MODELING THE COMMUNICATIONS CAPABILITIES OF THE INFANTRY SOLDIER

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ABSTRACT

The US Army's Land Warrior system provides each soldier in an infantry squad with a wearable personal area network (PAN) consisting of various sensors, a radio system, and a computer system, designed to enhance the individual soldier's awareness of his own situation and that of his unit. Each Land Warrior PAN in turn is a node in an IEEE 802.11 wireless local area network (WLAN) that connects him to the rest of his unit. Similar protocols connect each unit to its parent units and siblings. The bottom node in this tree architecture is the individual soldier.

This project models the data, video, and voice network in the Land Warrior 1.0 system, from squad member to company commander, in a light infantry unit. The model represents an actual IEEE 802.11 WLAN and simulates the flow of information generated by Land Warrior-equipped soldiers. The traffic sources used in the simulation place loads according to statistical distributions derived from measurements on a real Land Warrior network. The model we developed is being used in a continuing effort to analyze the performance of the Land Warrior network in a wide variety of scenarios.

INTRODUCTION

The U.S. Army's Land Warrior System provides each soldier in an infantry squad with a wearable personal area network (PAN) consisting of various sensors, a radio system, and a computer system. This PAN is designed to enhance the individual soldier's awareness of his own situation and that of his squad, and improve his ability to acquire and interpret critical decision-making intelligence [1].

Each Land Warrior PAN is a node in an IEEE 802.11 wireless local area network (WLAN) [2, 3] that connects him to the rest of his squad. This WLAN connects the entire platoon, company and battalion to enhance total situational awareness [1].

The purpose of this research was to model the proposed Land Warrior 1.0 WLAN from the soldier level to the company command level using OpNet software[4]. Raw data collected during a Land Warrior exercise was used as a basis for the model.

The focus of this research was modeling the network connectivity and assessing the robustness and scalability of the current WLAN architecture.

LAND WARRIOR

The purpose of the Land Warrior fighting system is to integrate the capabilities of an infantry soldier into a war-fighting system that maximizes a soldier's abilities in close combat. Land Warrior is designed to be the soldier’s system, incorporating all equipment for the infantry soldier. It enhances the combat effectiveness, situational awareness, lethality, mobility, and survivability of both the individual soldier and the infantry unit. This contributes to a more lethal force that will be more effective in exploiting both tactical and strategic objectives [1].

The Land Warrior 1.0 network contributes to the overall Land Warrior combat system by providing both individual soldiers and command echelons with situational awareness tools and improved communications capabilities. The network consists of a wearable computer network to collect information from the soldier’s environment and provide the soldier with combat intelligence. Each soldier’s PAN is a node in the network and is connected to all the other nodes in the squad and platoon by a IEEE 802.11 WLAN. From the platoon level, the network employs data over combat radio technology to link the network to the battalion and higher echelons.

The Single Channel Ground and Airborne Radio System (SINCGARS) radios provide the data link to battalion and higher echelons. SINCGARS radios provide combat radio communication with frequency hopping and digital data transmission capabilities at a data rate of 9600 bits per second.. This system operates between 30 and 87.975 MHz over 2320 channels, giving each channel 25 KHz.

Under current, non-Land Warrior, communications systems, infantry soldiers have only limited access to information regarding their unit's status in an engagement. All the intelligence has been limited to voice communications over combat radio. The Land Warrior system will provide voice and data transmission capabilities to each soldier.

The purpose of this project is to model this network. An OpNet network model simulates network and evaluates the performance against the specifications of the Land Warrior system. This model uses existing network protocols and network traffic data from field experiments using the Land Warrior System.

This project consisted of two components: evaluating experimental data and modeling the network using chosen network protocols. The data provides insight into network load and bandwidth constraints. Once the network data has been analyzed, the capabilities of the current network architecture was simulated and tested against the expected network usage.

DATA ANALYSIS

The network data upon which the OpNet model is based was taken from a Land Warrior 1.0 exercise conducted at Ft. Polk, Louisiana by a platoon of infantry soldiers (approximately forty to forty-five soldiers) equipped with the Land Warrior system. The platoon performed a night airborne (i.e., parachute) insertion and movement to contact.[1]

Data from this experiment was collected over a period of five hours, from approximately 0300 hours to 0800 hours, during the time between the platoon's landing and assaulting their objective.

