Enhancing Wargaming Fidelity with Communication Modeling Services

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ABSTRACT

As outlined in the 38th Marine Corps Commandant's Planning Guidance (CPG) 2019, wargaming is one of strategic focuses that will emphasize on the effective integration of professional wargaming in force design, education, and training. Following this guidance, US Marine Corp is looking for the next-generation wargaming that will embrace various types of wargaming, from concept development, capability development and analysis to wargaming for operational decisions and plans, training and education. As each of those wargaming types involves human players or actors making decisions in constructive contest environment and then dealing with the consequences of their actions, communications and networks to contain, extract, and disseminate time-sensitive, mission-relevant information have become a critical part of wargaming, requiring high fidelity models with realistic cyber, communications and networking.

Our previous work presented an innovative and unique prototype to incorporate high fidelity cyber, communications and networking simulation into a wargaming environment. In this paper, we will look at enhancement from different angle where we propose an architecture to provide communication modeling services during different phases of a wargame (define, design, develop, rehearsal, execute and post-game analysis) and for different types of wargaming. The architecture includes a wide range of communication modeling service from RF layer (reachability, link quality) to network planning, optimization and performance assessment. It can also emulate specific mission data flow in realistic network condition and cyber contest environment to better assess mission outcome. Its design is flexible, allowing different types of interfaces to communicate with other wargaming tools. REST API is used for quick response to a request from a wargaming tool. Interactive GUI interface allows a wargamer to be involved in the process of modeling communication service. Realtime interface allows exchanging data between CMS and other wargaming tools in real time either directly (e.g., DIS) or via middleware (e.g., TENA).

ABOUT THE AUTHORS

Dr. Ha Duong is R&D Software Engineer 5 at Aerospace Defense Government Solution, Keysight Technologies. Dr. Duong has worked on modeling vulnerabilities and cyber attacks in both IT and OT networks, and on how to use those models to understand and evaluate impact of cyber attacks on mission and operation execution. Recently, he works on methods and tools to create Network Digital Twin of various physical networks that will take simulation and emulation to the next level in meeting requirements of cyber and network testing. His current research interests include LVC-based cyber-attack representation, modeling and simulation techniques to represent complex operations in simulation environments, and analysis of cyber effects on IT and OT networks.

Dr. Jeffrey Weaver is R&D Director at Aerospace Defense Government Solution, Keysight Technologies. He obtained his Ph.D. degree in Electrical Engineering as an NSERC-PGS Scholar from Western University in Ontario, Canada. Dr. Weaver has held key technical and executive engineering roles during his career and has over twenty years of product development experience in hardware and software systems. His research interests include digital communication and propagation modeling using switched stochastic differential equations, signal processing and hybrid analytical-numerical modeling techniques. Dr. Weaver has seven patents in the areas of IP routing, VLAN, QoS, and high-performance hardware design

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INTRODUCTION

The 38th Marine Corps Commandant's Planning Guidance (CPG) 2019 [Commandant's Planning Guide] outlined common directions to the Marine Corps: force design, warfighting, education and training, core values, and command and leadership, where wargaming is an important part of force design, education and training. Following this guidance, US Marine Corp is looking for the next-generation wargaming that will embrace various types of wargaming, from concept development, capability development and analysis to senior leader engagement and strategic discussion, wargaming for operational decisions and plans, training and education [Next-Generation Wargaming]. All those wargaming types involve human decision-making that fundamentally relies upon communications and networks to contain, extract, and disseminate time-sensitive, mission-relevant information to win decisively against opposing forces. Therefore, communication and network have become a critical part of wargaming, requiring high fidelity models with realistic cyber, communications and networking effects to support development of effective operating concepts, capabilities, and plans.

In the previous work [Ha Duong], we presented the concept of a Network Digital Twin that can be used to enhance wargaming fidelity. With the capability to import system artifacts such as network topology, traffic profile, host profile, device configuration and vulnerabilities, the Network Digital Twin can be quickly set up and supports wargaming systems with high fidelity, physics-based cyber, communications, and networking modeling .

In this paper, we will look at enhancement from different angle where we propose an architecture to provide communication modeling services (CMS) during different phases of a wargame, such as design, develop, execute and post-game analysis and for different types of wargaming. There are existing interfaces to integrate different components including communication modeling in wargaming system. However, those interfaces typically address specific requirements in wargaming. As stated early, US Marine Corp and other DoD branches are looking at the next generation wargaming that requires a better solution with a wide range of communication modeling services in an integrated manner. The proposed architecture is to address this need with services from RF layer (reachability, link quality) to network planning, optimization, and performance assessment. It can also emulate specific traffic flow in realistic network condition and cyber contest environment. Its design is flexible, allowing different types of interfaces to communicate with other wargaming tools. REST API is used for quick response to a request from a wargaming tool. Interactive GUI interface allows a wargamer to be involved in the process of modeling communication service. Realtime interface allows exchanging data between CMS and other tool in real time either directly (e.g. using DIS) or via middleware (e.g. TENA).
While the paper demonstrates the architecture of communication modeling services in the wargaming system, the architecture itself can be applicable and useful for other M&S systems that have similar requirements in assessing communication quality and cyber resilience.

