ELECTROMAGNETIC PROPAGATION MODELING FOR DISTRIBUTED SIMULATION

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ABSTRACT

As the training industry converges on standards for Distributed Interactive Simulation, the next critical need is for better representations of electromagnetic propagation phenomena. Realistic radio simulation is essential for proper representation of command, control and communication functions. Accurate radar simulation is critical for the representation of various sensor and weapon systems for many types of platforms. Electronic countermeasures and counter-countermeasures must also be incorporated to adequately reflect the growing complexity of the modern battlefield.

This paper describes some electromagnetic propagation models that have been implemented for simulations commissioned by the U.S. Army Communications-Electronics Command (CECOM) and the Defense Advanced Research Projects Agency (DARPA) and discusses the "lessons learned" from those efforts. An approach for the efficient computation of radar intervisibility and target detection is described. Finally the DIS protocol extensions that will be needed to support and extend these models are discussed.

INTRODUCTION

Electromagnetic activity on the battlefield is widespread and growing. In addition to radio communication of voice, armed forces use systems throughout the spectrum for detection, targeting and disruption of adversaries. On the simulation front, interest has expanded from basic vehicle training to evaluation of the more complex interactions, and the effect that C3 systems have on soldier performance. While simulation of basic communications has been supported in the past, a more realistic approach has become desirable. In addition, distributed simulation is now being used as a testbed for concepts in radio-based data networks, such as the CVCC (Combat Vehicle Command and Control) elements mentioned later in this work.

In this paper, two applications of electromagnetic systems modeling are considered: combat radios and radar. The discussion of combat radio simulation is based on BBN's experience with the SINCGARS radio simulation implemented for CECOM at Fort Knox, Kentucky and Fort Monmouth, New Jersey over the last two years. The discussion of radar simulation centers on our implementation of the ADATS system for DARPA under the SIMNET contract (the DARPA-sponsored program for developing and demonstrating large-scale distributed-simulation technology).

RADIO SIMULATION

Modern combat radio systems provide means not only for voice communication, but also for digital data transfer among participants. Realistic simulation of this communication path is important in training situations, where techniques for taking advantage of this resource, and for coping with its failure, can be explored in the context of an exercise.

What Went Before

In earlier SIMNET vehicle simulators, radio communication was provided by means of citizens band (CB) radios interconnected by a network of coaxial cable and controlled by silk-screened front panels resembling those of the real combat radios (RT-442). This implementation was adequate for platoon-level training, but had certain limitations:

1. It does not allow for economical voice communication between simulators at geographically distant sites. An expensive phone line must be allocated between each site for each radio channel supported.

2. The channel allocation for CB limits one to 40 channels.

3. The radios cannot readily support data transmission.

4. Communications quality and range are uniformly perfect, regardless of distance, transmission power or terrain.

5. Simulations of direction-finding receivers and RF-seeking ordnance have no way of interacting with the vehicle radios.

6. There is no way of recording the radio traffic from an exercise with proper identification of the speakers.

In the next section, we will see how these issues are addressed in the work done for CECOM.

A Better Idea

At the direction of CECOM, BBN Systems and Technologies developed a network-based simulation of the Single-Channel Ground-Air Radio System (SINCGARS) for use both in existing M1 tank simulators at Fort Knox and in a testbed configuration at Fort Monmouth. The radio simulation implemented by BBN Systems and Technologies addressed the limitations of the CB radio approach as follows:

1. The radio simulation hosts communicate over the same simulation network as the other simulators, and can therefore take advantage of the site-to-site communication (long-haul networking, or LHN) already provided.

2. Because the "radios" are digital simulations, the number of distinct channels available is virtually unlimited.

3. The carrying of data on the simulated radio channels is provided for, including interfaces to various real and simulated sources of data.

4. Playing of received voice and introduction of errors into received data are determined by a propagation model that looks at transceiver characteristics and position on the simulated terrain, as well as signals from competing transmitters.

5. Simulations of direction-finding receivers and RF-guided ordnance can monitor the protocol data units (PDU's) used by the radio simulators to communicate over the simulation network to detect emissions from the simulated radios.