Analysis of Data

The data captured from the Ft. Polk experiment consisted of several statistics regarding frequency and types of message data. Over three hundred thousand lines of data were retrieved, consisting of a timestamp for the data, the size of the file, the IP addresses of the sender and receiver, and the type of data being transmitted.

A Java application was used to preprocess the raw network data and identify packets that fell into one of four categories: Active Soldier packets, voice over Internet Protocol (VOIP) packets, Email packets, and map overlay packets. Active Soldier packets contain the position location data (from GPS) about each soldier equipped with Land Warrior. VOIP packets are the most common, and they carry voice transmissions between soldiers. Email packets are used to send requests for artillery fire, requests for medical support, situation reports, and other messages. Overlay packets are used to transmit graphical information to be displayed on soldiers' map displays.

The following statistics and distributions describe the Ft. Polk data:

Voice Over IP (VOIP) packets
Inter-arrival times: Exponential [$\lambda = 112.537$]
Sizes: Lognormal [min = 64, $\mu = 118.041$, $\sigma = 27.4399$]

Global Positioning System (GPS) packets
Inter-arrival times: Weibull [min = 56, $\alpha = 2.73$, $\beta = 12$]
Sizes: Lognormal [min = 64, $\mu = 187.682$, $\sigma = 4.371$]

Email packets
Inter-arrival times: Exponential [$\lambda = 11.486$]
Sizes: Lognormal [min = 202, $\mu = 205.057$, $\sigma = 8.4649$]

Map Overlay packets
Inter-arrival times: Lognormal [min = 0, $\mu = 233.813$, $\sigma = 4.282$]
Sizes: Lognormal [min = 88, $\mu = 113.6$, $\sigma = 5.908$]

Analysis using Minitab[5] probability plots identified that the distributions were satisfactory fits to the data samples. Goodness of fit test will likely reject the null hypothesis that the distribution fits the data when the model is developed from a data set this large (n = 300,000).

[1] Land Warrior's effectiveness in enhancing situational awareness was demonstrated when a soldier was able to eliminate an enemy sniper solely through the use of his Land Warrior equipment. After receiving sniper fire, the soldier consulted his overlay map, noted the position of each of the members of his unit, and all human signatures. Finding a human signature that did not match the location of any friendly force, the soldier identified the enemy and eliminated the sniper without taking any loses due to fratricide.

Sample Data Set	Distribution Name	p.d.f Form in StatFit	Para-meters	Key Statistics	Test Statistics	Sample Statistics	Accept / Reject
VOIP IATs	Exponential	$f(x) := \frac{1}{\lambda}\cdot e^{\left[\frac{-(x-min)}{\lambda}\right]}$	λ = 112.537	μ = .004247, σ = 3.274	Chi^2 = 16.9 KS = 0.0618 And. = 2.49	Chi^2 = 283 KS = 0.826 And. = 983	All Reject
VOIP Sizes	Lognormal	$f(x) := \frac{1}{(x-min)\cdot\sqrt{2\cdot\pi\cdot\sigma^2}}\cdot e^{\frac{(-\ln(x-min)-\mu)}{2\cdot\sigma^2}}$	min = 64 μ = 3.84 σ = 0.693	μ = 118.041, σ = 27.4399	Chi^2 = 36.4 KS = 0.31 And. = 2.49	Chi^2 = 671 KS = 0.0158 And. = 121	All Reject
GPS IATs	Weibull	$f(x) := \frac{\alpha}{\beta}\cdot\left(\frac{x-min}{\beta}\right)^{\alpha-1}\cdot e^{-\left[\frac{(x-min)}{\beta}\right]^{\alpha}}$	min = 56 α = 2.73 β = 12	μ = 66.4 σ = 4.022	Chi^2 = 9.49 KS = 0.172 And. = 2.49	Chi^2 = 9.17 KS = 0.155 And. = 2.17	Accept
GPS Sizes	Lognormal	$f(x) := \frac{1}{(x-min)\cdot\sqrt{2\cdot\pi\cdot\sigma^2}}\cdot e^{\frac{(-\ln(x-min)-\mu)}{2\cdot\sigma^2}}$	min = 64 μ = 4.81 σ = 0.107	μ = 187.682 σ = 4.371	Chi^2 = 26.3 KS = 0.0292 And. = 2.49	Chi^2 = 126 KS = 0.428 And. = 34	All Reject
Email IATs	Exponential	$f(x) := \frac{1}{\lambda}\cdot e^{\left[\frac{-(x-min)}{\lambda}\right]}$	min = 102 λ = 11.486	μ = .0833 σ =132.87	Chi^2 = 12.6 KS = 0.104 And. = 2.49	Chi^2 = 140 KS = 0.366 And. = 22.8	All Reject
Email Sizes	Lognormal	$f(x) := \frac{1}{(x-min)\cdot\sqrt{2\cdot\pi\cdot\sigma^2}}\cdot e^{\frac{(-\ln(x-min)-\mu)}{2\cdot\sigma^2}}$	min = 202 μ = 2 σ = 1.21	μ = 204.178 σ = 7.165	Chi^2 = 12.6 KS = 0.103 And. = 2.49	Chi^2 = 737 KS = 0.834 And. = 289	All Reject
Overlay IATs	Lognormal	$f(x) := \frac{1}{(x-min)\cdot\sqrt{2\cdot\pi\cdot\sigma^2}}\cdot e^{\frac{(-\ln(x-min)-\mu)}{2\cdot\sigma^2}}$	min = 0 μ = -1.4 σ = 1.29	μ = 1.2725 σ = 5.908	Chi^2 = 21 KS = 0.0456 And. = 2.49	Chi^2 = 191 KS = 0.273 And. = 197	All Reject
Overlay Sizes	Lognormal	$f(x) := \frac{1}{(x-min)\cdot\sqrt{2\cdot\pi\cdot\sigma^2}}\cdot e^{\frac{(-\ln(x-min)-\mu)}{2\cdot\sigma^2}}$	min = 88 μ = 4.98 σ = 0.0974	μ = 233.811 σ = 4.304	Chi^2 = 37.7 KS = 0.0153 And. = 2.49	Chi^2 = 481 KS = 0.417 And. = 210	All Reject