WARGAMING TYPES and PHASES

A wargame involves human players or actors making decisions in an artificial contest environment and then dealing with the consequences of their actions. Wargames consist of players who make decisions, an environment they try to effect, rules that govern decisions to be made, and adjudication models that specify how actions affect both players and the environment.

In general, wargaming can categorized in different types as shown in Table 1 below

Table 1: Wargaming Types

Wargaming	Description
Concept development	Defining or validating concepts of future operation where warfighters, using military art and science, might employ new capabilities to meet future challenges and exploit future opportunities
Capability development and analysis	Identifying, assessing, validating, and prioritizing capability requirements, gaps, and solutions
Science and Technology (S&T)	Similar to capability development but emphasizing more on research of how new and emerging technologies may impact existing concepts, enable new capabilities or inform future force design changes.
Senior leader engagement and strategic discussion	Focus is not necessarily on adjudicating outcomes but using them to engage in discussion and to gain feedback from senior decision makers
Operational decisions and plans	Focuses on informing current and future plans, and challenges wargame that examines and assesses Operational Plans (OPLANS) through the use of Course of Action (CoA) wargaming to assess the feasibility, assumptions, risks and potential outcomes in order to identify elements that require modification
Training and education	Train warfighters on current or future roles in synthetic but realistic environment with operational or tactical problems and exercise decision making in the presence of limited information

It is noted that some wargaming types are closed to each other, for example, the wargaming of concept development often leads to new capability development and analysis. Or they may be overlapped, for example capability development and science & technology.

Regardless of what use case might be, once it was decided to use wargame to solve a problem or create knowledge, there is a sequential, well-defined process with following phases as shown in Figure 1

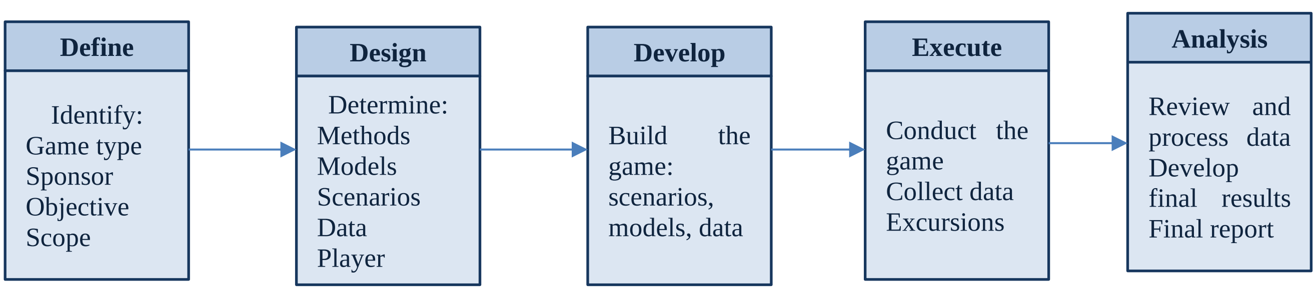

Figure 1 Wargaming Phases

It is noted that there could be multiple iterations where the wargamer can go back and forward between phases. For example, during the development phase, the wargamer identifies new models needed for the scenario, so she/he will go back to the design phase to redefine model or design a new one. More often, when conducting the game in the execute phase, the wargamer may need to change scenario, that results in excursion but sometime requires development of completely new scenario. Because of those iterations and if the execute phase is for Run-Of-Record, the wargamer can have a rehearsal phase between the development and execute phases to ensure the game is ready to play.

If the design phase concluded communication models should be a part of the designed wargame, this requires the wargamer to design communication models and scenarios where those modes are employed, and data needed for the analysis. Then, during the development phase, the wargamer develops a set of scenarios, and identifies communication modeling services required. The next section will describe some typical communication modeling services in the context of their use cases at different wargaming phases and show benefits of using CMS.

USE CASES of COMMUNICATION MODELING SERVICES

Planning for Force Deployment

This is a part of the development phase when the wargamer needs to create various scenarios for the game. Starting with a simple case, the wargamer wants to assess RF connectivity among force entities she/ he just lays down on specific terrain. The wargamer requests service of RF connectivity given radios location and operation area to check RF coverage. Assuming RF connectivity shows some loopholes, the wargamer can change laydown of force deployment such as add relaying radios to get better connectivity. Then, she/he can also request network topology planner to provide number of relaying radios that can ensure good coverage through the operational area.

Achieved RF coverage, the wargamer continues redefining scenarios with the service of network performance assessment. The objective is to characterize network baseline in term of load, throughput, delay, and Quality of Service (QoS). Those performance parameters determine if the network can handle mission traffic profile, and mitigations for overload situations. In such cases, QoS profiles need be assessed to ensure resource for high priority data are adequate.

Another aspect of the scenario the wargamer can look at is network resilience. For example, the wargamer can emulate a situation when a platform carrying relaying radio is damaged because of opposing force's strike. CMS can help to figure out if backup relaying radios can timely reestablish the network. If not, the wargamer can use CMS to evaluate alternatives such as SATCOM to increase communication range without relaying radios.

