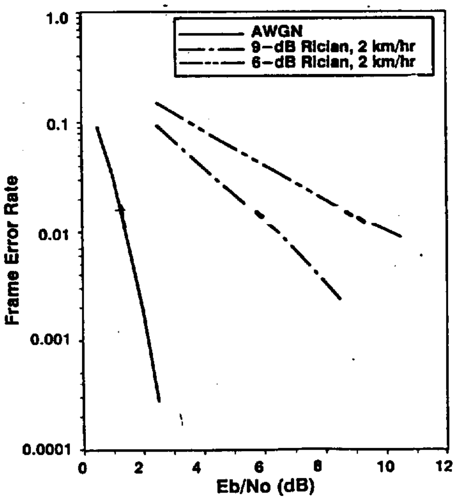

Figure 9. BCCH/AGCH Performance w/o ACI/CCI

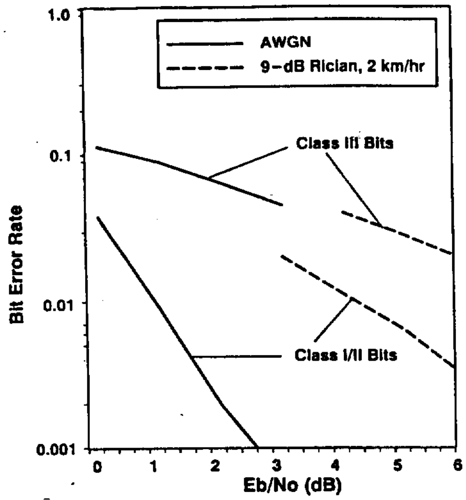

Figure 10. TCH/QBS Performance w/o ACI/CCI

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