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COMMUNICATION MODELING FOR A COMBAT SIMULATION IN A NETWORK CENTRIC WARFARE ENVIRONMENT

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ABSTRACT

Effective and efficient information sharing in a warfare environment is a key feature of the Network Centric Warfare (NCW) concept, and a combat simulation model should reflect this key feature. Most existing combat simulation models adopt a simplified communication model, which may lead to overestimating an actual level of communication performance. On the other hand, while providing accurate assessment of communication performance, a low-level, detailed, engineered model for communication tends to be overly sophisticated and computationally intensive to incorporate in typical combat models. In this paper, we propose a communication model in the context of an engagement-level of NCW combat simulation. In particular, we use a propagation loss model to determine a success or failure of individual communication attempts. We also define a set of model parameters to characterize various communication networks deployed in a battlefield. Preliminary simulation experiments and their results are presented to illustrate the proposed modeling framework.

1 INTRODUCTION

Network Centric Warfare (NCW) is a modern concept of warfare, and the core of the NCW concept is to attain information superiority from improved situational awareness. Situational awareness is improved by seamlessly connecting various entities in a battlefield, producing networked information. In order to represent an NCW combat environment in a warfare simulation, a simulation model must incorporate a process of accomplishing information superiority: acquiring battlefield information by reconnaissance units, sharing the information through a communication network, and utilizing the information in a decision process.

Due to a partial and uncertain nature of information acquisition, there often exists a gap between the situational awareness and the ground truth of a real combat situation. Sensors may provide wrong or distorted information. Communication of obtained information may further degrade information due to various losses, delay, and distortion. These factors render command and control (C2) and other combat agents to form incomplete situational awareness, which deviates from a real situation of a battlefield. Quality and timing of decisions made by C2 depends on the quality of situational awareness it attains. When based on poor situational awareness, it ultimately affects the combat effectiveness and leads to damages to friendly forces.

A combat simulation model should incorporate the process of forming a potentially incomplete situational awareness. This is especially important when a combat simulation model intends to capture a combat environment of NCW. It requires modeling various elements in C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance). Of these C4ISR elements,

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this paper discusses modeling of the communication component. Specifically, we focus on a method to model imperfect communication, which affects a decision process of C2.

To model the effects from various factors of a battlefield environment on communication, the proposed communication model adopts an approximation of engineering-level models: a propagation loss model and a communication network model. To demonstrate the utility, a simple experiment of communication between two agents and a pilot study of a close air support (CAS) scenario are presented.

2 PRIOR RESEARCH

2.1 Framework to Model Communication Functions for a Combat Simulation

While NCW modeling has traditionally focused on the C2 aspect of warfare, more recent NCW combat models tend to incorporate all elements of C4ISR. They are modeled as a separate and specifically characterized entity in a combat environment to assess their effect on C2 (Cares 2004, Tolk 2012). Along this trend, agent-based modeling is a widely employed modeling framework. Sensor, C2, and shooter elements are agents in an engagement-level NCW combat model (Alberts, Garstka, and Stein 1999). A sensor agent obtains information on friendly and enemy forces in a battlefield. A C2 agent analyzes the information obtained by sensor elements, and makes tactical decisions for other elements. Lastly, a shooter agent responds to an issued command by moving, attacking, waiting, etc. NCW effects are produced by the interactions among these elements in a battlefield environment.

An implication of the above representation is that a communication function must be accurately modeled in an engagement-level combat model. Figure 1 (a) shows an example of networked interactions of the three types of agents: sensor (*S*), decider (*D*), and influence (*I*) agents (Cares 2004). An enemy target (*T*) is detected by a sensor agent, and the sensor agent conveys information on the enemy target to a decider agent. Then, the decider agent delivers a command to an influence agent (i.e., shooter). Finally, the influence agent executes the command to influence the target. In Figure 1 (a), two arrows ($S \rightarrow D$ and $D \rightarrow I$) represent information transfer between two agents. A successful interaction requires a successful communication. Hence, representing the networked interactions among *S*, *D*, and *I* agents requires modeling of communication functions in a battlefield environment.

