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SATELLITE COMMUNICATIONS REPRESENTATION IN NETWORK SIMULATION

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ABSTRACT

This paper presents methodologies to represent satellite communications (SATCOM) behaviors in network simulation. This paper is based on tasks performed for generic network warfare simulation that employs traditional network simulation models. The methodologies also include the integration issues of SATCOM tools and the network simulation models. We first characterize space segments and assets involved in warfare operations and exercises, and then analyze system behaviors to measure space-link performance design results. The techniques adopted in effect will augment traditional network models with SATCOM capabilities through specialized satellite analysis models. The SATCOM tools produce detailed satellite orbit characteristics and radio frequency (RF) performance analyses for public and commercial satellites with multiple microwave bands. Automated interface mechanisms between the SATCOM and network simulation models are being developed to provide more interactive model collaboration.

1 REPRESENTATION OF SATELLITE COMMUNICATIONS IN NETWORK SIMULATION

For modern network simulations, both satellite and terrestrial networks must be modeled. System modelers will first augment existing network simulation models with SATCOM behaviors. These two areas start from different environments so there must be some integration not only from a system point of view but also from a modeling standpoint. This work will also include the integration of SATCOM tools and generic network simulation modes. In addition, traffic relationships between terrestrial and space links need to be addressed. While doing such a task, satellite capacity requirements realized at ground stations, e.g., teleports, can be assessed. The resolution, fidelity and measures of performance for the network model are defined according to the interoperability standards defined by the network in use and other interoperability requirements.

In dealing with the integration issues of SATCOM models and generic network simulation models, one must first characterize the space segments and assets involved in practical operations, and then model the Department of Defense (DoD) SATCOM architecture as shown in Figure 1 to produce link performance design and results. Much of the work of this paper in effect augments traditional network models with SATCOM capabilities. Specialized SATCOM models can be introduced to produce detailed satellite orbit characteristics and space-link radio frequency (RF) performance analyses. The RF analyses must be computed for various satellites using UHF, C, X, Ku, Ka, and EHF bands. All of such analyses can also be done for the existing and planned SATCOM networks with new bands or applications, keeping abreast with the architecture evolution of the Defense Information Systems Network (DISN).

Although satellite and terrestrial network models can work in collaboration, automated interface mechanisms between the two models should be devised to provide intimate real-time integration. To this end, best efforts will be made to preserve most of the critical characteristics inherent to each of the two models. While conducting such a task, satellite access capacity requirements will be assessed as a byproduct. Capacity assessment for ground stations or teleports are carried out based on the information exchange rates (IERs) from source and destination systems involved in simulation. The network modeler will first determine IERs necessary for a scenario available from a database named the integrated communications database (ICDB), and then compute a new set of IERs applicable to the ground stations interfacing both space and terrestrial systems. Communications applications with appropriate security and priority levels will be considered for this effort.

In representing SATCOM behaviors in network simulation, a generic satellite model should represent detailed satellite objects, entities, and associated link performance following user-definable attributes. The model will feature a number of communications devices including ground station interfaces involved in network operations as shown in Figure 1. Technical approaches for building such a model are addressed next. The task of building the generic satellite model will include a satellite ground station module which sends and receives data across the generic SATCOM domain. The ground station module will characterize a variety of functions used by current and planned SATCOM. The module will provide basic SATCOM ground station support functions including communications with GBS satellites that operate in broadcast mode. The module will handle a variety of DoD satellite terminals such as TSC-85, TSC-94, TSC-143, TSC-156 (tri-band STAR-T), and TSC-154 (EHF SMART-T). Each ground station will use terminals with a fixed number of ports and specific antenna patterns.

