Exploring Communications in an Urban Environment with Agent Based and High Resolution Simulations

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1. Abstract

Many modeling tools assume a static level of communications capability throughout a run, and even worse a perfect level of capability. In reality, communications are impacted by a wide number of variables such as the operational environment and variance in network traffic levels. The modeling tools we use should factor in the complexities of networking if possible, but many times when we increase fidelity in our models we increase their complexity and performance, making them less valuable for quick-turn analysis.

To better capture variability in communications and mitigate the downside of complex models, we have tied a high resolution communications model QualNet to New Zealand's agent based model Map Aware Non-Uniform Automata (MANA).

At a recent International Data Farming workshop we were interested in exercising this combined modeling tool to better understand the impact of communications assumptions, particularly in an urban environment. To accomplish this, we have developed a scenario with agents representing a mobile convoy, infantry, and unmanned aerial support that deploy and cordon a building.

This paper investigates the outcome of this communications centric scenario when the network is modeled abstractly and with high fidelity.

2. Introduction

Goals and Objectives

Getting information to the warfighter is increasingly playing a larger role in today's operations. Through modeling and simulation we can gain better insight into what type of battlefield information is important to specific elements on the battlefield, and what technologies or architectures are the most efficient or robust, given a wide range of operational situations. Every situation presents a dynamic set of variables, objectives, actors, and conditions. Too often we ignore these dynamic aspects or do not have sufficient tools to model them effectively. We will use a combination of models to study the impact of dynamic communications in an urban environment.

Definitions: Networks, Network Capacity, and Network Management

Networks are made up of nodes, which in the context of the military are command vehicles, soldiers, sensors, and other users and producers of information. Nodes are said to be connected (or linked) if they can exchange information. Such links are facilitated using radios, satellite terminals, and other communication devices. The capacity of a link (or channel) is quantified in terms of the maximum rate of information flow. In the case of the experiments detailed in this paper, capacity is the maximum number of messages that can be transmitted on a channel at any epoch in the simulation.

For our purposes, a channel is a medium shared exclusively by a dedicated number of predetermined users (nodes) to send and receive messages. The maximum capacity of a channel is a maximum number of messages that the users can transmit on the channel at a point in time. When we tie in QualNet the messages become packets on a more comprehensive model of the network.

In the real-world, the capacity of a channel is a function of the spectrum allocated to that channel. That allocation can change and thus the ***supply*** of capacity can be changed. In addition, the number of users on a particular channel can be changed, which can limit the access to that capacity**.** In this paper, we consider the adjustment of supply and demand of the capacity of a network. We consider this to be network management. Because communication capacity comes from frequency spectrum allocation, the real-world implications should be clear.

MANA and QualNet

At this juncture it is important to discuss the nature of the two models at work in this study. MANA is an abstract, agent based model that drives two types of simulations being used to explore this particular operation. The first simulation uses MANA as a standalone model that captures the communications effects discussed in the previous section in addition to more common measures of combat success such as loss exchange ratio. We also model a mission objective as a binary success or failure possibility for the blue force. In theory we are capable of using multiple mission objectives, but this is not explored for this specific study.

The second type of simulation we run federates MANA with QualNet in real-time using services provided by both MANA and QualNet. The network being modeled in MANA is emulated by QualNet, only in much greater detail. QualNet models the entire protocol stack from the application layer to the physical layer, in enough physical rigor to model real network traffic through its simulated interface. As MANA makes decisions about agent movement it informs QualNet of these changes to keep the two models synchronized. SA messages generated by MANA are converted into packets in QualNet and injected into the QualNet network. Once this occurs, MANA does not know when (if ever) the messages will reach their destination. If they do reach their destination then QualNet informs MANA and the respective SA messages are released onto the maps of the MANA agents. It is this exchange that allows us to dynamically model communications within the context of an operational scenario.