Wargaming Execution

As the game is being executed, each game tools need to synchronize in real-time. It is noted that the game can run in real-time, faster than real-time or slower than real-time. Regardless of what run time mode the game is in; all tools need to synchronize in time. For simplicity, the further discussion is for real-time mode i.e., simulation time is the same as wall clock time

CMS provides continuous real-time comm data as depicted in Figure 2, using one of two approaches, packet modeling and flow modeling. In packet modeling, a force entity simulator sends request to CMS to model specific message that will be constructed at sender and forwarded towards intended destination(s). The modeled message travels along network according network topology and its routing table and is subject to various delays such as transmission delay or queue delay. The message might be dropped at any point in the network because of various reasons, for example queue overflow, no route, and collision in RF environment. Moreover, effect of cyber attacks can be incorporated to make the model closer to realistic operational environment.

This detailed modeling is suitable for short data flow i.e., flow consists of few messages like C2 message. In the flow modeling, a force entity simulator sends request to CMS to model a flow, e.g., video streaming or voice call. The request contains flow description necessary for CMS (more specifically Scenario Generator) to construct flow model. For example, description of voice call is duration, sampling rate and encoding scheme. The CMS is expected to provide a report of flow performance, for example raw metrics number packets received vs. number of packets sent, end-to-end delay, jitter. The CMS can go further, based on raw metrics and flow type, to assess whether voice call is audible, or video stream is viewable

Post Wargame Analysis

As a part of post-game analysis, processing and reviewing data may reveal additional excursions needed. Since CMS is designed to keep record of all communication scenarios and their executions, it can easily modify those communication scenarios to make excursions as requested.

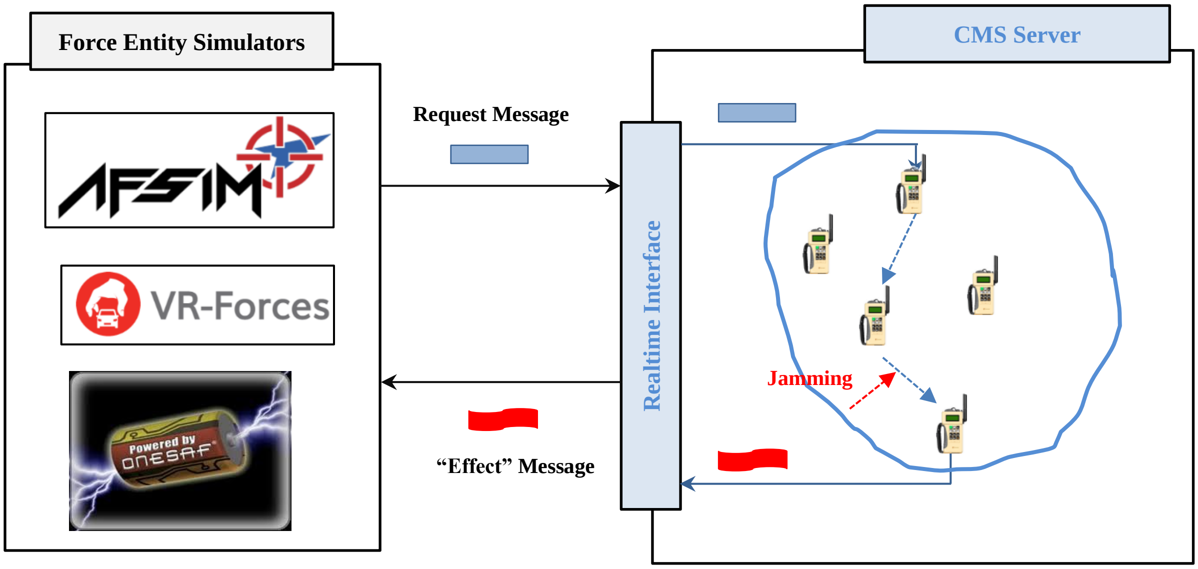

Figure 2 Continuous Communication Data via Real-time Interface

ARCHITECTURE for COMMUNICATION MODELING SERVICE

Need for Architecture of CMS

The use cases described in previous sections demonstrate diversified needs of communication modeling. Traditionally, force entity level simulators such as OneSAF, AFSIM, or VR-Force have built-in communication modeling capability that provides simplistic models, for example Line-Of-Sight RF modeling (i.e., as long as two radios in Line-Of-Sight within threshold distance, they can communicate). Realizing limitation of such simplistic models, the user has tried to interface force entity level simulators with high-fidelity network modeling tools to take advantage of realistic modeling. As an example, DIS/HLA have been used to conduct real-time platform-level wargaming across multiple M&S tools. While this type of real-time interface is needed for wargaming, but it is not suitable, sometime impossible for integration with other communication modeling services. If we revisit the use case of "Plan for Force Deployment", it is clear we need responsive services for RF connectivity, network topology and network performance. Those services require simulation to be executed as fast as possible so the wargamer can continue to adjust her/his force deployment. A REST API endpoint with request- response work much better in such case as the wargamer can send multiple requests for different force deployment plans and evaluate those plans based on responses from communication modeling services.

In wargaming systems with different wargaming phases and types, it is clear that, one interface is not solution to all wargaming use cases. It is also clear that the solution for communication in wargaming has to be an architecture where multiple communication modeling services and interfaces are combined. The architecture should be also flexible to include new communication modeling services without changing existing architecture.