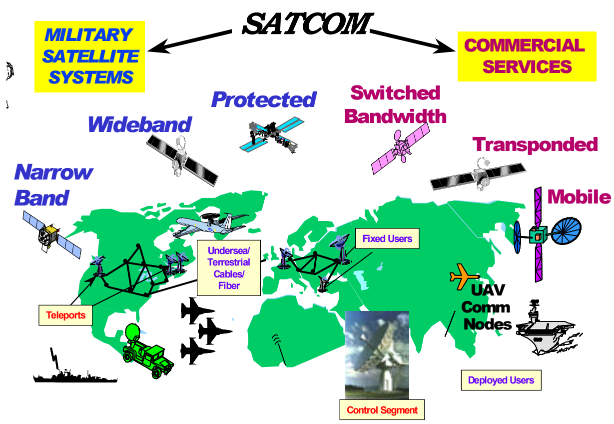

Figure 1: A Notional SATCOM Architecture

The Standardized Tactical Entry Point (STEP) is a large DoD ground station at which space and terrestrial network are interfaced. Concepts used for the STEP system will be used by the ground station model to provide a number (e.g., two for an IP network) of ports that are connected to a terrestrial network. This model can be readily adapted to handle DoD teleports that extend DISN services to deployed users via SATCOM. For example, each teleport will use three ports for each satellite platform object, a triple data rate for an IP connection, and an additional ATM port. Here, various antenna patterns will be handled to model earth coverage (EC) beams via horns or gimbaled dish antenna (GDA) and independent beam patterns via multiple beam antennas (BMA).

The satellite access mechanisms will be incorporated into the SATCOM model to portray interconnect functions among the satellite transponder ports. Moreover, a cross strapping capability by the transponder to distribute channels of different band types with their own beams or ports will be handled. Satellite system access algorithms such as Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Demand Assigned Multiple Access (DAMA), and Code Division Multiple Access (CDMA) mechanisms will be handled by the module. The antenna patterns and allocation of bandwidths among the participating ground stations will also be accordingly specified for a given SATCOM architecture. VSAT systems that are used for model scenarios will also be featured by the SATCOM model.

The space segment module will primarily handle DSCS (Defense Satellite Communications Satellite), government, and commercial satellites. The DSCS satellites with X bands are currently performing major DoD SATCOM functions and missions. The module will specify port and antenna patterns for DSCSs that will be employed for operational scenarios. For some cases, National Oceanic Atmospheric Administration (NOAA) satellites will be introduced by the SATCOM model for search-and-rescue operations as needed by operational scenarios. Modern MILSTAR EHF-band satellites that are highly survivable over jamming and interferences can also be modeled.

The SATCOM model will handle a variety of commercial satellites that will be used for commercial satellite communication initiatives (CSCIs). Commercial satellites such as INTELSAT, INMARSAT, and DOMSAT are often used to augment the existing DoD space systems for establishing timely connections with the sites in the area of responsibility (AOR). The module will feature satellites with different orbit characteristics such as Low Earth Orbit (LEO), Medium Earth Orbit (MEO), Geostationary Earth Orbit (GEO), and Highly Elliptical Orbit (HEO). Commercial satellites will use the SHF spectrum such as C, Ku, and Ka bands. Specific antenna and beam patterns inherent with those commercial satellites will be portrayed as prescribed.

The satellite space segment module will be able to cover a wide class of satellite system operations such as Fixed Satellite Service (FSS), Mobile Satellite Service (MSS), and Direct Broadcast Service systems. The associated port and antenna patterns for each type of operation will be configured to represent the right SATCOM behavior. For example, GBS with L or Ka-bands, as an MSS, can be modeled for given operational scenarios. Required SHF spectrum, orbit characteristics, and port/bandwidth specifications can also be appropriately set as tailored for each type of SATCOM operation.

The SATCOM model will provide essential analytical mechanism to handle various satellite spectrum and antenna patterns prescribed for DoD operations. The model will specify antenna types, sizes, and noise temperatures, ground station angular coordinates, compute equivalent isotropic radiated power (EIRP) and antenna gains, compute link budget terms and equations, and produce key signal-to-noise ratio performance measures. Such space-link signal performance results will be combined with message propagation delays for transfer to terrestrial network models to provide timely, accurate SATCOM performance attributes. Factors affecting the satellite link performance are EIRP, coding/modulation schemes, bandwidth, antenna gain, noise temperature, free space and atmospheric losses, orbit altitude, rain attenuation, interference, etc. The signal to noise ratios will be effectively used to analyze bit error rate, jamming, and interference features. Tradeoff analyses among hardware devices, transmission powers, and signal gains will also be performed through the model.