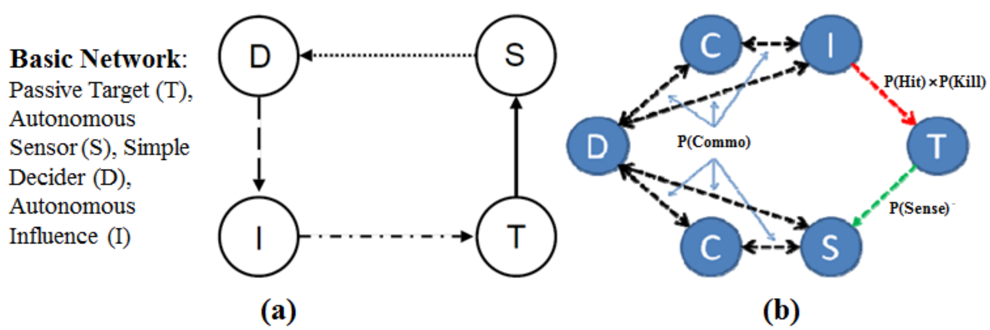

Figure 1: (a) An example of three types of agents: a sensor, a decider (C2), and an influence (shooter) (Cares 2004) and (b) an extended version of (a) with an explicitly-defined communication node (Tolk, Bowen, and Hester 2008).

In most of the existing NCW combat models, communication functions are modeled by a simple mechanism, e.g., a communication range model (Liu and Zhang 2008; Park et al. 2010). Table 1 shows how communication functions are modeled in a few well-known examples of agent-based, engagement-level NCW combat simulation systems. They use exogenously defined communication range that largely ignores terrain effects from a battlefield environment. They also assume all communication networks are identical, and do not incorporate varying performance characteristics of different networks.

To properly capture complexity of communication functions, recent developments in NCW combat modeling tend to view a communication model as an independent modeling element. For example, Tolk, Bowen, and Hester (2008) extend a combat network representation in Figure 1 (a) to model a communication function as an independent node (i.e., agent) in a combat network (communication (*C*) nodes in Figure 1 (b)). They implement various communication features such as full duplex communication, a controllable communication range, obstacles, and the probability of successful communication.

Table 1: Agent-based, engagement-level NCW combat models and their communication models (Liu and Zhang 2008; McIntosh et al. 2003; Yang et al. 2006).

Engagement-level NCW combat model	Communication model
ISAAC	• A given communication range • Single communication network
WISDOM	• A communication range and pairs between communicable senders and receivers are given • The probability model of the reliability and noise • Single communication network
MANA	• Given pairs between communicable senders and receivers • Parameters: the communication delay and capacity • Single communication network

2.2 Parametric Model and Engineering-Level Communication Model

While a simple parametric communication model offers the benefit of easy implementation, it tends to oversimplify the true complexity of communication. Information delivery via military wireless communication is affected by many factors in a battlefield environment. For example, two entities attempting to exchange messages may not be able to establish communication due to physical obstacles between them. Or a communication network in the region may be overloaded, and it may experience delay or loss of messages. In addition, a military unit uses various types of communication equipment with different characteristics, which yield different communication performance. Representing all these factors with a few predetermined parameters, e.g., range and probability, leads to a gross approximation and simplification. Hence, assessing the effectiveness of communication requires a model that captures various factors influencing communication functions in an NCW environment.

A possible solution to modeling communication functions in a battlefield simulation is to adopt an engineering-level communication simulation model. These types of models are physics-based and capable of a very detailed analysis. A primary purpose of such models is to evaluate performance of a communication network to aid in network design efforts. As such, these models are highly sophisticated and computationally intensive. This presents a significant challenge in adopting these models in an engagement level of NCW combat simulation. An engineering-level communication simulation model is most likely to be overly complicated and computationally expensive in the context of a typical combat simulation. A communication model for a combat simulation needs to find a balance between high fidelity of an engineering-level model and easy implementation of a simple parametric model.

Given that the primary role of a communication model in an engagement-level simulation is to generate imperfect (i.e., realistic) situational awareness on the combat situation, we propose an approximate engineering-level communication model. The goal of this model is to represent terrain effects and characteristics of communication networks with a level of detail required by an engagement-level combat simulation. The proposed communication model is composed of a propagation loss model and a communication network model. It builds on physical principles of radio wave communication while limiting the model's complexity to an acceptable level to incorporate into an engagement-level combat simulation.

3 PROPOSED COMMUNICATION MODEL

A modeling framework underlying a communication model discussed in this paper is an engagement-level agent-based NCW combat modeling (Park et al. 2010; Shin et al. 2012). In the framework shown in Figure 2, combat agents are constructed by component-based agent modeling – a higher-level combat agent (e.g., battle ship) is constructed by combining lower-level agents (e.g., ship, radar, missile launcher). A communication function is modeled as a separate modeling element, called "network layer", through which combat agents exchange information and commands. Each combat agent in a battlefield – *S* (sensor), *D* (C2), *I* (shooter) – is represented as a node on the network layer, and communication among combat agents is modeled within the network layer. Environmental factors such as terrain characteristics (e.g., height map) and weather are defined in an environment layer, and they are used in executing communication functions in the network layer.