Architecture Description

Given some use cases described in the previous section, the following CMS architecture is proposed in Figure 3. This architecture includes several components, interfaces, Service Manager, modeling services, Scenario Generator, Network Simulator, and Communication Data Database.

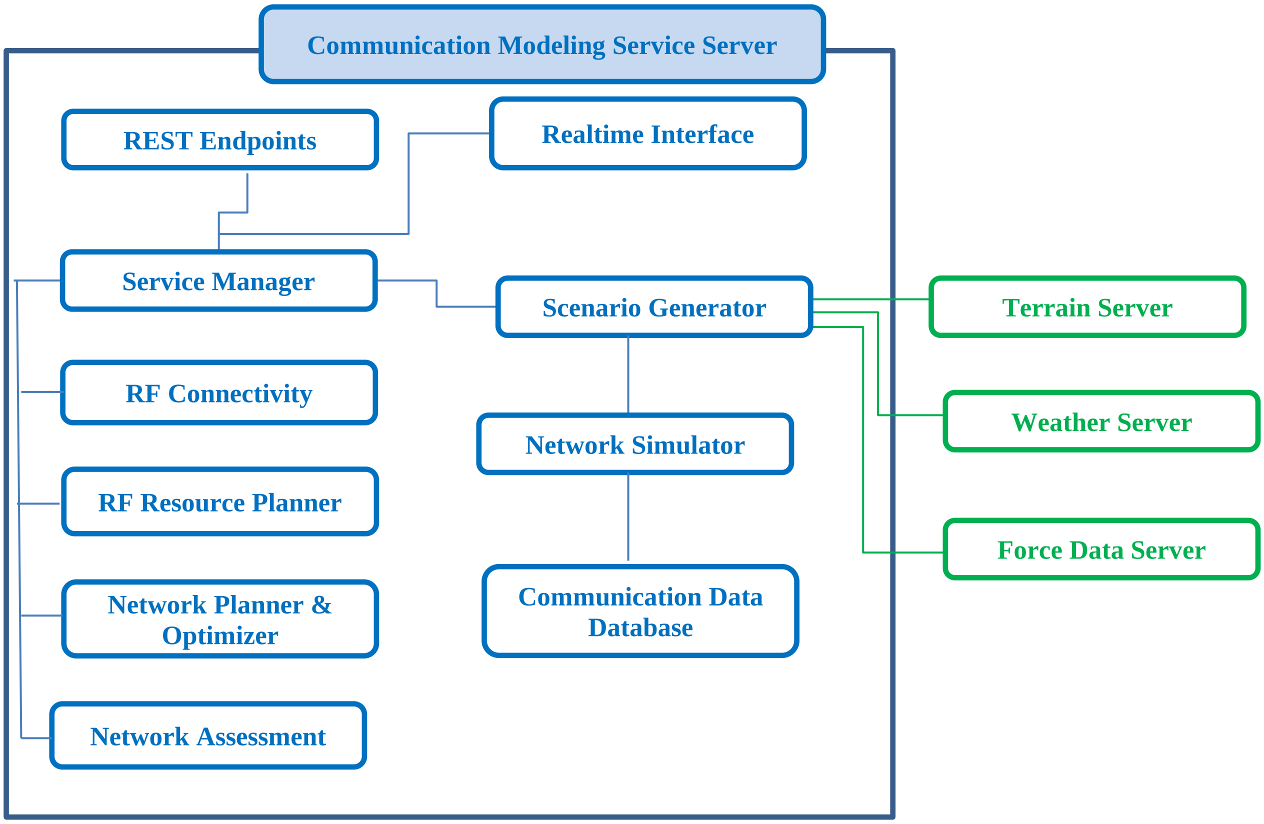

Figure 3 Communication Modeling Service Architecture

Service Manager is a central component managing not only different communication services but also interfaces and Scenario Generator.
Communication service components are to provide response to specific CMS request. For example

- Given a force laydown, what is RF connectivity among force entities with LINK-16 radios
- Given an area of operating, what is minimum number of relaying radios or base stations for good RF coverage with SNR of receiving signal not less than -70 dB
- Given a network topology with specific radios, what is achievable throughput with end-to-end delay no more than 200 milliseconds

Based on CMS request, communication service component prepares configuration data necessary for Scenario Generator to build communication scenario.
Depending on request type, the communication service component can process output data to prepare for the response once communication scenario's execution is completed or during its execution.
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There are currently two interfaces, REST endpoints and real-time interfaces. However, other interfaces can be added to the architecture to expand its capabilities.

The REST endpoints are very useful during the development phase of a wargame when the wargame is evaluating possible options of force deployment, and wants to know basic communication capabilities available to the force

The REST endpoints can be used during the execution phase, when the wargamer wants excursion from baseline. The excursion is to quickly test additional assumptions or hypothesizes that deviate the executing scenario from the baseline.

Real-time interfaces are for CMS to provide continuous real-time communication data, and for the wargame to provide force entities' status (position/mobility, operation status). Examples are DIS (Distributive Interactive Simulation) or TENA (Test and Training Enabling Architecture, https://www.trmc.osd.mil/tena-home.html) . This type of interface is used during the execution phase where the wargame requires accurate and in real-time modeling of packets, messages or flows (data/voice/video)

Regardless of what interface is used, once a CMS request is received, a workflow will start as shown in Figure 4. Service Manager will work with Scenario Generator to build a communication scenario corresponding to the request. A communication scenario typically includes network topology, radio/ device configuration, environmental factors (terrain, weather), and application traffic.