2 INTEROPERABILITY OF SATELLITE AND TERRESTRIAL NETWORK MODELS

Although the SATCOM and terrestrial network models can work with each other in tandem, automated interface mechanisms between the two model classes should be devised. Here, best efforts should be made to preserve most of key characteristics inherent to each model class. The COTS satellite models such as SOAP and STK generate text files as output or input during SATCOM modeling. The most suitable approach to integrate SATCOM models into traditional network models will be of interest. Coordination with developers such as OPNET Technologies, Aerospace Corp., and AGI is necessary to develop best ways to automatically import those simulation text files into a network simulation model.

The SATCOM model itself will be configured to handle multiplexer systems such as Promina systems with multiple versions of port specifications. These multiplexers are commonly used for STEPs or Teleports. The Promina systems will be interconnected to Ethernet and half Token ring LANs. The Promina's WAN ports model will be evenly divided between ATM and SLIP ports. The Promina's voice will use many ports, each capable of supporting aggregate phone systems. The SATCOM model must be compatible with the interface protocols and standards as supported by the Promina systems.

The SATCOM systems will work effectively with various wide-area network models. The network measures of performance (MOPs) such as delays, queue size, and throughput will be produced in a text format for use by traditional network models with ATM, frame relay, and IP subnetworks. Through this, the user will be able to view the subnetwork's performance from the analysis results from the network models. For network simulation, MOPs available in text format such as latency, delay, queue size, and throughput should be consistent with the overall combined network of satellite and terrestrial systems. Exchange of such key performance information will play a major role in integrating SATCOM and terrestrial network simulation models.

While experimenting with the satellite and terrestrial models, satellite access capacity requirements need to be assessed. Capacity assessment for teleports and STEP sites will be of interest to DoD decision makers and the assessment will be derived from the IERs collected for DoD operations. Such a task will first determine IERs necessary for a scenario prepared at a database such as the ICDB and the Emerging Requirements Database (ERDB), and then recommend a new set of IERs assessed at teleports or STEP sites. In this regard, all communication applications with appropriate security and priority levels will be considered. In addition, background traffic loading will also be taken into account. Each IER requirement originated from operational facilities will be dissected down into more elemental application requirements. This process should consider access frequency and work load for each application. It will be of interest to extract the total, regional (e.g., continental U.S) traffic requirements demanded for fixed or mobile SATCOM sites starting from the IERs.

There are several SATCOM models develop within the DoD. One is the STEP model developed by DISA (2000) and the other is the Navy Computer Telecommunications Area Master Station (NCTAMS) model by the Navy SPAWAR. Both model have been developed via a commercial tool named OPNET. In both STEP and NCTAMS, the SATCOM ground segment comprises major earth stations and user terminals. For example, STEP and teleport facilities interface with both terrestrial and SATCOM segment to establish satellite connections while NCTAMS facilities interface the service and joint community to ships afloat, serving as conduit for ships to communicate with land-based users. Both STEP and NCTAMS facilities will serve as military strategic-to-tactical interfaces between the terrestrial block and the deployed block of DISN.

At each ground station site, there are ground- and space-based systems working together to provide communications networks suitable interfaces with SATCOM assets. They also support current and future requirements of long haul reach back communications needs assessed at teleport locations. While these sites serve as most critical satellite communications entry points, other sites function also as gateways interfacing the user community to mobile stations such as ships and aircrafts. Teleport sites allocate and prioritize all communications assets in the area of interest to mobile stations operating at sea, including connectivity to the ships by UHF and SHF satellites and HF devices.