The proposed communication model consists of a propagation loss model and a communication network model since both affect the performance of communication (Shin et al. 2012).

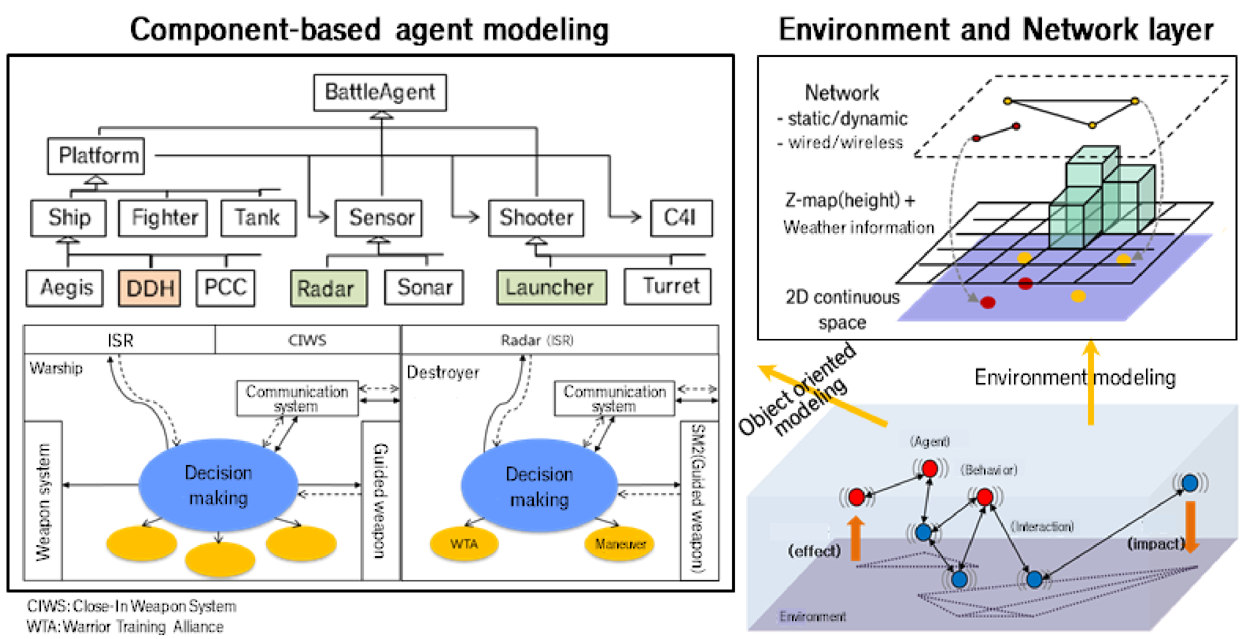

Figure 2: The proposed framework of agent-based, engagement-level NCW combat modeling (Park et al. 2010).

3.1 Propagation Loss Model

A radio wave is vulnerable to the environment between a sender and a receiver. Transmitted from a sender, it reaches a receiver through successive interactions with obstacles: reflection, refraction, and diffraction. These processes attenuate the signal due to distance, obstacles, and phase difference. So, transmitter power and receiver sensitivity should be large enough to overcome attenuation for successful communication.

A precise estimation of attenuation requires complicated computation: tracing all paths, calculating effects of reflection, refraction, and diffraction on each path, and estimating resultant amplitude and phase. Ray tracing is a popular method which approximately traces diverse paths. This method searches radio waves that reach a receiver, and evaluates attenuation on each path. Ray tracing is, however, computationally heavy to incorporate in an engagement-level combat model. Even with intensive computation, it does not consider all directions from a sender, so there is a missed area shown in Figure 3 (Bohacek et al. 2004).

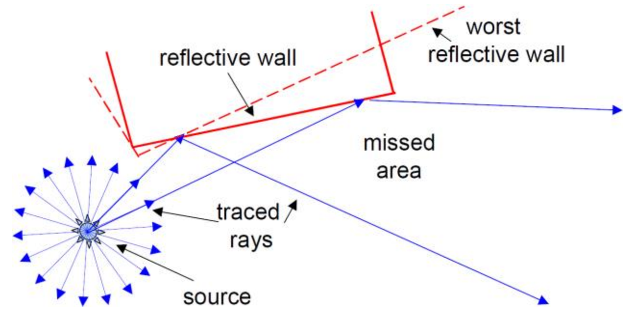

Figure 3: A description of ray tracing method (Bohacek et al. 2004).