Table 1. Data Distribution and Hypothesis Tests**.**

A Kolmogorov-Smirnov (KS) test, a chi-squared test, and an Anderson-Darling test were performed between simulated values generated by the theoretical distribution and the data points. The tests were conducted using StatFit[6]. The results from the goodness of fit tests are summarized in Table 1.

As expected, seven of the eight distributions would be rejected based on the goodness of fit tests. We relied on the graphical results from the probability plots to verify the suitability of the distributions and ensure the distributions would allow OpNet to simulate the network traffic.

Additional research will attempt to refine the data distributions by separating the data into different phases of the mission. Investigation using Monte Carlo techniques will possibly simplify the distributions by sampling the data set and attempting to fit the smaller samples. During the next Land Warrior exercise, we will investigate using multiple distributions to model operational phases of the platoon's mission.

OPNET NETWORK MODELING

Model Development

The Land Warrior 1.0 WLAN was modeled in OpNet. OpNet is a robust network-modeling package that has a number of very useful features. OpNet contains a number of predefined nodes. Nodes represent configurations of machines and the services provided by those machines. Network users/clients are defined by profiles, which specify the frequency of the generation of messages and requests for services. Users of OpNet can use predefined profiles or modify them as appropriate. This feature allowed us to modify usage profiles using the probability distributions computed based in the actual network traffic data.

The nodes in the model are *wireless LAN servers (mobile)* from the wireless palette in OpNet. The application profiles of each node were modified to represent soldiers, team, squad and platoon leaders, and company and battalion commanders. Application profiles were developed using the derived data distributions to for each of the primary message types: VOIP, GPS, Email and overlays.

The major scenarios worked with in this design are a platoon, a platoon with only two squads, a company, and a company with only two platoons. The profiles developed for these scenarios were profiles for the company commander, the two platoon leaders, the squad leaders, the team leaders, and member of squad. The commanders and leaders in the platoon were given two profiles to allow for the two nets they will utilize, one to their level and higher, and one to their level and lower.

OpNet facilitates the collection of statistics after each simulation run. The user must specify the maximum time to run the simulation, the seed, and the statistics desired. The results are displayed and can be exported for further analysis.

We have only partially completed the network modeling and gathered preliminary data. Eventually we need to run experiments consisting of multiple battalions. Due to the length of time needed to run scenarios of that size and the need to validate the model with the smaller scenarios first, experimentation with units larger than company (approximately 150 soldiers) remains as future work.

Data Collection

The simulations conducted in OpNet used existing software models for the IEEE 802.11 protocol for communication. The model was created from the squad up, beginning with a squad leader and two team leaders on a network, expanding to a full squad, enlarging that squad to three squads and a platoon leader, and finally creating two more platoons and a company commander. This gradual expansion of the model allowed for easier model validation.