The teleport systems interface with TCP/IP-based networks as reachback capabilities. Both major entry points interfaces with SATCOM are designated by an organization. These entry points extend network services to remote users primarily through SHF-band services. The STEP/Teleport facilities will provide pre-positioned connections into the fixed communications network block via multi-band services such as UHF, L, C, X, Ku, Ka, and EHF. Other satellite services including commercial satellites will also be provided at STEP/Teleport sites for connecting the terrestrial links of the theater combatant to the fixed network infrastructure.

The network simulation models will need an enhanced capability via a SATCOM model to represent the integrated communications network systems. The SATCOM model will further portray a variety of system behaviors of all components associated with the teleport site control, satellite communications, deployed network interface, and the terrestrial network interface segments. The model will also incorporate new modifications to the existing and planned SATCOM systems. At present, both models are is of low-to-medium fidelity of SATCOM with a sufficient level of details to be added. The STACOM model will be extensible to incorporate new capabilities within future development phases. Advanced multiplexers are teleports for connectivity to SATCOM. The network architecture can be mostly of LAN types rather than ATM or TCP/IP networking (see Oppenheimer 1999 and Tanenbaum 1966). Satellites used by teleports are GEO, MEO, and LEO satellites. The overall architecture can be either fixed or mobile satellite system.

A generic SATCOM model via commercial network simulations will have editable satellite nodes and will consist of ground station module, space segment module, and space link performance module. All of these will process, generate, store, receive, and transmit messages. They also perform other tasks according to user design and prescription. Satellite orbit characteristics, ground station angular positions, and other key RF signal performance measures can be more effectively computed by COTS SATCOM models other than terrestrial network models. Moreover, conversion of digital data flows into RF data flows must be done by the SATCOM models depending on signal modulation and coding specifications. If integration of SATCOM and terrestrial models is realized, the essential SATCOM characteristics can be readily incorporated into the network simulation models as needed during simulation.

Both STEP and NCTAMS models characterize STEP and teleport sites, respectively, serving as ground interfaces linking up with satellites. Both models feature various interfaces that are deployed between SATCOM and terrestrial communications networks. Both models do not however well represent satellite network mechanisms and RF performance. Both models have so far laid a good foundation for growth and show extensive treatment of multiplexers which are ready for SATCOM transmission. Since only satellite transmission relates all participating ground stations, both models need to treat in more detail the inner mechanisms of a satellites, i.e., transponder functions, interconnecting, cross strapping, baseband conversion, and channel scheduling. Both models need to develop a realistic, detailed SATCOM module that will also handle antenna gains, beam patterns, and cross-banding. Both models have so far treated SATCOM behaviors only at the top level and they need to represent more rigorous SATCOM capabilities and extend to incorporate new SATCOM capabilities planned for future teleports.

Satellite angular coordinate analysis and RF performance results can only be effectively computed by commercial-off-the-shelf (COTS) models such as SOAP and STK. Such satellite models have to be employed in deciding which satellite services must be provisioned to meet all DoD communications requirements and which SATCOM architecture is most cost efficient providing acceptable performance. The satellite models further need to handle satellite access algorithms that provide networking functions among satellite transponder ports that are linked to teleports with multiplexers. The models can also provide a cross strapping capability within a transponder to distribute channels of different bands destined for appropriate teleport sites. Satellite access algorithms such as FDMA, TDMA, DAMA, and CDMA need to be installed at the satellite model. In addition, antenna patterns and bandwidths allocations among participating teleport sites will also be accordingly modeled given a SATCOM architecture. The satellite model will also model VSAT (very small aperture terminal) systems.

The teleport systems have to provide more rigorous TCP/IP interconnection specifications. One of the key assumptions used for the data reachback model is that it represents most data sources as TCP/IP traffic sources. Telports also often use broadcasting features as well as mobile, maritime satellite communications. Depending on how much such services are provides, the system will have more of MSS than FSS features. Some systems use applications through LAN services. Communications applications that will contribute to IER generations will be different. For example, applications used for current teleport models will be extend to a wider class of applications.