6. Timestamping and identification of simulated radio broadcasts is built into the radio protocol, and is supported by the data logger (the device used at SIMNET installations for the recording and playback of exercises).

Many of the elements that comprise this realistic radio simulation can be applied to simulations of other electromagnetic systems, as we discuss later in this paper. Key among these elements is the transmission loss model. The radio simulators share the same simulation network as the vehicles with which they are associated, allowing access to position information without modification to the vehicle simulators. The position information is used by a propagation model to determine signal loss between receiver-transmitter pairs. This signal loss can then be applied to any simulated electromagnetic transmission to determine receiver capture, interference, and bit errors. Voice and data communication can therefore be subject to the same limitations as real-world systems, providing a more accurate training environment.

<u>A Propagation Model</u>

SINCGARS operates in the VHF band, between 30 and 88 MHz. Signals in this band are affected by terrain and atmospheric conditions, since it propagates both in ground and sky waves. CECOM recommended the Longley-Rice propagation model for this application, since the operating range and terrain fall well within the constraints of the model.

Longley-Rice uses experimentally-determined data regarding the effects of atmospheric and soil conditions to specify parameters regarding general propagation characteristics. It then adds information about the terrain, in the form of a "roughness figure". The calculation involves reading the terrain elevation at fixed intervals (50 meters) between the receiver and transmitter. In practice, this value is calculated each time a simulated radio moves a significant (50-meter) distance. Finally, it deducts for spherical spreading loss (a function of distance) to produce a loss figure for a given receiver-transmitter pair.

The model is quite convincing in operation. Driving around the Fort Knox terrain in an M1 simulator, communication with a stationary vehicle comes and goes as one goes over hills, around trees and moves closer or farther away.

<u>Radio Simulation Hardware</u>

The radio simulation is supported by a set of simulation hosts (shown in Figure 3.1) connected to the simulation network. Each has the resources to support crew interfaces to radio controls, the network interface, and a copy of the terrain model. In the implementation done for CECOM, the host (a Concurrent model 6600) supports multiple radios attached to multiple vehicles. A later version, done under the MULTIRAD program for the U.S. Air Force's Human Resources Laboratory, supports multiple radios for a single vehicle. It runs on less expensive Motorola VME-bus computer boards, thus allowing a return to the SIMNET concept of one-vehicle-per-host.

In both the CECOM and HRL systems, voice is recorded and played using a special board called a SIMVAD (<u>SIM</u>NET <u>V</u>oice <u>A</u>nalog-<u>D</u>igital). The SIMVAD contains two analog I/O channels, each with a dedicated DSP (digital signal processor) to do encoding and decoding.

Two encoding schemes are currently available. APCHQ (Adaptive Pulse-Code with Hybrid Quantization) was used on the original SIMVAD. It is well-suited to producing high-quality speech at minimal bit rates. CVSD (Continuously-Variable Slope-Delta) is less computationally-demanding, and lower-quality, but is more tolerant of the bit errors likely to be encountered in a combat situation. APCHQ is intended for use when high-quality speech is required to approximate the performance of analog radios. CVSD is used in the real SINCGARS radios, and is therefore best when simulating that radio system.

The SINCGARS simulation installed at Fort Monmouth supports connection of actual Army CHS (Common Hardware-Software) computing devices, in order to allow them to utilize the simulated radio networks for data communication. The Fort Monmouth installation can also be connected to real SINCGARS radios operating in their retransmit mode, to allow real SINCGARS radio nets to interconnect with simulated radio nets. A synchronous serial communications board supports both the CHS and SINCGARS connections.