New tasks, applications, and overall profiles for each of the soldier-nodes were created within the model to generate the proper amount of network traffic. The profiles are assigned to each soldier-node, and each profile contains a number of applications. Each application contains a given number of tasks, and the tasks themselves are composed of attributes, one of which is the frequency and size of messages sent. The probability distributions generated from the Land Warrior 1.0 field experiments were used to update the user profiles in the OpNet model.

Sensitivity Analysis

A 2^k Factorial Design was used to conduct a sensitivity analysis on the OpNet model[7]. In order to analyze the effect of a single factor on the model, it is a simple matter of adjusting the factor and calculating a confidence interval. In order to fully understand the behavior of the network, multiple factors must be adjusted. Factors that greatly affected this network were the addition of soldiers to the network, and adjusting several of the data distributions expected value to their maximum observed value. The simulation runs were conducted using a platoon with three complete squads. It took approximately five hours to run four simulations with each simulation generating data for one hour of simulated time.

Since there are *k* factors in this design, and it is necessary to examine how each factor individually affects the outcome of the experiment as well as potential interactions between factors, a 2^k factorial design was used to plan the experiments. This required that two levels were chosen for each factor, a maximum and a minimum value, and a simulation was run with every possible combination of these factors. Table 2 illustrates these combinations, with each factor assigned a plus sign (+) when the factor was at its maximum level, and a minus sign (-) when the factor was at its minimum. The factors to be investigated were the frequency of the messages sent over the network for Email, overlay, and voice data. The size of each sent message is assumed to be constant.

GPS inter-arrival times did not have any statistically significant differences over the operations and are therefore assumed to be constant, with a mean inter-arrival time of one minute. This was supported both by the design documentation as well as the analysis of the network traffic data. GPS, or Active Soldier, packets are supposed to be sent once by each soldier every minute.

The inter-arrival times of Email, map overlays, and VOIP were analyzed. These three factors provided eight data points for analysis. For the response values, the maximum net delay and maximum throughput were measured. The simulation values used in this analysis were determined by analyzing the three-squad platoon model. All experiments began with the same seed value to improve repeatability and to ensure that different streams of pseudo random numbers did not account for any changing results when the size of the network was increased.

Network delay and network throughput were designated as the response values, by which the overall effectiveness of the network would be measured. To obtain response values, the network simulation in OpNet was altered and run several times to obtain a mean value for both the network delay and the network throughput. The positive or negative designation was multiplied by the corresponding design point response to determine the effect of each factor on the network. For example, the following equation represents the effect of Factor 1, the unit size, on the network:

$$e_1 := \frac{-R_1 + R_2 - R_3 + R_4 - R_5 + R_6 - R_7 + R_8}{2^k}$$

The resulting e_j value is defined as the difference between the average response when factor j is at its '+' level and when it is at its '-' level. In essence, the process takes the dot product of the factor column with the response column. The result is a mean error value resulting from the lack of or the presence of the factor being analyzed. The simulation was repeated several times, with minimum values for each factor defined as the mean of each distribution, and maximum values for each inter-arrival time defined above.

Factors					
	Factor 1	Factor 2	Factor 3		
Design Points	Email IATs Avg / Max	Overlay IATs Avg / Max	Voice IATs Avg / Max	Net Delay	Through put
1	-1	-1	-1	0.00654	7412.67
2	1	-1	-1	0.00703	8594.44
3	-1	1	-1	0.00654	7412.67
4	1	1	-1	0.00703	8594.44
5	-1	-1	1	0.00623	8058.89
6	1	-1	1	0.00817	9100.89
7	-1	1	1	0.00623	8058.89
8	1	1	1	0.00817	9100.89

Table 2. Design of Experiments

Factor effects were computed as shown in the following table:

Factor	Effect 1 (Delay)	Effect 2 (Throughput)
e1 (Email)	~0	1111.885
e2 (Overlay)	0	0
e3 (Voice)	~0	576.335

Table 3. Factor Effects Chart

When an effect shown in the table has a positive value, it increases the effect by a positive value of that amount; conversely, when the effect has a negative value it decreases the effect by that amount. These results show the average difference made by the addition of the particular factor being analyzed. For this experiment, negative values are preferable for Delay, which means that the factor is decreasing the network delay when it is added. The factors being added to the network increased delay and decreased throughput.