3 PERFORMANCE CHARACTERISTICS OF SATELLITE COMMUNICATIONS

The satellite space segment module will consider HF, VHF, UHF, SHF, and EHF radio frequency bands that will possess specific attributes regarding data rate, transmission, power, and COMSEC overhead. For example, HF, VHF, and UHF systems will be used for SINCGARS operations as base radio communication media. Most SATCOM satellites will use L, S, C, Ku, and Ka of the SHF spectrum, or the higher EHF spectrum. The range and specifications of the radio frequency spectrum will be defined by the user.

Digital binary signal can be handled by analog signal by using the following modulations Amplitude Modulation, Frequency Modulation, Frequency Shift Keying, Phase-Shift Modulation. The three basic forms of modulation are amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM). Their digital representations are amplitude-shift keying (ASK), frequency shift keying (FSK) and phase-shift keying (PSK). The common PSK used for SATCOM is the Quadrature Phase-shift Keying (QPSK). QPSK allows the user to transmit date four times the actual symbol rate, e.g., 9600 bps over a 2400-baud line.

When QPSK is used signal coding and modulation, the required bandwidth given data rate demand, in bits per second, is given as

$$B_{IF} = \frac{(1+\rho)}{2} R_b \quad (1)$$

where ρ is the signal roll-off factor. For usual raised cosine filtering is used, the roll-off factor is around 0.3.

The equivalent isotropic radiated power (EIRP) is combined effect of transmission antenna gain and transmission power and is commonly expressed in a decibel unit of dBW. For a common, paraboloidal antenna, the isotropic power gain is increasing in frequency used by the signal and the antenna reflector diameter in meters. A typical value of η, the aperture efficiency is 0.55. Let r denote the range, the distance from the transmitter to the receiver, e.g., from a ground station to a satellite. Then the signal flux density at the receiver (the captured energy per unit area by the antenna) is be defined to be

$$\Psi_M = \frac{EIRP}{4\pi r^2} \quad (2)$$

When the signal reaches the receiver, the transmission power starting with EIRP will decrease in order of the square of the distance from a ground station to a satellite. In other words, the signal will experience free-space loss as well as other miscellaneous losses. Besides the free-space loss, other propagation losses are the atmospheric absorption loss, the polarization mismatch loss, and the antenna misalignment loss. For some cases, a receiver feeder loss which is usually very small and effective only at the receiving antenna will be accounted for.

The signal-to-noise ratio is of most critical interest for measuring the SATCOM signal characteristics. Let P_R denote the received transmitter power and let P_N denote the sum of white Gaussian noise and total jammer power. Let [X] be the decibel of X with the relationship [X] = $10log_{10}X$ or X = $10^{[X]/10}$. Then the signal-to-noise ratio in decibels is expressed as

$$[\frac{C}{N}] = [P_R] - [P_N] \quad (3)$$

Let G_R denote is the receiver antenna gain and it is defined by

$$G_R = \frac{4\pi}{\lambda^2} A_{eff} = \frac{4\pi}{\lambda^2} \eta A$$

The decibel equation for the received power is given by

$$[P_R] = [EIRP] + [G_R] - [Losses] \quad (4)$$

where [*Losses*] includes the free-space loss (FSL), the receiver arbitrary loss, the receiver line loss, and the transmitter path loss. The FSL is defined by

$$[FSL] = 10\log(\frac{4\pi r}{\lambda})^2$$

Here, both the G_R and FSL are decreasing in wavelength so they are increasing in frequency. It is well known that the antenna gain increases with an increase in radio frequency but the path loss also increases. As a consequence, the received power at the output of the antenna remains the same even though the frequency increases from 4 to 11.5 GHz.