As a reasonable alternative, we adopt a propagation loss model on a direct path between a sender and a receiver. This method approximately analyzes the environmental effects while reducing time to search all radio paths, and thus it seems more suitable to an engagement-level combat model. There are many theoretical and empirical equations that can be easily applied to an engagement-level combat model.

Propagation loss (PL) on a direct path is computed as the sum of free space loss (FSL), diffraction loss (DL), and gaseous loss (GL_w and GL_{O_2}):

$$\mathrm{PL}(\mathrm{dB}) = \mathrm{FSL}+\mathrm{DL}+\left(\mathrm{GL_W} + \mathrm{GL_{O_2}}\right)\times d\ ,$$

where d is communication distance in kilometers. This model deterministically decides success or failure of communication. If transmitter power minus the total propagation loss is larger than receiver sensitivity, it is considered a successful communication, and a failure otherwise. Transmitter power and receiver sensitivity are a function of specification of a communication device used by combat agents.

Below, a brief description of FSL, DL, and GL is provided.

3.1.1 Free Space Loss Model

Free space loss (FSL) is defined as the ratio of the received power to the transmitted power in free space. Equation (1) is a well-known form of a FSL model (Willis 2007):

$$\mathrm{FSL(dB)} = 32.44 - 20\log(f) - 20\log(d)\ , \tag{1}$$

where f is the carrier frequency in MHz, and d is the propagation distance in kilometers.

3.1.2 Diffraction Loss Model

A radio wave is bent by an obstacle when an obstacle is on its path. Diffraction loss (DL) increases depending on the amount of an obstacle's intrusion into a direct path of a wave. In estimating DL, an obstacle is typically approximated as a knife edge. The amount of intrusion is determined by Fresnel zone, which is an oval shaped region along the radio wave's direct path. Most energy of a radio wave is concentrated in the first Fresnel zone. In general, when more than 60 percent of the first Fresnel zone is clear from an obstacle's intrusion, the communication is considered as line-of-sight (LOS) communication.

Equation (2) gives approximate DL as a function of Fresnel-Kirchhoff diffraction parameter (Lee 1982).

$$\mathrm{DL}(\mathrm{dB})=\begin{cases}-20\log(0.5-0.62v), & -0.8<v\le 0;\\ -20\log\left[0.5\exp(-0.95v)\right], & 0<v\le 1;\\ -20\log\left[0.4-\left\{0.1184-(0.38-0.1v)^2\right\}^{1/2}\right], & 1<v\le 2.4;\\ -20\log(0.225/v), & v>2.4.\end{cases} \tag{2}$$

The Fresnel-Kirchhoff diffraction parameter, v, is

$$v=h\sqrt{\frac{2(d_1+d_2)}{\lambda d_1 d_2}},$$

where d_1 (d_2) is the distance from an obstacle to a sender (a receiver) in meter, h is the height of an obstacle in meter from an axis of direct path (can be either positive or negative), and λ is the wave length in meter. When v is less than minus 0.8, DL equals zero, which implies LOS communication.

Equation (2) is valid if there is only one obstacle on a radio wave's path. When multiple obstacles exist, one of the common methods is to approximate by multiple single-edges that represent the multiple obstacles (Akkaşh 2009, Willis 2007). Among a few known methods, our model uses the Bullington method. The Bullington method defines a principal edge representative of all knife edges. The principal edge is then regarded as only one knife edge on the path. In a situation shown in Figure 4 (a), where two distant hills are represented by multiple edges respectively, the Bullington method is preferred to other approximation methods in terms of approximation error and computation time.

Using the height-map in the environment model of Figure 2, a hill in a battlefield is converted into multiple edges at each cell of the height-map. Then, we use the Bulligton method to compute a principal edge between the transmitter and receiver. Computation of a principal edge is illustrated in Figure 4 (b). It uses two vectors of the largest angle, originating from a transmitter and a receiver, and the intersection of the two vectors defines a principal edge. In Figure 4 (b), two vectors $T1$ and $R3$ intersect at P, which defines its principal edge.

