Incorporating Navigation Effects into Synthetic Environments for Improved Cyberspace Training

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ABSTRACT

Global Navigation Satellite Systems (GNSS) such as the Global Positioning System (GPS) are used by military organizations for precise Positioning, Navigation, and Timing (PNT) services. GNSS systems, however, are vulnerable to attacks including jamming and spoofing. These attacks can block GPS signal reception entirely or can cause users to appear at incorrect locations, resulting in operation disruption and safety issues. For example, during the current Russian-Ukraine war, Russian forces have faced widespread GPS disruption caused by long-range drone-based GPS jamming attacks by Ukraine. The modern warfighter is vulnerable to such PNT-based attacks, and as a result needs to train on identification and mitigation of PNT-based attacks to retain full military operational capabilities in the modern battlespace.

To support multidomain operations training in this complex operational environment, the Army's Live, Virtual, Constructive, and Gaming (LVC&G) training systems need to incorporate realistic PNT disruption effects. However, in many cases, current LVC&G systems lack sufficient modeling of the GPS satellite constellation. In this work, we describe our initial efforts to provide an architecture to integrate high-fidelity modeling of GPS signal information into the synthetic training environment. We established an architecture, toolset, and approach to communicate GPS signal information produced by the GPS Interference and Navigation Tool (GIANT) into the simulation-driven training environment, where GPS jamming and spoofing effects are placed on simulated GPS receivers. The Cyberspace Battlefield Operating System Simulation (CyberBOSS) system provides an integrating architecture between GIANT and simulated GPS receivers in the One Semi-Automated Forces (OneSAF) system. This approach supports scenarios that incorporate detailed effects of operating in a GPS-degraded environment, including disruption of navigation and weapon fire tasking. We discuss the next steps to be taken to further integrate detailed PNT modeling into simulation-driven exercises, including future coordination with live training participants.

ABOUT THE AUTHORS

Dr. Omar Hasan is the Chief Software Architect at Dignitas Technologies, where he serves as the principal investigator on cyberspace-related research efforts. Dr. Hasan has 23 years of experience in software development, focusing on the Modeling and Simulation (M&S) areas of simulator interoperability, distributed simulation, and simulation architecture and infrastructure. He has extensive experience in object-oriented software analysis and design, open-source technologies and methodologies, and collaborative software development. Dr. Hasan has held architect and software engineering lead positions on both the One Semi-Automated Forces (OneSAF) and Joint Land Component Constructive Training Capability (JLCCTC) programs. He has also supported software development and cyber test event execution activities for the National Cyber Range (NCR). Dr. Hasan holds a B.S. and M.S. in Engineering from Columbia University and a Ph.D. in Engineering from Rutgers University.

Andrew Mendoza is a Senior Software Engineer at Dignitas Technologies with over 7 years of software development experience within the Modeling and Simulation (M&S) industry. He currently serves as deputy software lead on the CyberBOSS program. Mr. Mendoza previously performed software design and implementation as the lead developer of the Intelligent Cyberspace Adversaries Tool Suite (ICATS). He also has experience developing battlespace training software through his involvement with the Battlespace Visualization & Interaction (BVI) program that utilizes distributed interactive technology to visualize geospatial data for training, mission planning, mission command, and After-Action Review (AAR). Mr. Mendoza holds a B.S. in Computer Science from the University of Central Florida.

Jeffrey Welch has 22 years of software development experience within the modeling and simulation industry. He is the current software development lead for the CyberBOSS program and related research efforts at Dignitas Technologies. He has worked on various research programs as well as directly on Virtual and Constructive simulation systems with emphasis on scenario generation, dynamic environments, interoperability, and complex system integration. His project involvements include direct support for JLCCTC, Brigade Combat Team Modernization (BCTM), Synthetic Environment (SE) Core, OneSAF, Combined Arms Command and Control Training Upgrade System (CACCTUS), and Joint Simulation System (JSIMS) programs. He holds an M.S. and B.S. in Computer Science from the University of Central Florida.

Bob Burch is Chief Technology Officer for Dignitas Technologies, with roles as technical advisor for Dignitas and principal investigator over a set of research programs including the U.S. Army Combat Capabilities Development Command Soldier Center (DEVCOM SC) Soldier Effectiveness Directorate (SED) Simulation and Training Technology Center's (STTC) CyberBOSS and ICATS. Mr. Burch has 40 years of experience in modeling and simulation. Mr. Burch has a wide range of virtual simulation experience from vehicle platform systems modeling to simulation frameworks. Mr. Burch was Software Architect and a System Architect for OneSAF. Mr. Burch has practical experience in the development of Product Line Architectures in support of both Virtual and Constructive systems. He was a key contributor for PLA development for OneSAF, SE Core, and the United Kingdom's Combined Arms Tactics Trainer (UK CATT) programs. He holds a B.S. in Computer Science from the University of Central Florida.