Network topology may be depicted physically or logically but let assume it is a structure of how radios/ devices are connected physically. The connection can be point-to-point or shared link.

Network topology can be built from a mission communication plan that is typically a part of the wargame development phase or derived from force structure.

In the later approach, a structure of planned force deployment can be used to derive a network topology or at least its initial version that can be redefined. For example, a wargamer plans Forward Arming and Re-Fueling Point (FARP) mission [MCWP 3-21.1 Aviation Ground Support] where Marines are inserted forward in the battle space and quickly establish or occupy an existing expeditionary landing field to support rearming and refueling of manned and unmanned aviation assets. The force deployment includes multiple teams and personnel, commanded by Operation Facility (OPFAC). This FARP force structure implies two tier communication architecture: tier 1 is communication between members in each team, and tier 2 is communication between teams and OPFAC. Therefore, a network topology can be built accordingly as shown in Figure 5.

When building network topology, Scenario Generator also retrieves radio and device data from Force Data Server. In a wargaming, Force Data Server is a central database that stores among many things, force entities' data such as mobility (i.e. speed), logistic (i.e. fuel consumption), weapons (i.e. missile, gun), electronic (radios, communication, EW). Since communication plan or force structure are (or should be) referenced to Force Data Server, it is straightforward for Scenario Generator to map a radio/ device in communication scenario to Force Data Server.

If terrain is a part of a wargaming scenario, its area coordinates will be included in the CMS request. Then, Scenario Generator can request terrain files from Terrain Server. In communication modeling, terrain affects RF signal propagation, hence should be included in the communication scenario.

Similarly, weather such as precipitation rate might also have impact on some upper frequency ranges, hence should be included. Note that Terrain Server and Weather Server are not only used by CMS but other wargaming tools.

Output from Scenario Generator will feed into Network Simulator for execution.

Network simulator, usually implemented as discrete event engine, simulates the interactions between the different network entities such as routers, switches, radios, end workstations, access points, links (wired and wireless). In particular, the network simulator takes into account environmental factor such as terrain and weather when simulating wireless links. By using discrete event algorithms, the network simulator changes system state when the interactions occur at discrete points in time. Since the network simulator can jump from one discrete point to the next one, this allows simulation to be executed faster than wall clock time, hence saving time on scenarios with long simulation time.

As the network simulator executes a scenario, it also generates instrumentation data that reflect network behavior. The types of collected data depend on nature of communication modeling service request. Also, the data are also needed for post-game analysis, so SQL database was selected to meet those requirements. Beside data needed for the communication modeling service request, the network simulator may collect detailed packet transmissions to investigate root cause of issues. Those details include every packet transmission from sender, through immediate nodes and at the final destination, and packet navigation through protocol layers.