Scenario Overview

The area of operations is relatively small at 5 km^2, but the Blue force does have a Forward Operating Base (FOB) acting as the Tactical Operations Center (TOC) for this city. The TOC has limited capability to process information from UAVs operating in the area, and make decisions about troop movements based on this information. More in depth analysis of the information would require other assets in theatre.

The Blue force has at its disposal one Stryker Brigade, and for this particular mission only one Stryker Battalion is available for operations. One of the Companies is currently in a reserve status, so only two Co’s are operational. One of the operational Co’s will remain active to support this mission, but remain at the FOB. As the mobilized Co moves toward the target, one platoon moves toward the north of town, and one takes a more southern route to the target. Intelligence believes that the Red lookouts will attempt to determine the likely destination of patrol route of the Blue forces based on their movements, so Blue has learned to be more deceptive about convoy movements. As they are moving toward the target location, Blue has the use of two UAVs (not pictured in Figure 1), an armed orbiting MQ-9 Predator and a RQ-5A Hunter. Two Stryker squads can potentially be given fragmentary orders based on surveillance data.

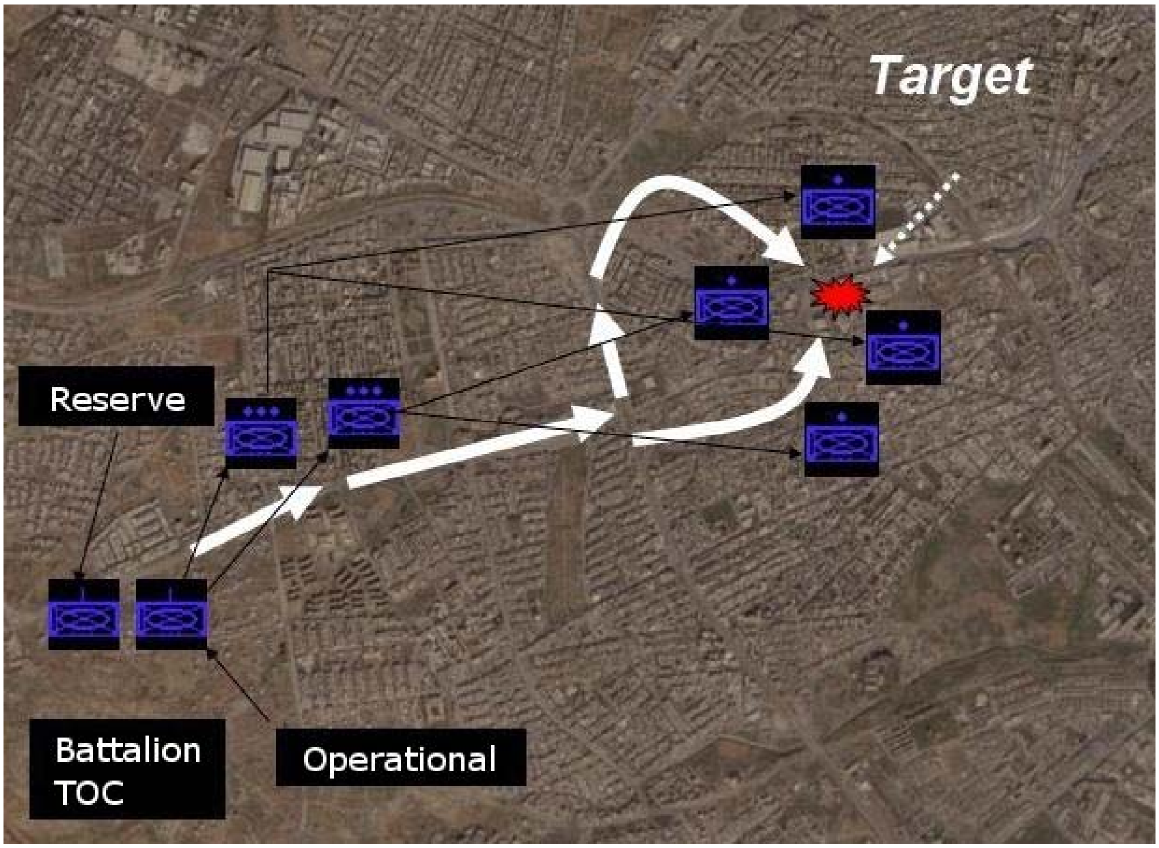

Figure 1: Scenario Overview

They move through the urban streets in a scripted fashion until they reach their planned locations for a cordon and search operation. The opposing forces (OPFOR) are located in the target building with several lookouts placed in random locations depending on the seed number. If the OPFOR see blue forces maneuvering they can pass the SA to the entities located in the target building which will begin to flee. UAVs can then be used to track those leaving the building and pass the SA back to the TOC. The TOC can then issue a fragmentary order (FRAGO) to preordained blue forces to move to a location and intercept OPFOR fleeing the location.

The primary objective of the Blue force is to search and secure the target location seen in Figure 2. If they encounter enemy combatants their first priority is to detain them, but if they are armed, the use of lethal force is approved. The Blue force should minimize non-combatant casualties as much as possible, understanding that keep the locals happy and feeling secure will pay dividends later. Any fleeing combatants can be pursued, but only for the distance of several blocks beyond the target location. Any ordnance discovered will require a detachment from the ordnance Battalion to move to the target location for proper disposal.