The decibel equation for the available noise power from a thermal noise source, Boltzman's constant k=$1.38x10^{-23}$ joul/Kelvin gives [k] = - 228.6. Gaussian noise, is given by $P_N = kT_NB_N = N_oB_N$. So the decibel of P_N becomes

$$[P_N] = 10log_{10}(kTB_N) \quad (5)$$

The total link signal-to-noise ratio, [*C/N*], is now given as

$$[\frac{C}{N}] = [EIRP] + [G_R] - [LOSSES] - [k] - [T_s] - [B_N] \quad (6)$$

The alternative expression of the above using [G/T] is

$$[\frac{C}{N}] = [EIRP] + [\frac{G}{T}] - [LOSSES] - [k] - [B_N] \quad (7)$$

Next, using the relationship $[\frac{C}{N}] = [\frac{C}{N_o}] - [B_N]$, we have the signal-to-noise density ratio as

$$[\frac{C}{N_o}] = [EIRP] + [\frac{G}{T}] - [LOSSES] - [k] \quad (8)$$

Let $[\Psi_M]$ be the maximum saturation flux density without considering back-offs. Using the saturation flux density, (8) becomes

$$[\frac{C}{N_o}] = [\Psi_M] + [A_o] + [\frac{G}{T}]_U - [k] - [RFL] \quad (9)$$

where A_o is the function of the frequency in GHz.

For SATCOM signal using QPSK, the BER can be computed using $[\frac{E_b}{N_o}]$ as below.

$$BER = \frac{1}{2}(1 - erf(\sqrt{\frac{E_b}{N_o}})) \quad for\ 0 \le [\frac{E_b}{N_o}] \le 12.$$

$$BER \le 10^{-8} \quad for \quad [\frac{E_b}{N_o}] \ge 12 \quad (10)$$

The total link signal-to-noise density ratio is defined to be

$$[C/N_o] = [C/N] + [B_N] \tag{11}$$

The total link bit energy to noise density, the ratio of energy per bit to noise density, is

$$[E_b/N_o] = [C/N_o] - [R_b] = [C/N] + [B_N] - [R_b] \tag{12}$$

Note that E_bN_o is slightly smaller than C/N for QPSK.

Suppose one is interested in computing the combined uplink and downlink C/N ratio. This performance is essentially used for generic network design and simulations models where attributes are needed for each communications link. Note that a complete satellite circuit consists of an uplink and a downlink. Let $(\frac{N}{C})_U$ and $(\frac{N}{C})_D$ denote the noise-to-carrier ratios for uplink and downlink respectively. It has been proven by Roddy (1996) and Spilker (1977) that the combined noise-to-signal ratio value, *N/C*, is additive in those of involved links in the path. Therefore, we have

$$\frac{N}{C} = (\frac{N}{C})_U + (\frac{N}{C})_D \tag{13}$$

This can be expressed as

$$\frac{N}{C} = 10^{[\frac{N}{C}]_U/10} + 10^{[\frac{N}{C}]_D/10} = 10^{-[\frac{C}{N}]_U/10} + 10^{-[\frac{C}{N}]_D/10} \tag{14}$$

Finally, using the relationship [*C/N*] = -[*N/C*], the combined [C/N] can be expressed in terms of uplink and down link carrier-to-noise ratios as

$$[\frac{C}{N}] = -[\frac{N}{C}] = -\{10^{-[\frac{C}{N}]_U/10} + 10^{-[\frac{C}{N}]_D/10}\} \tag{15}$$

Using the similar argument used for the case of each link, the combined link Eb/No and BER can also be computed from [C/N} as computed from (15).