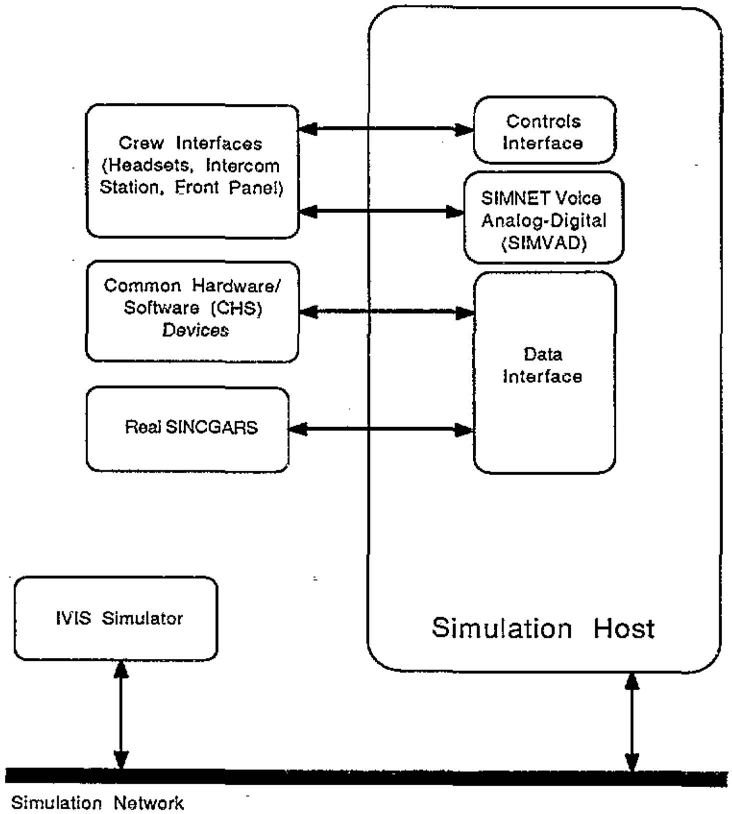

Figure 3.1. Radio Simulation Hardware Layout

A network-based interface is also provided to allow connection of IVIS (Inter-Vehicular Information System) simulators to the simulated SINCGARS radios. The IVIS simulators, which provide a graphical communication interface to tank commanders, were developed concurrently with the SINCGARS simulation for use in experiments at Fort Knox. This is an example of the testbed concept. The IVIS simulators were developed to allow the Army Research Institute to explore user interface concepts. Using a realistic SINCGARS simulation with the simulated IVIS units allows investigators to evaluate performance under the limitations it would face in the real world.

The Radio Network Monitor

The Radio Network Monitor (RadMon) is a system for monitoring the radio simulators. It is a separate computer residing on the simulation network, with a graphical display. It is capable of producing a map of the radios, and of showing their connectivity, as determined by tuning and signal loss. It records changes in the state of the radios on the network, allowing for the collection of statistics on loading of the simulated radio networks.

RadMon is useful to technicians in troubleshooting the radio simulation during exercises. Its primary application, however, is as an analysis tool for the testbed application. Because it can supply statistics regarding channel utilization, concepts in combat radio network organization and integrated voice-data protocols can be explored in the controlled environment of the simulated world.

RADAR SIMULATION

The concepts that have been applied to providing more realistic simulation of radio communication can readily be extended to other types of electromagnetic simulation, including radar systems.

The ADATS Simulation

BBN Systems and Technologies completed a simulation of the Air-Defense/Anti-Tank System (ADATS), including its radar targeting system, in 1990. It uses a propagation model specific to the system simulated in order to provide accurate performance.

The ADATS radar simulation consists of a collection of simulation hosts residing on the network with the vehicles it is targeting. The radar simulation hosts sends out Radiate PDU's, which notify other simulators that they are being illuminated and indicating whether or not ADATS successfully detects them. The PDU's are recorded by the data logger for future reference. The target vehicles, upon reception of such a PDU, directs their threat receiver to respond appropriately. The ADATS simulators themselves use four criteria to determine successful detection:

- Target Velocity.
- A roll-of-the-dice weighted by range and target vehicle type.

- A roll-of-the-dice regarding the effectiveness of jamming by the target. The simulators supporting the target vehicles do not support ECM, so this function also fell to the ADATS simulators.

- Line-of-Sight; as determined by an intervisibility function that examines the terrain.

The weighting of the roll-of-the-dice decisions is adjusted to accurately reflect the statistical behavior of the real systems.

The Intervisibility Library

For the frequencies at which the radar operates, line-of-sight is a major factor in propagation. In developing the ADATS simulation, BBN Systems and Technologies invested considerable effort in producing software to quickly and efficiently determine line-of-sight. This software is referred to as the intervisibility library.