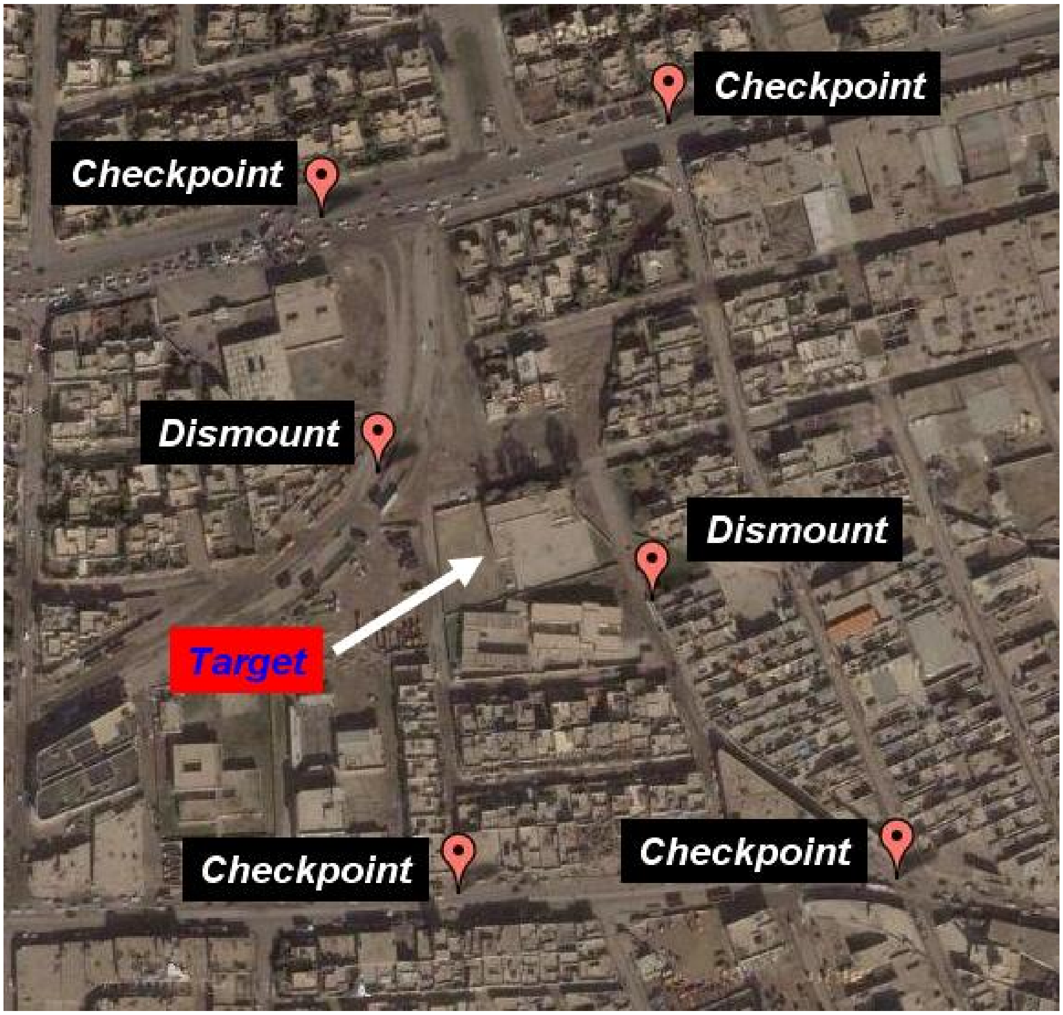

Figure 2: Close up of the cordon & search area

The blue force communicates using a simple hierarchical network that features the TOC as the information distribution center. A notional view of this network is seen below in Figure 3.

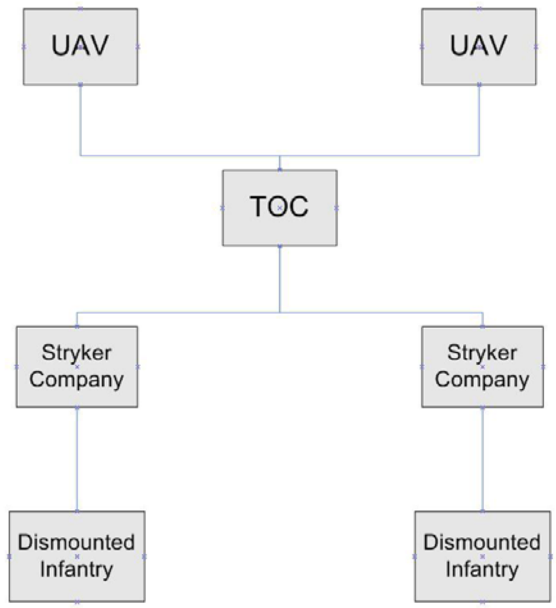

Figure 3: Simple communications hierarchy for the blue forces

The traffic on the network is essentially three types of information: SA, movement orders, and UAV video traffic. The SA messages are generated as entities move around the battlefield and sense other entities that could be friendly, enemy, neutral or unknown. Movement orders are set in advance, and can occur at a specific time, or based on a trigger from some event occurring in the scenario. Finally, the UAV video is modeled as the UAVs conduct surveillance of the target area. The UAVs use significantly increased amounts of bandwidth and communicate only with the TOC.

3. Experimentation and Analysis

Parameter Space

The experiment is intended to investigate the impact of static assumptions of communications in an urban environment, and our design of experiments should reflect that. For the MANA runs we used the following parameters:

Capacity – The number of SA messages an agent can receive on a communications link

Accuracy – The quality of the SA message (i.e. a mistaken report of red for blue)

Message Processing Time – The time it takes a agent to process an SA message

Reliability – The reliability of the communications link

Latency – The latency of the communications link

Range – The range of a communications link

For the MANA-QualNet experiments we used the following parameters:

Channel Size (kHz) – The size of the channel

Accuracy – The quality of the SA message (i.e. a mistaken report of red for blue)

Message Processing Time – The time it takes a agent to process an SA message

Radio Power (dBm) – The power of a radio

Channel size and radio power are more detailed representations of capacity and range. Latency and reliability were thrown out in the MANA-QualNet runs because QualNet calculates these values dynamically during the simulation.

MANA Only Results

In the first scenario we used MANA by itself, and explored using a large number of parameters and parameter values.