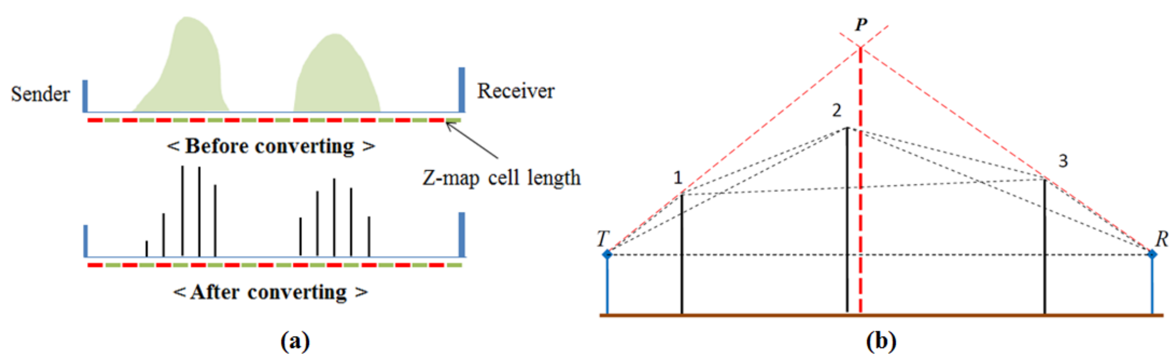

Figure 4: (a) Converting two obstacles into several knife edges in the height-map model of Figure 2 and (b) geometry for the Bullington method (Akkaşh 2009).

3.1.3 Gaseous Loss Model

Gaseous loss (GL) increases when the frequency of radio wave and the resonant frequency of gases in the medium cause resonance. Relevant gases are oxygen and water vapor. Significant attenuation occurs at 22.3, 183.3, 323.8 GHz for oxygen, and at 57-63, 118.74 GHz in case of water vapor (Willis 2007). These frequencies are not used in current military communication, and thus GL is not much of a concern as of now. We still include a GL model for comprehensiveness and in case a new (higher) frequency band is introduced to meet future communication demand. Equations (3) and (4) are GL models of water vapor (GL_w) and oxygen (GL_{O_2}), respectively (Willis 2007);

$$\mathrm{GL_w}\left(\mathrm{dB/km}\right) = \left\{0.05+0.0021\rho+\frac{3.6}{\left(f-22.2\right)^2+8.5}+\frac{10.6}{\left(f-183.3\right)^2+9.0}+\frac{8.9}{\left(f-325.4\right)^2+26.3}\right\} f^2\rho 10^{-4}, \tag{3}$$

$$\mathrm{GL_{O_2}}\left(\mathrm{dB/km}\right) = \begin{cases} \left[7.19\times10^{-3}+\dfrac{6.09}{f^2+0.277}+\dfrac{4.81}{\left(f-57\right)^2+1.5}\right] f^2\times10^{-3}, & f<57; \\ 14.9, & 57\le f\le 63; \\ \left[3.79\times10^{-7}f+\dfrac{0.265}{\left(f-63\right)^2+1.59}+\dfrac{0.028}{\left(f-118\right)^2+1.47}\right]\left(f+198\right)^2\times10^{-3}, & f>63, \end{cases} \tag{4}$$

where f is the sending frequency in GHz and ρ is the water vapor concentration in g/m^3.

3.2 Communication Network Model

Because NCW is realized by a tactical data link and various communication networks, an NCW modeling framework should differentiate each network's characteristics: e.g., network performance, frequency band used in a specific network, and type of platforms allowed to join the network. Table 2 summarizes the list of modeling variables to represent a communication network in a communication model for a combat simulation.

Table 2: Modeling components of a communication network.

Components	Description	Example
Available platforms	• Defines a list of platforms (combat agents) that can join a communication network – A platform (combat agent) is associated with certain type of communication network depending on its communication devices	F4 fighter
Frequency	• Specifies the frequency used for a communication network – Assume only one frequency is used for each band – Assume the same frequency is used by all platforms on a same network	500 MHz
Transfer rate	• Defines the rate of data transfer – Assume a constant rate for a communication network	64 kbps
LOS / Non-LOS	• Specifies whether non-LOS communication is feasible or not	Non-LOS
Half / full duplex	• Specifies whether the type of duplex (half or full)	Full duplex
Capacity	• Limits the size of data or the number of platforms communicating concurrently	100
Data type	• Specifies whether a network can handle voice or data	Only voice
Reliability	• Communication security is ranked by point scale	8.5 / 10

4 EXPERIMENTS AND RESULTS

4.1 Effect of the Proposed Propagation Loss Model

We first examine the significance of inclusion of the proposed propagation loss model in modeling communication in a battlefield. To achieve this, the proposed propagation loss model is compared with a simple communication range model. The range model does not consider environmental effects and simply determines the success of a communication attempt by the distance between a transmitter and a receiver.

In the experiment, two nodes randomly move on a hilly terrain (constructed using terrain data of a real-world location), and they attempt communication for 1,000 instances. We assume a communication device has the following specifications: the frequency of 300 MHz, the acceptable propagation loss of 115 dB, and typical range of 15 kilometers (Toyota Gibraltar Stockholdings Ltd. n.d.). Simulation experiments with the above setting are executed for 80 replications, and results from the two models are compared.