Case Scenario: A satellite link from A to B needs to be established via an INTELSAT GEO satellite as shown by Figure 2. QPSK signal modulation is used to transmit information via 383 Kbps. BER of 10^{-5} is required for signal quality. From (10), a minimum 9.5 dB of $[E_b/N_o]$ is needed. From ground stations A, C-band uplink is used. From the satellite to station B, Ku band is used. The circuit requirement of R_b = 386 Kbps produces B_N = 257 kHz from (1). The roll-off factor is known to be 0.33. The uplink $[C/N]_U$ is computed from SOAP and STK as 25.313 dB. Then suing the bandwidth B_N, $[C/N_o]_U$ is next computed as 79.413 dBHz. Using R_b this give of $[E_b/N_o]_U$ at 23.547 dB. The GEO satellite is capable of cross strapping to switch the signal from C zone beam to Ku-band spot beam. Satellite analysis models such as SOAP and STK computed the downlink $[C/N]_D$ as 34.993 dB. Given the bandwidth B_N, $[C/N_o]_D$ is computed to be 89.413 dBHz. Using R_b this again gives $[E_b/N_o]_D$ = 33.547 dB. For the combined path from A to B, $[C/N_o]$ = 78.969 dB by (15) and (11). With the given R_b this again gives $[E_b/N_o]$ at 23.103dB, well above the minimum threshold value of 9.5 dB. The propagation delay from A to B via satellite is computed to be 267.96 milliseconds.

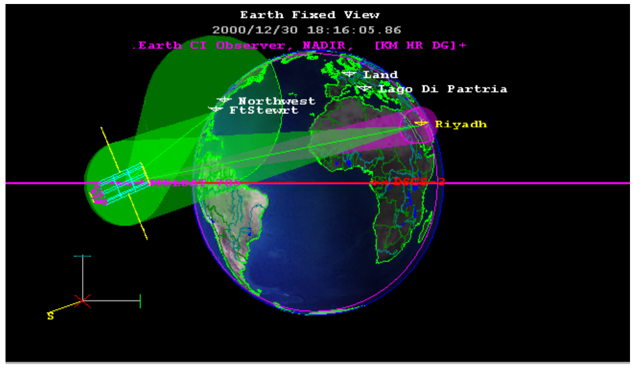

Figure 2: Satellite Connections among Ground Stations

4 INTEGRATION OF SATELLITE AND TERRESTRIAL NETWORK SIMULATION MODELS

To maximize the contributions of both models, integration is sought. More often than not, satellites are regarded as dummy gateways consuming a round-trip propagation time of 270 ms. Actually, there is a lot to be known beyond the propagation time.

Sometimes, LEOs and MEO are also used in DoD SATCOM. Then transponders do a lot of additional functions, interconnection and cross strapping, and cross banding. Antenna beam patterns and strengths for various sites must be taken into account for DoD operations.

Multiple access mechanisms such as FDMA, TDMA, and CDMA must be installed in the network model to truly model SATCOM behaviors. Often, the alternative to preassignment is DAMA concepts used for TDMA and FDMA. In DAMA, all circuits are available to all users and are assigned according to the demand. DAMA results in more efficient overall use of the circuits but is more costly and complicated to implement. Both FDMA and TDMA can be operated as preassigned or demand-assigned systems. CDMA is a random access systems, there being no control over the timing of the access or of the frequency slots accessed.

The most critical performance attributes to be exchanges are the distance between the ground stations to the satellite, the propagation time, *S/N*, E_b/N_o, and *BER*. If such attributes are not available the generic network model should be able to computed. To achieve such a capability, a specific satellite module with custom code must be developed, which is equivalent to launching a new SATCOM model development. If the network model can handle all of these, there would be no need of the model integration. However, orbital and RF attributes require specialized, advanced methodologies. Thus it will be mutually beneficial to maintain the two models working in tandem during simulation.

5 SUMMARY

This paper has discussed how the network with satellite systems can be simulated by combining generic network simulation model with specialized satellite models. After computing requisite performance attributed at the satellite model, these attributes will be transferred to terrestrial models. Conversely, topological information from terrestrial network can be dynamically used by satellite models. Some performance attributes will be analytically computed by satellite models. Key, common performance information will be transported back and forth between the terrestrial and satellite models. This paper has shown how additional performance attributes can be computed analytically. This work will contribute to automated integration of different models in collaboration.

DISCLAIMER

This paper is based on a modeling and simulation study conducted for the DISA/D8 SATCOM Modeling Group. The results and findings of this paper do not necessarily reflect the official policies and positions of the Defense Information Systems Agency.

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