3-12-2009

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Recommended Citation

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THE BENEFITS OF A NETWORK TASKING ORDER IN COMBAT SEARCH AND RESCUE MISSIONS

THESIS

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THE BENEFITS OF A NETWORK TASKING ORDER (NTO) IN COMBAT SEARCH AND RESCUE MISSIONS

THESIS

Presented to the Faculty

Department of Electrical and Computer Engineering

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Computer Engineering

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March 2009

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Abstract

Networked communications play a crucial role in United States Armed Forces operations. As the military moves towards more network centric (Net-Centric) operations, it becomes increasingly important to use the network as effectively as possible with respect to the overall mission.

This thesis advocates the use of a Network Tasking Order (NTO), which allows operators to reason about the network based on asset movement, capabilities, and communication requirements. These requirements are likely to be derived from the Air Tasking Order (ATO), which gives insight into the plan for physical assets in a military mission. In this research we illustrate the benefit of an NTO in a simulation scenario that centers on communication in a Combat Search and Rescue (CSAR) mission. While demonstrating the CSAR mission, we assume the use of the Joint Tactical Radio System (JTRS) for communication instead of current technology in order to mimic likely future communication configurations.

Our premise is that the knowledge in an NTO can be used to achieve better CSAR missions and yield better decision-making opportunities to the mission commanders. We present a scenario that hinges on the transmission of a critical image update from the headquarters to the survivor in the context of a CSAR mission. We attempt to transmit the image with the aid of an NTO and then without the use of an NTO under high and low traffic loads.

Our results show that the end-to-end delay with the aid of an NTO in high traffic conditions is shorter when compared to operations without the aid of an NTO and bandwidth requirements are also lower. In low traffic conditions, the end-to-end delay is shorter without the aid of an NTO, but at the cost of higher bandwidth utilization.

Acknowledgments

I would like to thank my thesis advisor, Dr. Kenneth Hopkinson, for his support and purposeful guidance throughout this effort. In addition, I would like to thank Dr. Barry Mullins and Dr. Henry Potoczny for their support.

I would also like to express my gratitude to those who provided moral support and encouragement along the way. The care and love of my friends and family enabled me to stay focused and determined during my research.

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THE BENEFITS OF A NETWORK TASKING ORDER IN COMBAT SEARCH AND RESCUE MISSION

I. Introduction

1.1 Motivation

As networks continue to evolve to operate in wireless domains, future wars will move to net-centric. This will push the limits of networking. The war networking will be more wireless. As the wireless war networking evolves, it will raise security issues. However, security problems are not the focus of this thesis. Instead, this thesis will investigate issues related to networking of military assets, especially air assets. The Air Tasking Order (ATO) is designed to gain positive control over an air space for Military aircraft. This provides the commanders and decision makers with the big picture of all of their air assets. This thesis argues that a similar document for the network and communication aspects of the mission, called a Network Tasking Order (NTO), can provide critical information related to the network connectivity among the daily flights described in the ATO.

Previous work related to NTO was a group research project (GRP) at the Air Force Institute of Technology [1]. Follow-on work to the initial GRP has been performed by Matthew Compton and has appeared in a published article in the Military Communications Conference in 2008 [1]. Nonetheless neither of these research efforts examined a constructed mission using an NTO. This thesis will promote better understanding of the use of an NTO in the context of a CSAR mission.

1.2 Overview and Goals

The knowledge contained in an NTO could be of the utmost importance in maximizing mission effectiveness through better communication. With the aid of NTO, networking for air assets will be well-planned and centrally controlled. This central control and set of higher-level networking capabilities will help the decision makers and commanders while planning their operations. Also, they can manage operations more securely and efficiently. The NTO is still a research concept, but illustrating the benefits of an NTO in a CSAR mission will aid in the NTO's development.

This thesis advocates the use of an NTO, which allows operators to reason about a network based on asset movement, capabilities, and communication requirements. This research combines the concepts of the ATO, the Joint Tactical Radio System (JTRS) and of CSAR. In this research, air assets will be using JTRS instead of current technology.

An entire CSAR mission is depicted; however the simulation is run only in the execution phase of the CSAR mission for demonstration purposes. This does not mean that the other phases are not important. A scenario is presented where a critical image update is routed with the aid of an NTO, but is broadcasted when NTO knowledge is not available.

The premise is that the knowledge in an NTO can be used to achieve better CSAR missions in terms of a shorter end-to-end delay performance metric and yield better decision-making opportunities to the mission commanders.

1.3 Thesis Layout

Chapter 1 introduces the research topic and gives a description of the motivation resides behind the effort. Chapter 2 presents background information and essential concepts are introduced. In Chapter 3 the methodology is outlined in order to describe how the experiments were conducted. In Chapter 4 discussion and analysis of the experimental results are given. In the final chapter, conclusions are drawn from the results and areas for future research.