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INTRODUCTION

Global Navigation Satellite Systems (GNSS), such as the Global Positioning System (GPS), are used by military organizations for precise Positioning, Navigation, and Timing (PNT) services that allow forces to accurately determine positions, navigate along routes, and maintain tactical system time synchronization. GNSS systems, however, are vulnerable to attacks including jamming and spoofing. These attacks can block GNSS signal reception entirely or can cause users to appear at incorrect locations, resulting in operation disruption and safety issues. For example, during the current Russian-Ukraine war, Russian forces have faced widespread GPS disruption caused by long-range drone-based GNSS jamming attacks by Ukraine. The modern warfighter is vulnerable to such PNT-based attacks, and as a result needs to train on identification and mitigation of these attacks to retain full military operational capabilities in the modern battlespace. To support multidomain operations training in this complex operational environment, the Army's Live, Virtual, Constructive, and Gaming (LVC&G) training systems need to incorporate realistic PNT disruption effects. However, in many cases, current LVC&G systems lack sufficient modeling of the GPS satellite constellation. These systems also lack modeling of the Electromagnetic Spectrum (EMS), including GPS signal transmission and reception, or use lower-fidelity representations, such as fixed GPS satellite positions. This lack of fidelity of modeling GPS transmissions within Army kinetic simulations hinders the use of those systems for training and experimentation of offensive and defensive Electromagnetic Warfare (EW) tactics required in the modern battlespace.

APPROACH

This section describes the high-level approach taken in our work to integrate high-fidelity modeling of GPS signals with existing Army Constructive simulations to improve the modeling of PNT-based electromagnetic attacks (EA) for training and experimentation. This approach supports scenarios that incorporate detailed effects of operating in a GPS-degraded environment, including disruption of navigation systems and degradation of weapon fire accuracy. Our approach provides an architecture to integrate high-fidelity modeling of PNT signal information into the synthetic training environment. We established an architecture, toolset, and approach to communicate GPS signal information produced by the GPS Interference and Navigation Tool (GIANT) into the simulation-driven training environment, where GPS jamming and spoofing effects are placed on simulated GPS receivers. The Cyberspace Battlefield Operating System Simulation (CyberBOSS) system provides an integrating architecture between GIANT and simulated GPS receivers modeled in the One Semi-Automated Forces (OneSAF) system.

In this work, we developed an architecture used to integrate high-fidelity modeling of PNT signal information into the synthetic training environment. We utilized this architecture to instantiate a working prototype for testing and experimentation. To execute this prototype, we performed several development tasks. First, we designed and developed extensions to the CyberBOSS Cyberspace Data Model (CDM) to communicate GPS position error data between systems. Second, we developed new models within the Cyberspace Effects Server to receive GPS position error data from GIANT and convert that data to a format that is consumable by Constructive simulation models such as OneSAF. Third, we enhanced the OneSAF system to receive entity perceived location data derived from the GPS position error data and utilize the perceived location in its modeling of navigation and firing tasks. Finally, we developed user interfaces to visualize the PNT effect information within the CyberBOSS Control Tool user interface

(UI). We developed an example scenario that we used to demonstrate the feasibility of our approach and provide the basis for expanding this work in future efforts.

ARCHITECTURE

This section describes the high-level architecture developed to integrate high-fidelity modeling of PNT signal information into the synthetic training environment. This architecture, depicted in Figure 1, consists of two Constructive simulation components; a kinetic battlefield simulator and a high-fidelity PNT system simulator. Cyberspace domain-related information between the two simulation systems is communicated using a cyberspace brokering architecture, which provides cyberspace effect models as well as user interfaces utilized by exercise facilitators.