Figure 5 (a) shows the fraction of successful communication from the range model and the proposed propagation loss model. The range model yields 72 percent success fraction, while the propagation loss model shows only 37 percent of successful communication. The vast difference between the two models comes from the fact that the hilly terrain become obstacles to disturb communication in many instances. Figure 5 (b) confirms that most of communication attempts (98.6 percent) were in the non-LOS (NLOS) condition, where a communication attempt was hindered by some obstacles. Results in Figure 5 suggest that the performance of communication can be significantly overestimated if environmental effects are ignored by using a simple range model for communication.

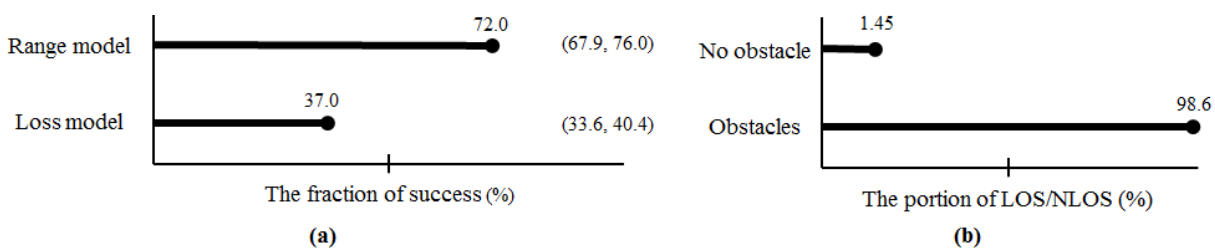

Figure 5: Experimental results: (a) fraction of successful communication on a range model and the proposed loss model (numbers in parenthesis indicate 95% confidence interval) and (b) portion of LOS and NLOS condition.

A closer examination of the results reveals more details on the source of discrepancy between the two models. We classify the outcome of each communication attempt from the two models into four categories: Case 1 where the two models report successful communication, Case 2 where the range model reports a success while the propagation loss model reports a failure, Case 3 vice versa, and Case 4 where the two models report a failure. Figure 6 (a) shows that the two models agreed on 61.9 percent of the communication attempts (Case 1 and 4), and disagreed on 38.1 percent of the instances (Case 2 and 3).

The fact that only 1.5 percent of the total communication instances falls into Case 3 indicates that the distance threshold of 15 kilometers is more or less equivalent to {300 MHz, 115 dB} setting of the propagation loss model. This suggests that when the two nodes are a distance of more than 15 kilometers and thereby being judged a failure by the range model, the propagation model also reports a failure in most cases.

Case 2 is particularly important since it represents the overestimation of communication success by the simple range model. Case 2 represents a situation where the two nodes are close to each other (i.e., within the communication range), but the propagation loss is significant enough to render a communication attempt a failure. The reason for this disagreement is due to the existence of obstacles causing NLOS communication, which is evidenced by Figure 6 (b) and (c). Figure 6 (b) shows a minor difference in FSL for Case 1 and Case 2, which suggests FSL is not a major cause of discrepancy between the two models. This is expected because FSL is a function of distance between the two nodes, and both Case 1 and Case 2 represent communication attempts when the two nodes are at their proximity. The source of disagreement is the diffraction loss shown in Figure 6 (c). When the diffraction loss is relatively small (21.1 dB in Case 1), a communication attempt is successful. On the other hand, in Case 2, the diffraction loss is higher at 31.3 dB, causing failure even when the two nodes are nearby.