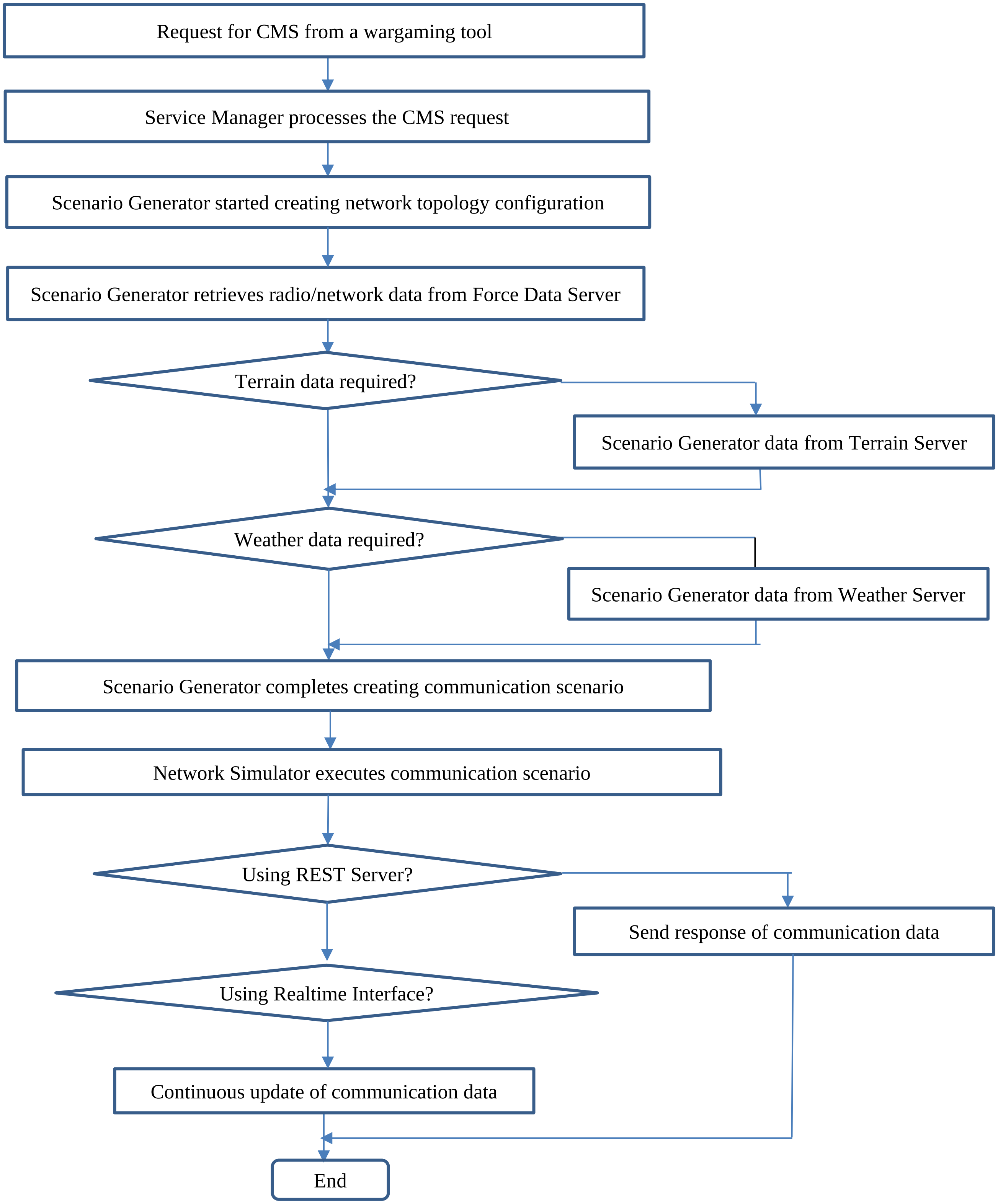

Figure 4 Work Flow for Communication Modeling Services

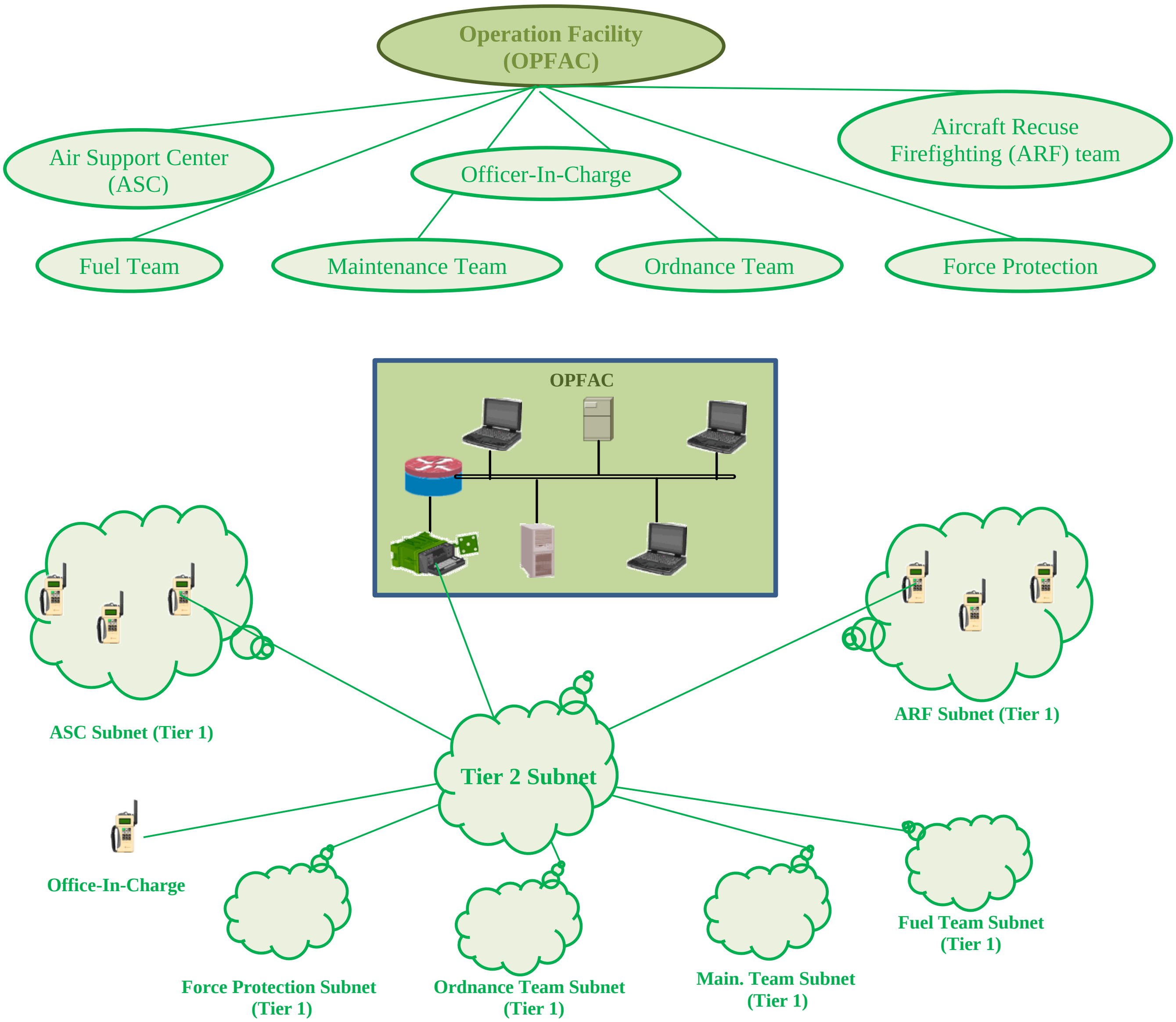

Figure 5 FARP Force Structure (Top Figure) and Its Derived Communication Network (Bottom Figure)