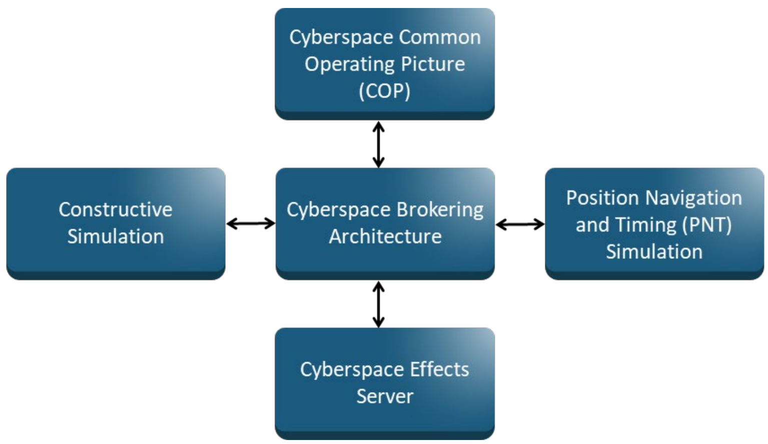

Figure 1. High-level architecture used for communicating PNT cyberspace effect information between PNT simulation and kinetic battlefield simulation systems.

A description of each of the components of this architecture is given in Table 1.

Table 1. Components within the EW effect bridging architecture.

Architecture Component	Description
Constructive Simulation	Provides models of friendly and threat actors, cyberspace devices, cyberspace operations and effects
Cyberspace Brokering Architecture	Provides data model and communication mechanism for communicating cyberspace-related information between connected simulation systems
Cyberspace Effects Server	Provides modeling of PNT effects and other cyberspace and EW effects
Cyberspace Common Operating Picture (COP)	Provides exercise facilitator / white cell functionality to control and monitor cyberspace effects within the training environment
Position, Navigation, and Timing (PNT) Simulation	Provides high-fidelity models of satellites, receivers, antennas, Inertial Navigation Systems (INS), and emitters models used to compute PNT system performance and its impacts on mission effectiveness

We describe each of these components in more detail in the following sections.

Cyberspace Brokering Architecture

The Cyberspace Brokering Architecture provides services and data models to promote integration of existing and emerging LVC&G systems, cyber ranges, and other cyberspace M&S tools to foster integrated training and analysis. In this work, we utilized the CyberBOSS system architecture to provide this functionality. The CyberBOSS system architecture, shown in Figure 2, is a microservices based system in a Service Oriented Architecture (SOA) that uses well defined software interfaces and protocols to facilitate system integration and expansion to other systems. [1] The architecture is flexible and extensible with an emphasis on adaptation to future cyberspace training and analysis needs. This system architecture employs an open and transparent hub-and-spoke approach where client applications connect into a common, federated data bus that is managed by a centralized server. The group of connected client applications forms a federation. Services maintain the model of the state of the cyberspace terrain across the training environment to provide a common and consolidated view for all connected federates. All client applications communicate using CDM representation to specify cyberspace-specific information (e.g., cyber attacks, cyber control, cyber status, etc.). [2] The CDM is compliant with emerging cyberspace data standards such as the Simulation Interoperability Standards Organization (SISO) Cyber Data Exchange Model (CyberDEM). As depicted in Figure 2, a wide variety of system types may interoperate through the CyberBOSS system architecture, including LVC&G systems, cyber ranges, cyberspace effect and operation models (e.g., EW and PNT models, network models, intelligent adversary models), and cyberspace effects tools.