Experiment 1:

For the first experiment we modeled the following parameter space in a full factorial design.

Parameter	Design Points
Capacity	1,20
Accuracy	75,100
Latency	0,30
Reliability	30,100
Range	10,300
Process Time	10,300

Doing a regression analysis we saw an r^2 of .62, indicating a marginal fit that was reasonable for the first set of runs.

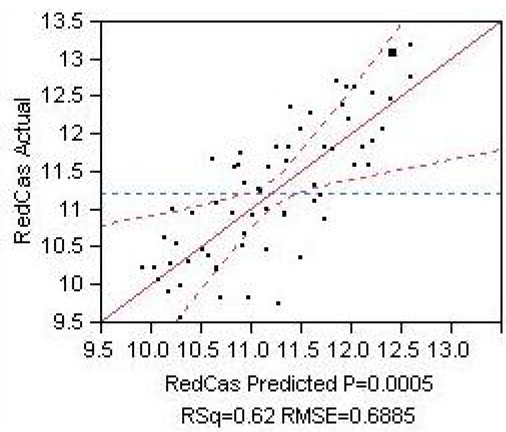

Figure 4: The regression plot for the first experiment

There were some interesting results in this experiment, specifically that high latency was the most important factor, and that blue performance improved significantly when this was the case. We traced this back to the fact that red also had a higher latency, and in the cases where it was 30 seconds, red was entirely captured or killed. While we were trying to understand what makes blue more effective in this scenario, we inadvertently found that it was more important to in effect, jam red's communications.

Several edge cases stood out, specifically one where there were 93% red casualties, and one with 6% red casualties. In the 93% case, there were successful FRAGOs to blue forces who were able to intercept agents who otherwise would have departed. In the 6% case, a blue vehicle was getting stuck, potentially representing a situation where the vehicle is detained for some reason.

Experiment 2:

For the second experiment we removed the process time parameter and added a third point to the latency. We then ran a full factorial design and achieved an r^2 of .61.

Parameter	**Design Points**
Capacity	1,20
Accuracy	75,100
Latency	0,30,60
Reliability	30,100
Range	10,300

Again we overwhelmingly saw that it was more important to jam red's lookout sensors from alerting the entities in the target location of the impending attack.

MANA-QualNet Results

Experiment 1:

This experiment proved several surprises in a regression analysis that had an r^2 of .73.

Parameter	**Design Points**
Channel Size (Bandwidth)	200,500
Accuracy	75,100
Power	30,40
Processing Time	10,300

Firstly, the difference between a 1W and 10W radio (30-40 dBm) was minimal. This was consistent with our observation from the MANA standalone runs that the scenario does not stress the capacity of the radios enough. We thought the level of traffic would be sufficiently stressing, but without any background traffic or large number of units to generate SA, it is relatively insignificant. This may not be the case in a real world environment. The second surprise showed that processing time was the most important factor in the experiment. This was interesting considering that processing time was the least important factor in the initial MANA experiment, so much so that we removed it from the second design. Despite this difference, we saw that increased process time correlates to an increase in red CAS. A possible explanation is that the messages being sent to the TOC are being processed and sent back out as a FRAGO order to a location that is not a hotspot by the time the units arrive. A short TOC processing time doesn't appear to impact this. Visual inspection of the model demonstrated that as FRAGOs were followed, they were taking place too early in the scenario, and had a negative impact on the outcome as observed by the loss exchange ratio (LER). A long process time would delay the FRAGO from being sent, allowing the blue force to get into a position that would better effect the outcome.