II. Background and Literature Review

2.1 Introduction

In this chapter fundamental concepts and recent research in the areas of the NTO, the Combat Search and Rescue mission, and the Joint Tactical Radio System are presented. Section 2.2 introduces NTO's and discusses their relationship to ATO's. Section 2.3 defines the aim and phases of CSAR missions. Section 2.4 defines the Joint Tactical Radio System (JTRS) and clusters of JTRS.

2.2. Network Tasking Order and Air Tasking Order

The word NTO is new, but the idea of an NTO is not new to the Department of Defense (DoD). The idea of an NTO resides behind the question "How could the Air Force benefit from networking connectivity in a military scenario where we can take advantage of the highly planned nature of the proceedings." This yields the idea of managing networking connections between the air assets.

The feasibility of managing network connections between air vehicles has been investigated by many entities in the DoD. The first solid attempt was done by the 50th Network Ops Group at Shriever AFB [2]. A daily network tasking order is published to assist in allowing command and control of the Air Force Satellite Control Network, which includes the Defense Support Program, the Navstar Global Positioning System, the Defense Satellite Communications System, NATO III, and Milstar [1]. However, the first appearance of the term NTO, with the meaning that has just been presented, was in a group research project (GRP) at the Air Force Institute of Technology [1]. Follow-on work to the initial GRP has been performed by Matthew Compton and has appeared in a published article in the Military Communications Conference in 2008 [1].

A Network Tasking Order can be built by looking at the Air Tasking Order (ATO), which contains daily schedules of air related operations. The Air Tasking Order or ATO is defined in Department of Defense doctrine as a method used to task and disseminate to components, subordinate units, and command and control agencies projected sorties, capabilities and/or forces to targets and specific missions [3]. The ATO life cycle is 72 hours. There is one in planning, one in execution and one in assessment. For this research it is sufficient to say the ATO spells out what tracks (elliptical paths flown by orbiting aircraft) are to be used by refueling and ISR assets, describe flight missions/paths for nearly every aircraft in the battlespace as well as providing targeting, to Airmen throughout the theater [1]. From the ATO, the network can be fed predictive information about where mobile nodes (aircraft) are expected to be and from the data determine when they should be there and when the nodes might be within coverage areas of other nodes[3]. The ATO includes all of the details of a day’s flights such as mission types, aircraft types, the number of aircraft, etc.

The example of an ATO is shown below.

```
1- TSKCNTRY/US//
2-SRCVTASK/F//
3-TASKUNIT/555FS/ICAO:ETAD//
4-AMSNDAT/C2342/CSAR//
    /DE/TGT-ID        /LOCATION           / TOT
                /01/               -/294248N0473106E/241200ZJAN/
                /02/               -/294300N0473896E/241215ZJAN/
                /03/               -/294300N0473805E /241233ZJAN/
                /04/               -/294236N0473106E /241303ZJAN//
5-MSNACFT/1/ACTYP: F16C/SANDY01/2MK-82/1654/3322//
6-AMSNLOC/AGL200/1//
```

In the sample ATO above, the mission is divided into 6 lines. The first line represents the task country. In this case, the country is the U.S. The second line lists the service task, which is the Air Force in this sample. The third line is the task unit, which corresponds to the 555 squadron at Spangdahlem Air Base (ETAD) according to ICAO code. The fourth line represents the aircraft mission data, and is C2342 in the sample. These codes are given by Air Force. The mission is Combat Search and Rescue. The following lines show the spider points coordinates (29 42 48 North 47 31 06 East), date of the flight (24 JAN), and times the aircraft will be over the spider point (12 00 Z). The fifth line represents the mission of the aircraft. There is one F-16C with the call sign SANDY01. The aircraft is equipped with two MK-82 missiles. 1654/3322 are the IFF/SIF codes. The sixth line represents the altitude of the flight and priority of the flight. The altitude of the flight is 200 feet above ground level (AGL). The mission priority is 1.

We can easily define potential mission network communication by looking at the air vehicles' routes, their altitude, and the time frames of their presence in the ATO [1]. This type of data, combined with auxiliary information, enables the idea of a Network Tasking Order (NTO) [1]. An NTO should contain the following information.

- Each asset's transmission range/speed.
- The information's mission priority (which assets' packets must be sent first).
- Determining the preplanned routes which the assets' packets will go through.

An example NTO derived from the ATO above could contain these lines:

```
TSKNODE/US/F/555FS//
NODETYP/50/11MBPS//
PCKTPRIORTY/1//
PREPLANNEDRT/1652/3322//
```

The first line represents the country, service, and unit information. The second line represents the asset's transmissions range (50 miles) and speed of downlink and uplink (11 Mbps). The third line represents the packet priority . The fourth line represents possible preplanned routes that the packets will go through. The numbers (1652, 3322) represents the aircrafts' IFF codes.

The NTO information can be kept in a database whenever a unit is assigned to a mission in order to allow a lookup of the asset's networking capability [1]. We know that every mission has different characteristics; in every mission the required information, such as the asset's transmissions range and speed, can be important when routing and determining which information to transmit given bandwidth constraints throughout the mission [1].