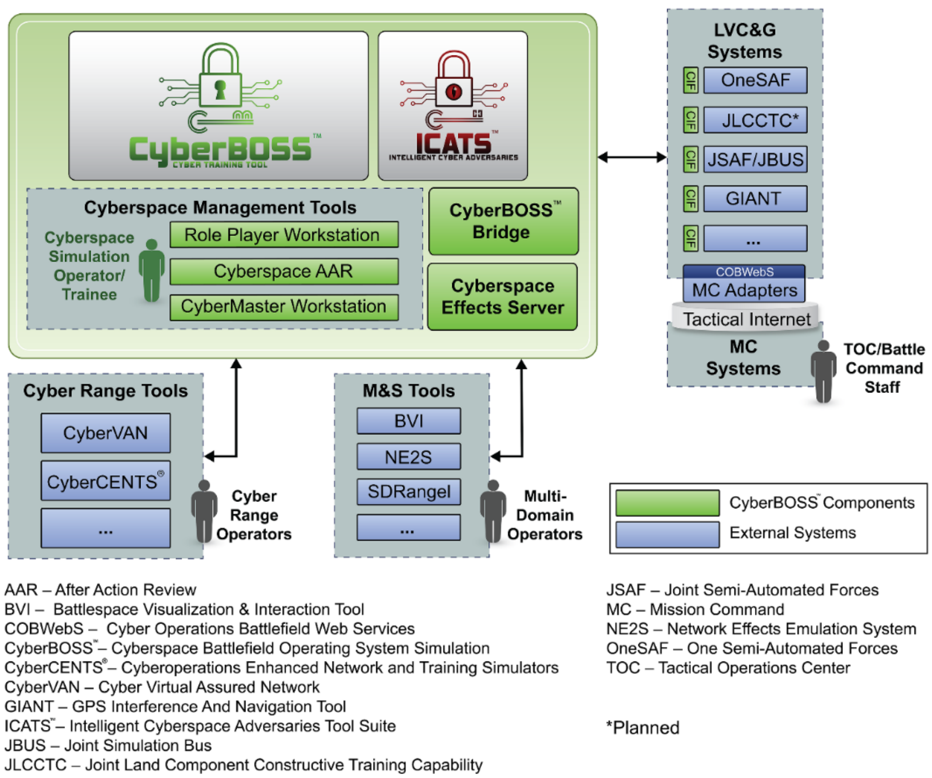

Figure 2. CyberBOSS cyberspace data model and brokering services are used to communicate EW and cyber effects between LVC&G simulations and other training systems.

For the purposes of this work, we utilized this architecture to broker PNT cyberspace effects across federated simulation systems. Specifically, we focused on connecting three federated applications using this architecture to model and communicate PNT effects: 1) GIANT, as the high-fidelity PNT simulator, accurately modeled GPS jamming of affected devices, 2) the Cyberspace Effects Server [3] was used to store and convert GPS position error data into formats consumable by the kinetic simulation, and 3) OneSAF, as the kinetic simulation, that modeled tasks such as mauver and weapons fire that utilized the GPS data. These federated applications are described in the sections below.

Cyberspace Effects Server

Our architecture contains the Cyberspace Effects Server, a federate within the CyberBOSS federation that models cyberspace effects which can be placed on simulated and real devices within the federation. The results of the cyberspace effects are delivered to the training audience through the internal modeling and user interfaces of the simulation and through changes to the stimulation of tactical devices. The Cyberspace Effects Server utilizes an extensible architecture that allows for the incorporation of new cyberspace effects models that can be requested, instantiated, and provided as services to all CyberBOSS federates. The benefit to the approach is that the cyberspace effect modeling provided by the Cyberspace Effects Server can be reused across systems, minimizing the need to write additional code within each connected system. In this work, new models for supporting GPS jamming effects were added to the Cyberspace Effects Server. These models, which can be controlled by actions from the simulation or by cyber exercise facilitators / white cell operators, provide mechanisms to utilize PNT-related data received from the PNT simulation and convert that data to formats that are usable by the kinetic battlefield simulation. The Cyberspace Effects Server GPS jamming effect information is periodically communicated to the kinetic battlefield simulation using the CDM and messaging services.

Constructive Simulation

In the LVC&G training environment, the Constructive kinetic battlefield simulation provides modeling of simulated Blue Force (BLUFOR) units as well as modeling of threat actors that can perform simulated kinetic and non-kinetic attacks on BLUFOR units. The simulated non-kinetic actions may result in effects in the cyberspace, EW, and Information Operations (IO) domains. In this work, we deployed OneSAF as the kinetic battlespace simulation in our prototyping. OneSAF is a U.S. Army entity-based Constructive simulation and is extensible and composable for deployment in a wide variety of use cases. OneSAF was chosen for this work since it contains rudimentary models for GPS-enabled devices. These models were extended in this work to utilize PNT effect data provided by the high-fidelity PNT simulation, thus improving the realism of the GPS modeling within OneSAF. This provides improved modeling of the effects of GPS degradation within the battlespace and the ability to demonstrate how that degradation affects mission success, for example adversely affecting munition targeting or entity navigation capabilities.

PNT Simulation

In this work, we utilized a high-fidelity Constructive PNT simulation system to model PNT system performance. GIANT (https://www.giantsw.com/), along with its associated GPS Environment Generator (GEG) component, was chosen as the PNT simulation used in this work since it is accredited for use in the GPS Warfighter Collaboration Cell (GWCC) and is included in the Air Force Standard Analysis Toolkit (SAT) and Army Space Operations System (SOS). GIANT is a Constructive and repeatable simulation used to evaluate multi-sensor systems such as GPS/GNSS and the Inertial Navigation System (INS) for effectiveness across a wide range of operational conditions. It computes PNT system performance and its impacts on mission effectiveness in benign or electronic contested environments. GIANT includes databases of satellites, receivers, antennas, INS, and emitters. The GIANT Simulation Engine (SE) executes a discrete time-stepped simulation that runs much faster than real-time. The GIANT Graphical User Interface (GUI) software is used to configure and view the results of the GIANT SE. A typical GIANT simulation run consists of one or more GPS/INS-equipped platforms moving along a route, employing optional air-to-ground or surface-to-surface precision guided munitions against multiple targets, in an electronic environment that includes zero to many GPS interference sources or jammers, and a GPS constellation. The simulation evaluates electromagnetic signal propagation and visibility using detailed ellipsoid, geoid, and digital terrain models. The resulting geometries and power levels determine the signal environment experienced by the modeled antenna and receiver systems. Antenna, including antenna electronics, and receiver behavior are modeled, ultimately resulting in the calculation of position error as a function of the combined GPS/INS solution at each point along the route. This work involved periodically communicating the position error for use within the kinetic battlefield simulation, using our GPS jamming models to support translation and conversion of GPS signal error data between the two simulation systems.