The intervisibility library operates by drawing two rays between the "observer" (the ADATS vehicle, in this case) and the target. One ray runs from observer to the "head" of the target, while the other is run to the "foot" of the target. This is done to determine whether line-of-sight is obscured partially or fully.

The library then checks the terrain database along each ray. The terrain is organized into squares, each of which has associated minimum and maximum elevations. If the minimum elevation at a square's boundary exceeds the ray elevation at that square, then it is assured that line-of-sight is obscured. If the maximum elevation for a square is below the ray elevation within that square, absence of obstruction within that square is assured. Otherwise, the more time-consuming task of checking individual terrain components is begun. Finally, vehicles are checked to see what impact they have on line-of-sight.

In the case of the ADATS simulation, the rays are extended beyond the target to determine if they strike terrain in the background. If so, ground clutter is included in the above-described detection criteria.

The ADATS systems' issuance of Radiate PDU's opens the door for improvements. For example, target vehicles, using hardware similar to that used to support the SINCGARS radio simulation (or sharing such hardware on vehicles equipped for radio simulation), could implement protective jamming systems. With the jammers directly associated with the target vehicles, the effects of jamming could be more accurately modeled, allowing such factors as vehicle damage, operator error and more accurate terrain conditions to be taken into account. At the same time, this distributes the computational load.

Adding the propagation model to the ADATS simulation allows more accurate event-by-event simulation by incorporating the effects of terrain-dependent signal loss, interference from other transmitters (including other ADATS units) and (when available) target-based jammers and other countermeasures.

PROTOCOL IMPLICATIONS

Protocol extension in support of radio simulation involves addition of the Radio PDU, which has four variants:

- Transmitter. Used by simulation hosts to advise others of a change in transmitter state. This includes transition from idle to transmitting, increase or decrease in transmission power, and selection of new transmission frequency or hopset. The information is noted by other radio simulators to determine handling of subsequent signal variants. It is also used by the radio network monitor (RadMon) to determine radio net connectivity.

- Receiver. Used by simulation hosts to advise others of a change in receiver state. This includes transition from idle to receiving, increase or decrease in received power, or change in transmitter being received. Ignored by the other radio simulators, it is used by RadMon to determine connectivity in a given radio net.

- Signal. Carries 26-millisecond segments of encoded voice or digital data. Processed by other radio simulation hosts based on information from Transmitter variants previously received. Noted by RadMon in its radio network activity statistics.

- Intercom. Contains 26 millisecond segments of encoded voice from an M1 crew station whose intercom switch is keyed. Issued by the radio simulation host to allow logging of intercom traffic. Not a radio simulation function, but takes advantage of the radio simulator's ability to digitize all microphone input.

All four variants are recorded by the Data Logger, a system installed at most SIMNET sites to record network activity during exercises for after-action review.

CONCLUSIONS

As an enhancement to crew training, radio simulation with propagation modeling has a significant impact. Soldiers at Fort Knox responded to the more realistic communications appropriately. As a testbed for communications concepts, the potential of the SINCGARS radio simulation is just now being explored, with the installation of a facility at Fort Monmouth.

The introduction of jammer simulations, a readily-developed variation of the existing radio simulation, will allow more realistic training of radar operators, pilots and others concerned with countermeasures.

A cross-fertilization between the radio and radar approaches can improve the realism of each. The consideration of competing transmitters, and the addition of Radio PDU's will allow radar systems to better model jammers. The line-of-sight determination provided by the intervisibility library will allow radio simulation to extend into the UHF band, where Longley-Rice is not suitable.

BBN's experience in the CECOM and DARPA programs provides guidance for future extensions to the DIS standard, which must represent electromagnetic radiation in a manner that can support a wide range of applications.

Realistic radio communications and radar coverage will certainly play a major role in future distributed simulations.

These applications can share the simulation network. They are designed to minimize network traffic, and to cope with network latencies and the need for a uninterrupted data flow when speech is actively being reproduced. Loading is comparable to that of vehicle simulators, and newer networking technologies, such as FDDI, are opening the way to exercises with even greater numbers of participants.

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