APPLICATION of CMS in CONCEPT DEVELOPMENT WARGAMING

Background

As described in section "WARGAMING TYPES and PHASES", the concept development is an exploratory wargaming to visualize future operations where warfighters, using military art and science, might employ capabilities to meet future challenges. In particular, new emerging communication technologies are area the wargamer would like to have better understanding how they would shape the future fight, and some of them might become game changer. In this section, we will examine how the wargame of concept development can be played to explore 5G network in the context of tactical radios.

The Department of Defense (DoD) has long expressed interest in 5G network, hence established the "5G to Next G" initiative to accelerate the use of 5G networks and associated 5G technologies in support of DoD use cases. In particular, the US Marine Corps (USMC) is interested in exploring the suitability of 5G networks and technologies for its expeditionary operations.

5G [https://en.wikipedia.org/wiki/5G] consists of digital cellular networks that, like its predecessors, are divided into small geographical areas or cells that allow spectrum reuse and increase service capacity. Moreover, 5G includes some breakthrough technologies that offer more and better services such as enhanced Mobile Broadband (eMBB), massive Machine-Type Communications (mMTC), and ultra-reliable low latency (URLLC). As with Network Digital Twin, 5G services and capabilities are very attractive for many DoD applications, such as networked sensors for force protection and persistent ISR, edge computing using ML/AI, connected vehicles / autonomous platforms and Command and Control / Situational Awareness (C2/SA).

Currently, USMC relies primarily on UHF and VHF voice radios, limiting data exchange and creating highly detectable electromagnetic signatures. Even using more advanced networking radios (for example, PRC-117G with SRW and ANW2), communications capabilities cannot support the diverse range of networked devices such as radars, cameras, and a wide range of short-to-midrange sensors (acoustic, seismic, magnetic, and infrared) envisioned for future expeditionary advanced base operations, thus requiring more capable communication technologies such as 5G to ensure adequate bandwidth with guaranteed QoS communication while enabling more advanced options for low probability of detection and interception.

Using CMS in Wargaming of Tactical Scenario

Assuming it was decided to use wargaming to evaluate new concept using 5G as tactical radio network. In the development phase, the wargamer is building a set of tactical scenarios that can use 5G network in their operations. One of scenarios to be played is FARP mission that was briefly described in the previous section. The wargamer decides to look at two communication modeling services, RF coverage area, and network performance provided by FARP 5G network configuration.

As the wargamer is developing the FARP scenario, she/he also needs a communication plan. As discussed in the previous section, such communication plan can be derived from the force structure. In this particular FARP scenario, two-tier communication plan is derived. If existing UHF/VHF radios are used, we would need to configure each subnet in different frequency and space between them big enough to ensure no or minimum inference. So, a spectrum usage plan is needed. If 5G replaces existing UHF/VHF radios, we do not need to configure each subnet separately as 5G offers huge data capacity that should be enough to accommodate entire FARP.

As the traditional FARP mission has relied heavily on human force to protect the mission, the new concept introduces the diverse range of networked devices such as radars, cameras, and a wide range of short-to-midrange sensors (acoustic, seismic, magnetic, and infrared). Such networked devices and sensor allow much better monitoring over much larger area, therefore OPFAC is able to coordinate strike to proactively eliminate potential threads. That would change the way how the mission can be executed with minimum human force protection. At the same time those networked devices and sensors require high data rate links which 5G network promises to deliver.

Next, the wargamer wants to figure out how may gNb (5G base stations) needed in the are of operation. The wargamer starts with one gNb (Figure 6), and realizes it is not enough to cover a group of force protection at the north. The, she/he adds two more gNbs, resulting in better coverage for entire are of operation (Figure 6).

Achieved RF coverage, the wargamer moves to verify network performance. There are different performance assessments, some of them are

- Maximum load the network can handle within packet drop and delay
- Network performance (throughput and delay) with typical traffic profile