The GEG is composed of a simulation engine and a GUI. The GEG SE exposes the GPS/INS navigation and interference models of the core GIANT simulation to distributed simulations, enabling those simulations to represent the effects of GPS jamming on the navigation performance of the systems participating in the simulation event. The GEG GUI provides configuration, execution control, and monitoring of the GEG SE. As described below, in this work we built interfaces within GEG to communicate the PNT navigation error results modeled in GIANT to CyberBOSS and subsequently to OneSAF for application to OneSAF kinetic models.

PROTOTYPING EFFORTS

This section provides details on our prototyping efforts using the above architecture to communicate PNT effects between the simulation systems. In our prototyping, we focused on simulated jamming of Constructive BLUFOR tactical devices, such as GPS receivers and Command and Control (C2) devices. Our prototype communicated and applied the navigation error data from the GIANT/GEG simulation to the Constructive kinetic simulation space modeled in OneSAF, using our brokering architecture.

The overall flow of data between the simulation systems in our prototype is shown in Figure 3. Within the prototype, communication of entity positional information between OneSAF and GEG occurred using Distributed Interactive Simulation (DIS) Entity State Protocol Data Units (PDU). Upon receipt of Entity State PDUs containing data for simulated BLUFOR entities, GEG began modeling the GPS receivers assigned to these entities. During its modeling, the GEG periodically sent GPS position error data for these entities using CDM PNT navigation error data event messages which contained GPS error values such as Circular Error Probable (CEP) and horizontal and vertical position error. The PNT event messages were received by the Cyberspace Effects Server which utilized models created for this effort to calculate perceived location values for the associated entities based on the entity ground truth location and the GPS position error data received from GEG. The entity perceived locations were then communicated to OneSAF which utilized these values in its kinetic models, such as calculation of the target location during Call-for-Fire (CFF) tasking.

The sections below provide details of our prototype development for several aspects of our solution. Data flow step numbers in Figure 3 are cited in the sections below for reference.