Comparison of MANA vs. MANA-QualNet Results

The comparison between the results of the MANA runs and MANA-QualNet runs showed that mean red casualties were very close, but that communications were generally poorer than our initial static assumptions. For instance, we assumed that message completion rates (modeled in the form of reliability in MANA) would be between 30% and 100%. Using the radio model in QualNet, the mean Message Completion Rate (MCR), the ratio of messages received over sent for the scenario was actually 12%. A similar effect was seen with delays, where we assumed 1 and 30 second delays, but the result as you can imagine depended much more on network conditions and link locations (particularly in an urban environment), creating a huge range of delay from less than 1 second all the way to 350 seconds. Any delay beyond a few seconds will be noticeable by users, particularly in voice communications. Longer delays of several minutes for position location reporting would be less noticeable to end users, but potentially costly to the outcome of the operation.

Comparison	**Mean Red CAS**	**MCR**	**E-E Delay**
MANA Only	11.21	30%-100%	1-30s
MANA-QualNet	10.43	12%	.3-350s

The comparison of parameters in terms of red casualties shows that processing time was the most significant factor, the opposite of the MANA only runs. As processing time increases, the number of red casualties increases, which is counter-intuitive. Further experimentation is required, but one can speculate that the increased processing time somehow alleviated heavy traffic conditions at a point in the scenario where the SA information was most valuable, however this is not proven by the data.

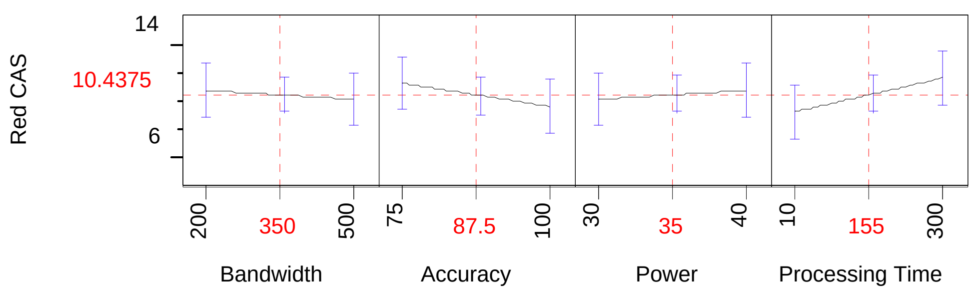

Figure 5: Comparison of Parameters

Conclusions

This initial exploration into urban communications has laid the foundation for future analyses with this scenario, and assessment of how operating in an urban environments can impact communications. One area for further analysis would be to leverage the dynamic tasking of agents. Instead of sending ground forces to investigate, use the UAV as a direct fire weapon, something more consistent with today's operational activities.

Further work will involve stressing the impact of incorporating a high fidelity communications model in data farming exercises. We did see that mean red CAS across the exercises were quite similar, but there was a striking variation in the message completion rate (MCR) and end to end delay, as seen in the comparison table from the previous section. While the scenario outcome in terms of LER was not impacted by this variation in quality of service, one could presume that if operationally significant information was lost it could drastically impact the outcome of the mission. To study this in more detail, message prioritization would have to be modeled.

References

Anderson, M, M. Lauren, and D. Galligan, , “Exploring the 2002 Seminar Games JANUS Wargaming Results With MANA”, New Zealand Defense Technology Agency Report 196, July 2003.

Galligan, David P., Mark A. Anderson, and Michael K. Lauren, “Map Aware Non-Uniform Automata,” Users Manual, MANA, Version 3.0, Defense Technology Agency, New Zealand, 2004.

Ilachinski, A., *Cellular Automata: A Discrete Universe.* World Scientific Publishing Co. Pte. Ltd., 2001.

Lauren, M., R. Stephen, and N. Hore, “Application of the MANA Model to Operations in East Timor”, New Zealand Defense Technology Agency Report 194, August 2003.

Porche, I., L. Jamison, & T. Herbert, "Framework for Measuring the Impact of C4ISR Technologies and Concepts on Warfighter Effectiveness Using High Resolution Simulation", *2004 CCRTS*, available at http://www.dodccrp.org/events/2004/CCRTS_San_Diego/CD/papers/233.pdf