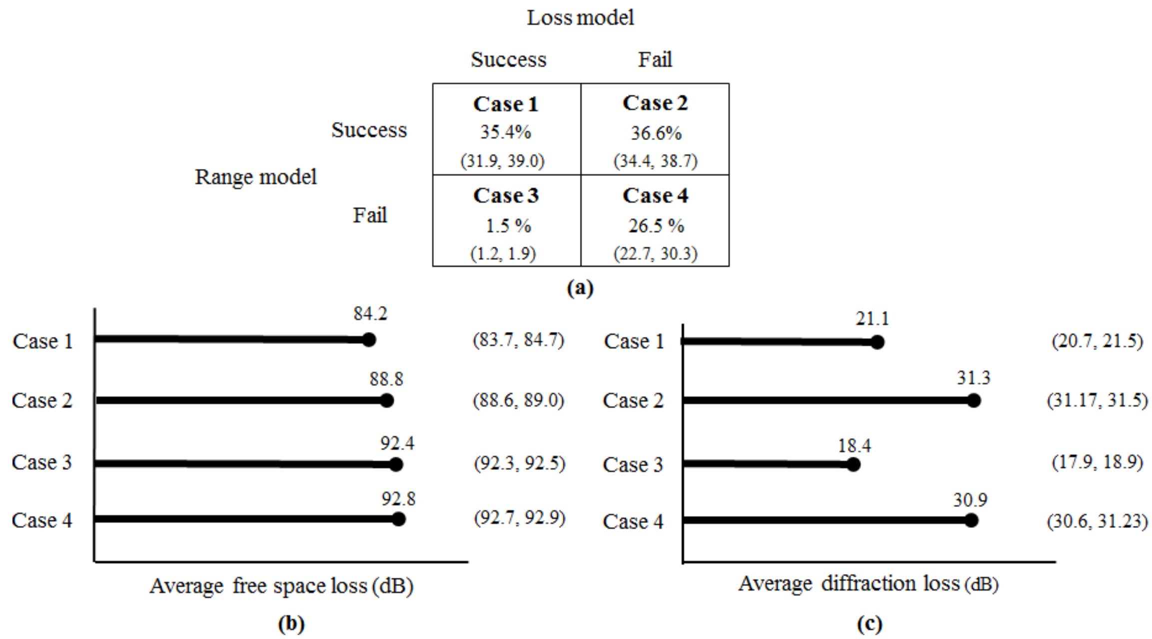

Figure 6: Experimental results: (a) categorizing a communication attempt in four cases and the portion of each case, (b) average free space loss, and (c) average diffraction loss.

4.2 Experiments Using CAS Scenario

A close air support (CAS) scenario is a good example to assess the effect of communication in an NCW environment. In this scenario, a sensing unit detects an enemy. A request for CAS is made to the tactical air control party (TACP), and fighter aircrafts sally into the enemy area and attack the enemy.

Specifics of the CAS scenario for our experiment are as follows: assets of friendly forces are located at OO position, and guarded by four K2 tank units. Three RASIT radars are deployed north of the friendly force's position to detect possible intrusion by the enemy force. Several units of enemy forces make their move to attack the friendly force. RASIT radars detect the intrusion of the enemy force that move south toward the friendly force's position. RASIT radars send the information to the C2 post (i.e., TACP). C2 assesses the size and the threat level of the enemy force based on shared situational awareness, and if necessary, it requests support by fighters (F4 fighter jet). Up to ten F4 fighter jets can be called upon to provide CAS. The dispatched fighter jets carry out a sortie into the enemy area. During a sortie, fighters continuously receive commands and information from the C2 post, sharing information on the enemy force. Each fighter is assumed to carry out only one sortie. It is also assumed that it can attack at most four times during one sortie, and its kill probability depends on the accuracy of information (i.e., current location of enemy targets) it obtains from the C2 post. This assumption makes the communication an essential factor for the effectiveness of CAS mission. With the support from the fighter jets, K2 tanks are then engaged in combat with the enemy force. Note that it is assumed for simplicity that RASITs and F4 jets are not destroyed by the enemy's attack, and only K2 tanks are subject to enemy attacks. A simulation run is terminated when either enemy forces or friendly forces are completely destroyed.

Four types of hypothetical tactical data links are assumed in the scenario. C2 and K2 tanks are connected via an Army network. C2 communicates with the fighter jets through an Air Force network. RASIT radars send surveillance information to C2 via a RASIT network. K2 tanks and F4 fighter jets are linked via an Air-to-Ground network. Table 3 shows a list of each network's performance characteristics. For all these networks, we assume unlimited data transmission capacity. Two of the communication network parameters – data type and reliability – are not considered in this scenario.

The above CAS scenario is implemented on the proposed modeling framework (Figure 2) with the communication model discussed in section 3. We use AnyLogic™ v6.6.0 to model the scenario. Figure 7 is a screen capture from a simulation experiment in the AnyLogic™ environment. Figure 7 (a) shows an initial situation, and Figure 7 (b) shows the moment that RASITs detect enemy forces and send the information to the C2 post. Simulation experiments are replicated 20 times.

Table 3: A description of communication networks in a CAS scenario.