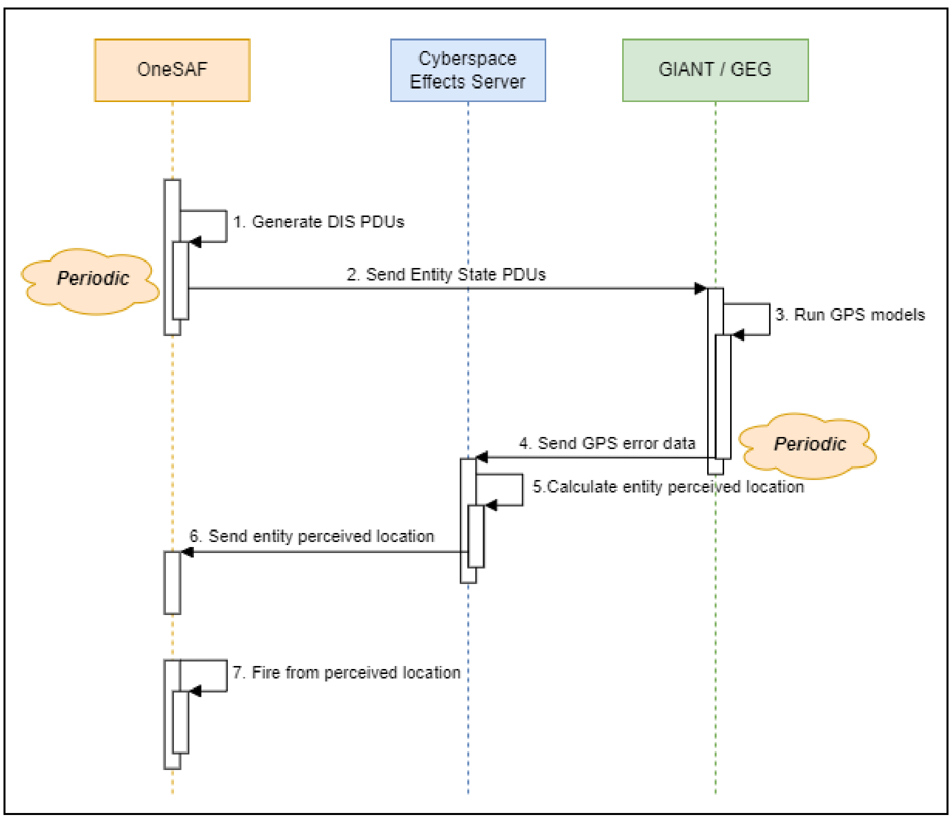

Figure 3. Overall flow of data between the Cyberspace Effects Server, OneSAF and GIANT/GEG systems in our prototype.

Development of Interfaces to Communicate GPS Position Error

As shown in Step 4 in Figure 3, GPS position error data was periodically communicated between GEG and the Cyberspace Effects Server for all entities correlated to players modeled by GIANT/GEG. In our prototyping, we developed an interface to communicate this data by extending the CDM with a new PNT event message that encapsulates GPS error data produced by the GEG. We also extended and utilized the CyberBOSS Interface Framework (CIF) software library to develop a client adapter within the GEG. Using the CIF, GPS error data produced in the GEG was periodically communicated to the CyberBOSS federation. In this work, as shown in Step 6 in Figure 3, we also developed CIF interfaces between CyberBOSS and OneSAF to communicate GPS position error data. OneSAF was enhanced to enable it to consume entity perceived location values calculated by the Cyberspace Effects Server using the GEG GPS position error data.

Development of Model to Adapt GPS Position Error for Kinetic Battlefield Simulation

As shown in Step 5 in Figure 3, our prototype utilized a new model we developed within the Cyberspace Effects Server to receive GPS position error data from GEG and transform that data into the entity perceived location. In contrast to the raw GPS position error data, the perceived location is consumable by OneSAF models and is usable by OneSAF kinetic models of entity movement, firing, and other tasks. We developed the **PNTNavigationModel** in the Cyberspace Effects Server to process incoming CDM PNT navigation error data events and calculate perceived location values for entities referenced within the event. This model uses the algorithm depicted in Figure 4 to calculate the entity perceived location using the entity ground truth location and GPS error values received from GEG. The algorithm selects a random latitude, longitude, and elevation for the perceived location by applying a Gaussian distribution using the horizontal and vertical position error values supplied by GIANT/GEG. As described in the previous section, once calculated by the Cyberspace Effects Server, the perceived location of the entity is communicated to OneSAF for application to its kinetic models.

The random value comes from a Gaussian distribution using 0 mean and the input standard deviation (horizontal position error value or vertical position error from GIANT).
Part of the computation is computing a delta x and y for the horizontal portion and a delta z for the vertical portion.

- x = Random_value_from_normal_distribution (0 mean, 1-sigma_horizontal_error) (meters)
- y = Random_value_from_normal_distribution (0 mean, 1-sigma_horizontal_error) (meters)
- z = Random_value_from_normal_distribution (0 mean, 1-sigma_vertical_error) (meters)
  - For random value, will need a seed value -- use one starting seed then make the three successive random draw so that all are independent
- Perceived lat (deg) = truth lat (deg) + y / R * 180 / pi
- Perceived lon (deg) = truth lon (deg) + x / R * 180 / pi
- Perceived alt (m) = truth alt (m) + z
  - Here, x, y, and z are in meters
  - R is radius of earth (6366707.01804 meters)

Figure 4. Cyberspace Effects Server PNT model algorithm showing the derivation of entity perceived location latitude, longitude, and elevation.

Enhancement of Kinetic Battlefield Simulation Models

As shown in Step 7 in Figure 3, we enhanced OneSAF models to utilize the GPS error data produced by the high-fidelity GPS modeling simulation system. We updated the CyberBOSS OneSAF extension to receive perceived location updates sent by the Cyberspace Effects Server. Components of the OneSAF GPS extension were extended in the CyberBOSS OneSAF extension to allow setting and utilization of the received perceived location values by OneSAF GPS receiver models. A new GPS model, the **GPSModelHRExternal**, was added to the OneSAF CyberBOSS extension which built upon GPS models from the OneSAF GPS extension to store perceived locations received from the Cyberspace Effects Server. This model supports the retrieval of GPS navigation data for OneSAF entities during execution of fires missions and other activities. A separate GPS receiver component, termed the **GPSReceiverExternal**, was developed that extended the GPS receiver from the OneSAF GPS extension. This GPS receiver model utilized the entity perceived locations supplied by the GPSModelHRExternal which were derived from the GIANT/GEG modeling. During its modeling of the GPS receiver, the GPSReceiverExternal periodically calls the GPSModelHRExternal model to retrieve the last stored perceived location of the entity, which was calculated using the above algorithm from the GIANT/GEG GPS position error data.