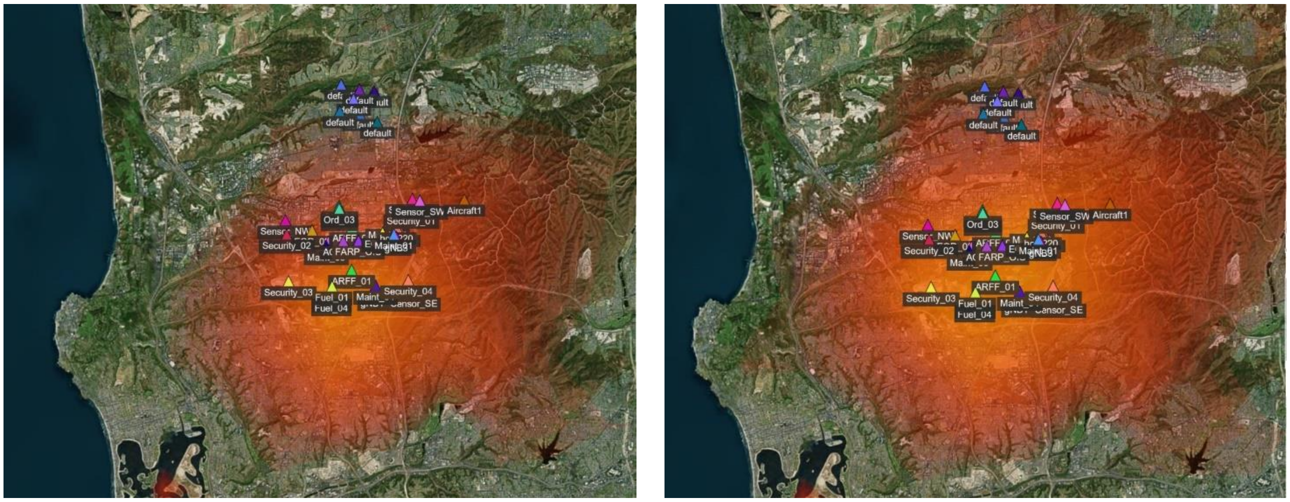

Figure 6 RF Heatmap with One gNb (Left Figure) and Three gNbs (Right Figure)

Figure 7 shows performance metrics (load and delay) obtained from the request of network performance assessment with typical FARP traffic profile (mixed voice, data and video streaming).

We can continue other requests of CMS to ensure 5G network configuration can meet FARP mission requirements.

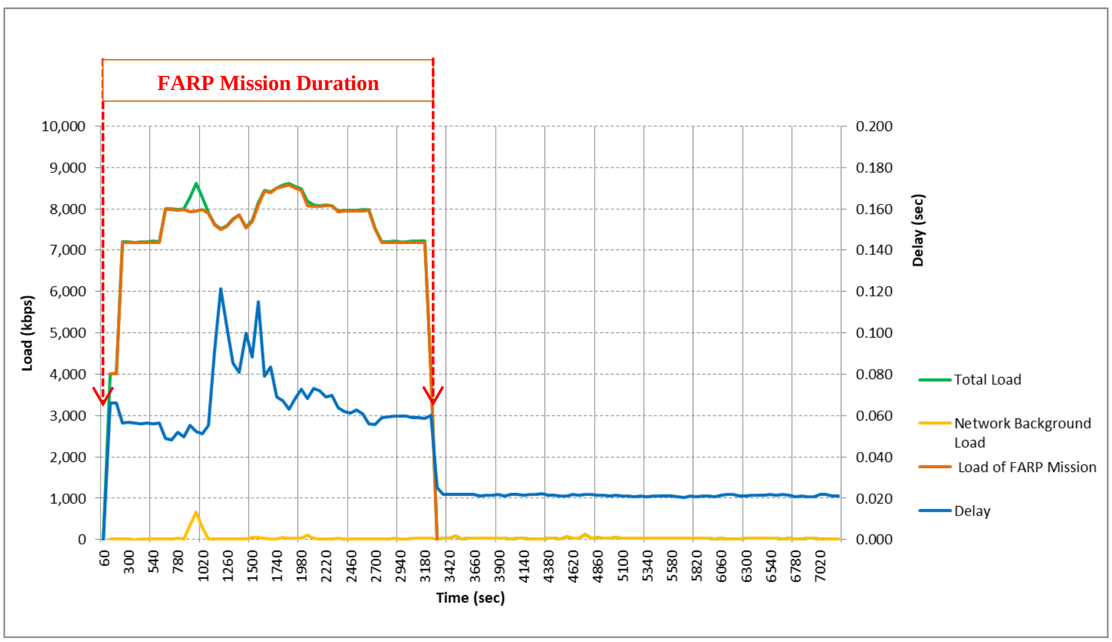

Figure 7 Network Performance in FARP Mission

SUMMARY

In this paper, we discussed the architecture for communication modeling services to enhance wargaming. As DoD, particularly US Marine Corp, have considered wargaming as an important part of warfare concept and capability development, force design, education and training, warming capability and fidelity need to be at new higher level, resulting in needs of diversified communication modeling services, from RF connectivity, RF spectrum usage from network planning, optimization and performance assessment. The proposed architecture including various components such as interfaces, Service Manager, Service Components, Scenario Generator, Network Simulator that offers flexibility to add more communication modeling services as their needs grow. We demonstrated use of communication modeling service in a wargame for concept development through 5G network deployment in the FARP tactical scenario.

Although the architecture was discussed for wargaming, it can be extended to support other application domains. For example, it can be used to provide modeling services in enterprise network deployment, maintenance, and upgrade, as well as testing. "What if " modeling service can be requested when we want to upgrade the current network. RF coverage service is needed when adding new Access Points to the existing WiFi network.
In fact, the architecture can be applied to any business operation that has similar needs of communication modeling services as a wargaming scenario. For example, in sport events or concerts the organizer definitely needs to plan RF network (5G, WiFi) to ensure good coverage and adequate network capacity to meet user experience expectation (i.e. network QoS) for fans and attendees.

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