These results may at first appear counterintuitive. Recall, however, that this modeling was just for a single platoon and (later) company. At this scale, the network is not fully loaded. The addition of more Email packets, for instance, greatly increases throughput while doing little to delay. As the network becomes more fully loaded, we would expect throughput to reach some maximum value (related to the underlying technology of the WLAN). We would also expect the delays to begin increasing at that point. The determination of how many soldiers can be on the network before this peak load point is reached is the subject of future work on this project.

None of the factors examined in this experiment have a significant effect at the platoon level on message delay time measured in seconds. It has been determined that a delay time of more than 300 milliseconds is perceptible by human senses; nothing even approaching this can be seen here on the platoon level. When this factor is analyzed on the company or even the battalion level, however, this may change and there may be serious effects.

Out of the three factors examined, Email has the most significant effect on measured throughput, increasing our measurement on average by 1111.885 bytes. VOIP has the second highest effect on the throughput, an effect of 576.335 bytes. These are the largest producers of network traffic. In this simulation, the overlay option was not utilized frequently enough to produce a significant effect on the network. This again may change as the company and battalion elements are added.

This experiment determined which factors had a significant effect on the network, but in order to gain a precise understanding of the manner in which these factors affect it, or to determine a mathematical relationship between factors, further experiments must be run on different size units. The most useful part of this analysis is its ability to determine which factors have the most significant impact on the network, and to determine whether or not that factor causes the network to cease functioning effectively and methods perhaps of reducing that factor's impact on the network. By adjusting these values, it is possible to determine the sensitivity of the network to different ranges of these factors. By expanding this experiment to include additional units and a broader range of transmissions frequencies, the limits of the capabilities of the network can be further explored.

FUTURE WORK

The purpose of this project was to build the foundation model for future research and in-depth analysis. The current model only has four main scenarios; future scenarios would include a battalion-sized task force of different company size and composition for use in conducting sensitivity analysis and testing.

The individual profiles in this model currently account for the two command nets on which the platoon leader, squad leader, and team leader will communicate. The model should be expanded to include such considerations for the company commander and the amount of traffic that will be coming down from the battalion commander. Although the company commander is the highest command element to be equipped with Land Warrior 1.0, the communications traffic from the battalion commander will affect the company commander's communications profile, network throughput, and delay.

The model currently has updated distributions for voice, overlay, and Email transmissions that are common for all soldiers. However, soldiers at different command levels will likely need different distributions to model differences based upon position. For instance, it is likely that squad leaders will generate more VOIP packets than privates. Detailed data identifying the job of each node must be collected in upcoming field experiments.

As additional field experiments are conducted, additional data must be collected and more detailed analysis must be performed. The use of Bluetooth as a protocol for the PAN and implementing Mesh Radio technology to replace the SINCGARS tactical radio technologies are alternative technologies that should be explored in simulation.

CONCLUSION

This project involved developing an OpNet model of the Land Warrior 1.0 WLAN from the soldier level to the company commander to allow for network analysis. Data from the Land Warrior network field exercise was captured and analyzed to further refine the base OpNet model.

Preliminary simulations were run using the OpNet model with a platoon with three squads. Effects of three different factors on the network were examined, and it was determined that none of these factors had significant effect on network delay at the platoon level, but both Email and VOIP had a significant effect on throughput. Through further simulations and sensitivity analysis, mathematical relationships between the factors and the results can be determined.

REFERENCES

[1] Dismounted Battle Laboratory, "Operational Requirements Document for Land Warrior," U.S. Army Training and Doctrine Command, Ft. Benning, GA 3 February 1999.

[2] G. Held, *Data Over Wireless Networks: Bluetooth, WAP, & Wireless LANs*. New York, NY: McGraw-Hill, 2001.

[3] A. S. Tanenbaum, *Computer Networks*, 3rd. ed. Upper Saddle River, NJ, 1996.

[4] OpNet Technologies, "OpNet Technologies -- Software That Understands Networks," at http://www.opnet.com/, 20 September 2001.

[5] Minitab, "Minitab Homepage," at http://www.minitab.com/, 20 September 2001.

[6] Promodel Corporation, "PROMODEL - Manufacturing, Healthcare, and Service Simulation Solutions," at http://www.promodel.com/, 20 September 2001.

[7] J. L. Devore, *Probability and Statistics for Engineering and the Sciences*, 4th ed. Pacific Grove, CA: Duxbury Press: Brooks/Cole Publishing Company, 1995.