Development of User Interfaces to Visualize PNT Effects

A main function of CyberBOSS is to act as a cyberspace Common Operating Picture (COP) for visualization of cyberspace effects occurring within the training audience. In this work, we added functionality to the Control Tool to support visualization of PNT effects. This visualization allows exercise facilitators to identify the targets of PNT cyberspace attacks and to understand the discrepancy between the ground truth location and perceived location of targeted entities.

As mentioned above, several PNT navigation error parameters are continuously received from GEG as GIANT models the EMS surrounding each GPS device. The Cyberspace Effects Server uses the data received from GEG to calculate the three-dimensional distance between the target's ground truth location and perceived location. Additionally, a geographic coordinate at a randomly-selected angle and at this distance from the target's ground truth location is given. This information is used to visualize the PNT effect on the Control Tool map view.

An example of visualization of a PNT effect within the Control Tool is shown in Figure 5. In the center of the figure, the icon for the targeted entity is shown at its ground truth location. A shaded icon is shown for the same targeted entity at its perceived location, in this case 716.36 meters from its ground truth location. An arrow is drawn to indicate the discrepancy between the ground truth location and the perceived location. This perceived location is shown at a randomly-selected direction, so a circle of that radius is drawn indicating that the actual perceived location is at any point along the circumference of the circle. As the actor moves within the terrain and as the EMS changes due to terrain or targeted jamming effects, the circumference of the perceived location circle periodically changes. Double clicking the target icon opens a popup menu that allows the user to see the full set of PNT navigation error data received from GEG for that actor.

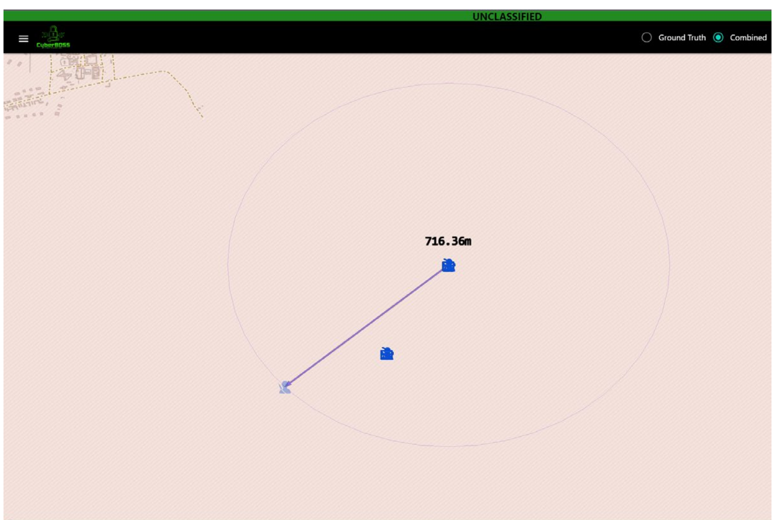

Figure 5. Visualization of a PNT effect within the Control Tool.

EXPERIMENTAL RESULTS

To demonstrate the feasibility of our approach to integrate PNT effects within kinetic simulation environments, we developed and experimented with a representative scenario that was implemented across the systems depicted in the above architecture. In the scenario we used for experimentation and demonstration, threat forces utilize EW techniques to jam GPS-enabled BLUFOR equipment. The threat forces perform spectrum analysis to discover radio frequencies used by the BLUFOR. During an Electromagnetic Attack (EA), as depicted in Figure 6, the threat forces activate a GPS jammer in the battlespace which disrupts BLUFOR GPS-enabled equipment. This causes a reduction in BLUFOR GPS location triangulation accuracy due to disrupted signal. Upon engagement with the threat forces, the BLUFOR Forward Observer (FO) issues a CFF at the threat location. However, the CFF Target Location Error (TLE) is increased due to signal disruption by threat jammer, reducing BLUFOR fire lethality.