Network	Platforms	Frequency (MHz)	Rate (kbps)	LOS/ NLOS	Half/full duplex	Threshold (dB)
Army	C2, K2	100	38.4	NLOS	Full	115
Air Force	C2, F4	1,000	238.0	LOS	Full	115
RASIT	C2, RASIT	100	38.4	NLOS	Full	115
Air-to-Ground	K2, F4	500	64.0	NLOS	Half	115

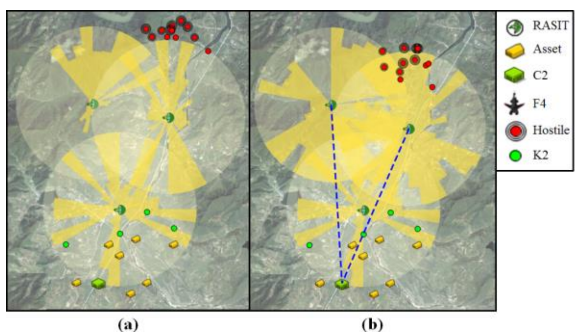

Figure 7: AnyLogic™ model implementation of a CAS scenario.

We measure the fraction of successful communication attempts, fraction of successful attacks by the fighter jets, and preserved friendly force after engagement. Preserved friendly force is defined as a weighted sum of the number of survived K2s and of unused F4 fighter jets, with a weight of 6 and 10, respectively. This is to measure the amount of consumption of friendly force's combat capacity.

As a reference for comparison, we run the CAS scenario with an ideal communication assumption. Under this assumption, all communication attempts between any two combat agents are always successful. Results from this experiment are used to highlight the effect of incorporating the proposed communication model in a combat simulation. Figure 8 shows the experimental results.

The fraction of successful communication is about 50 percent when using the proposed communication model (Figure 8 (a)). That is, half of the commands and information could not reach an intended receiver. Key information in the CAS simulation includes the number and type of the enemy force, and their location information. This information is the basis for C2 to determine if, when and how many fighter jets are needed for CAS operation. Information on the location of the enemy force is delivered to the fighter jets to improve the kill probability of their attacks. Failure to communicate these pieces of key information results in a negative consequence in the mission. Fraction of successful attack by fighter jets is 43.5 percent, compared to 83.6 percent under the ideal communication model (Figure 8 (b)). These factors lead to a larger consumption of combat resources: more fighter jets needed to be dispatched, more K2s lost during the engagement (Figure 8 (c)).

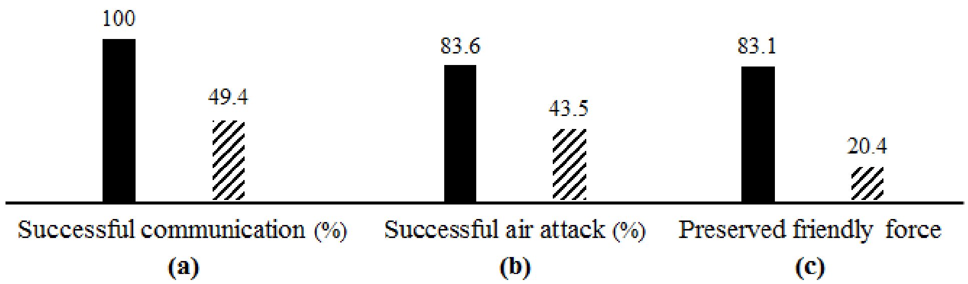

Figure 8: Results from CAS experiments: the probability of (a) successful communication and (b) successful air attack, and (c) amount of preserved friendly force (solid bars for ideal communication, hashed bars for the proposed communication).

5 CONCLUSION

A central benefit of Network Centric Warfare is improved situational awareness and a common operating picture shared by combat participants. Due to a partial and uncertain nature of information acquisition and delivery, there often exists a gap between the attained situational awareness and the ground truth of an ongoing combat situation. A combat simulation model should incorporate the process of forming a potentially incomplete situational awareness. This is especially important when a combat simulation model intends to capture the NCW combat environment.

This paper focuses on a method to model imperfect communication affecting a decision process of a C2. To model the effects from various factors of a battlefield on communication, the proposed communication model adopts an approximation of engineering-level models: a propagation loss model and a communication network model. The propagation loss model determines success or failure of a communication instance by computing total attenuation of radio waves caused by communication distance and terrain effects on a direct path between two parties. A gaseous loss model is also included for comprehensiveness. The communication network model defines modeling variables to characterize the individual communication network deployed in a real battlefield environment. A simple two-node communication experiment and a case study on a close air support scenario demonstrate that a simplistic parameter model can severely overestimate the outcome of a combat simulation, hence justify the proposed communication model.

A communication model for an engagement-level combat simulation needs to find a balance between high fidelity of an engineering-level model and easy implementation of a simple parametric model. The propagation loss model and communication network model proposed in this paper offer a reasonable level of details at low computational cost for a combat simulation in an NCW environment.

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