Figure 6. Control Tool depicting threat jammer affecting BLUFOR GPS-enabled devices.

Using this scenario, we executed simulation runs in which the threat jammer was not activated and runs in which the threat jammer was activated. This allowed us to view differences in success of the simulated fire mission between these cases and examine the effectiveness of integration of a high-fidelity GPS model such as GIANT/GEG with traditional kinetic military simulations. The results of each execution configuration are given below. Our results show that there are clear benefits from the incorporation of accurate GPS modeling in the training environment to represent complex EA vectors such as jamming.

Outcome of Experimentation Without GPS Jamming

When simulated threat jammers were not activated in the scenario, jamming emissions were not communicated to GIANT and did not affect its modeling of the EMS. Therefore, no BLUFOR GPS signal degradation due to threat jamming occurred. During the execution of the CFF mission, the ground truth location and perceived location of the FO was relatively equal within a natural margin of around 1-2 meters, due to various external variables such as terrain and tracked GPS satellite distance as modeled by GEG. The FO was able to accurately calculate and communicate the target location of the fire mission to the firing units, resulting in lethal BLUFOR fire upon OPFOR units. The BLUFOR achieved mission objectives and the BLUFOR fire lethality remained unaffected by the OPFOR.

Outcome of Experimentation with GPS Jamming

When simulated threat jammers were activated in the scenario, jamming emissions were communicated to GIANT and affected the modeling of the EMS. Several BLUFOR units in range of the jamming attack, including the Forward Observer, experienced degraded GPS signals. During execution of the CFF mission, while the GPS jamming was active, there was a significant difference between the ground truth location and perceived location of the FO. The FO was unable to accurately calculate and communicate the target location of the fire mission due to this location discrepancy and the incorrect target location was communicated to the firing units. This resulted in the reduced BLUFOR fire lethality since the BLUFOR units fired upon an area outside of lethal range and the OPFOR targets began to mobilize unharmed.

FUTURE WORK

Outputs from this research effort produced an interface between CyberBOSS and a high-fidelity PNT model (GIANT), enabling brokering of an initial set of PNT objects, events, and effects data to all connected systems, and demonstrate the impacts of a Denied, Degraded, and Disrupted Space Operational Environment (D3SOE) in a connected Constructive simulation (OneSAF). Building upon this foundational capability, future work includes developing interfaces to additional LVC&G M&S systems that the Army and Joint force use today but lack sufficient GNSS representations to accurately model and simulate realistic D3SOE events and effects. In addition, future work includes developing additional PNT scenarios that incorporate modern, resilient GPS receiver and antenna technologies, to model and measure mission effectiveness in degraded GPS environments when units are outfitted with different types of GPS receiver and antenna technologies. Future work also includes utilizing this architecture to synchronize the simulated D3SOE events and effects with Live training audiences, so that they can observe the impacts of the simulated PNT events on their Live tactical systems and radios, providing an accurate and realistic environment to train in and work through their tactics, techniques, and procedures (TTP) in denied, degraded, and disrupted GPS environments.

CONCLUSION

PNT-related attacks such as GPS disruption, degradation, and spoofing are increasingly used by threat military organizations to cause operation disruption and safety issues for our forces. The modern warfighter is vulnerable to such PNT-based attacks, and as a result needs to train on identification and mitigation of PNT-based attacks to retain full military operational capabilities in the modern battlespace. To support multidomain operations training in this complex operational environment, LVC&G training systems need to incorporate realistic PNT disruption effects. However, existing LVC&G simulations lack sufficient modeling of the EMS, including GPS signal transmission and reception, or use lower-fidelity representations, such as fixed GPS satellite positions. This hinders the use of those systems for training and experimentation of offensive and defensive EW tactics required in the modern battlespace. This work has provided an architecture for integration of a high-fidelity model of PNT signal information into the synthetic training environment. We utilized this architecture to instantiate a working prototype for testing and experimentation. To execute this prototype, we designed and developed extensions to the Cyberspace Data Model used to communicate GPS position error data between systems. We developed new models to receive GPS position error data and convert that data to a format that in consumable by Constructive simulation models. We also enhanced the kinetic simulation to receive entity perceived location data derived from the GPS position error data and utilize the perceived location in its modeling of navigation and firing tasks. To demonstrate the feasibility of our approach and provide the basis for expanding this work in future efforts, we developed an example scenario used for prototyping during this effort. This initial work provides a basis for communication of more sophisticated PNT effects coordinated across the simulation environments though the architecture developed here to support the warfighter with improved multidomain operations training and experimentation capabilities.

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