The NTO can also aid in congestion management. This could be done by either routing traffic from other routes or by storing it to send at times of lower activity. Bandwidth management could also be achieved by allowing the high priority information to be transmitted while dropping lower priority information. Likewise the connectivity of all assets in the air; who can talk with whom and under what conditions the quality of the traffic and burstiness of traffic can be gleaned from the NTO. This helps the routing agents to make better decisions for congestion management.

In this research, the goal is to show through simulation that the NTO has the potential to improve network performance in terms of end-to-end delay. Combat Search and Rescue scenarios with the aid of NTO can decrease end-to-end delay with the task of optimizing network topology and routing.

CSAR is simulated in this research because of the nature of the mission and availability. Also, CSAR missions are more diverse and active than other missions in regards to critical traffic routing and mission priorities.

The major problem with utilizing the NTO could lie with the constraints in current technology. As mentioned earlier, current communication technology is not suitable for NTO enhancement. Instead of using current communication technology, we are going to assume the use of Joint Tactical Radio System (JTRS), which will be described in the Section 2.4. It is important to note that JTRS is still in the conceptual stage. However, the JTRS standard will go a long way towards solving interoperability communication problems for the U.S. Armed Forces.

From the Air Force perspective, every asset in the ATO will have communication capabilities with the JTRS aid. This will help the creation and utilization of the NTO. With the aid of the NTO, network coverage will be seen as more critical than it is today and will be used by decision-makers. An illustration of the network coverage afforded with an NTO is shown in Figure 1.

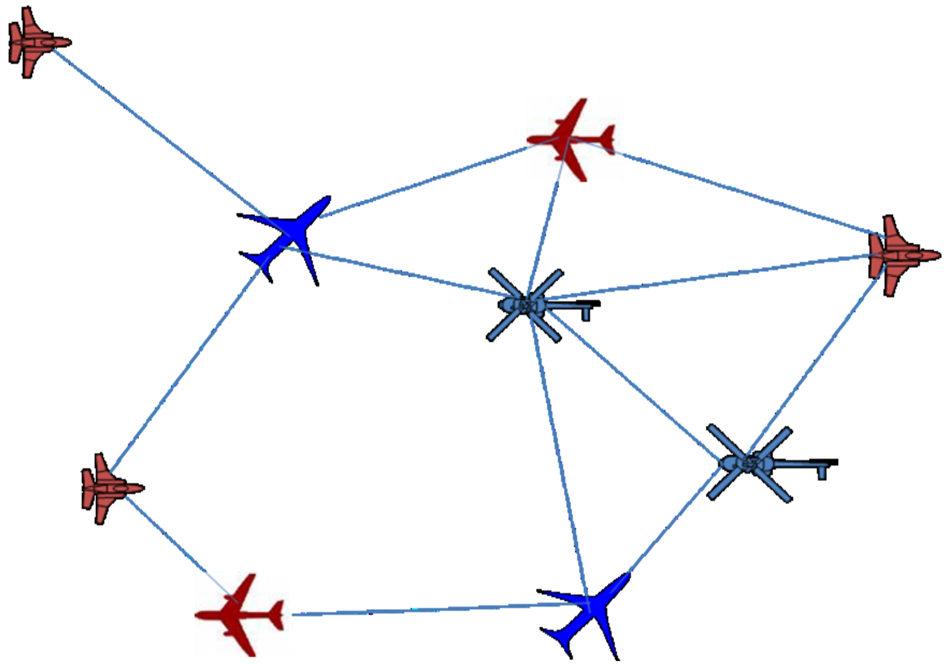


Figure 1. An Illustration of the Proposed NTO Network Coverage

As mentioned earlier, the JTRS will define the communication capabilities, requirements, encryption requirements, and other underlying architectural details. The NTO can be used to ensure the interoperability of the assets' communication.

2.3 Combat Search and Rescue

> *0300 hours (Zulu) somewhere north of Baghdad – Major Chris Foster, call sign BACH-21, was flying a CAP mission supporting two flights of Air Guard F-16s attacking an Iraqi armor division retreating south towards Baghdad, when suddenly he had a warning on his Surface-to- Air Missile (SAM) radar indicating he was being looked at by an Iraqi radar system. BACH-21 whipped his plane over into a left SAM break. As G-forces began to press against him, he felt his aircraft shake violently and continued to roll inverted as an SA-6 slammed into his right wing. Fighting the G-forces he fumbled for the firing mechanism of his ejection seat, found it, and pulled the handles. The canopy immediately blew-off and suddenly he was alone in the air, three miles above the barren deserts of Iraq. Completely numbed by the shock of ejection and the deployment of his parachute, he made good use of the time remaining during his decent. He pulled out his PRC-112B radio and tried to establish radio contact with his wingman. He called twice and got no response from his wingman orbiting farther south to stay*

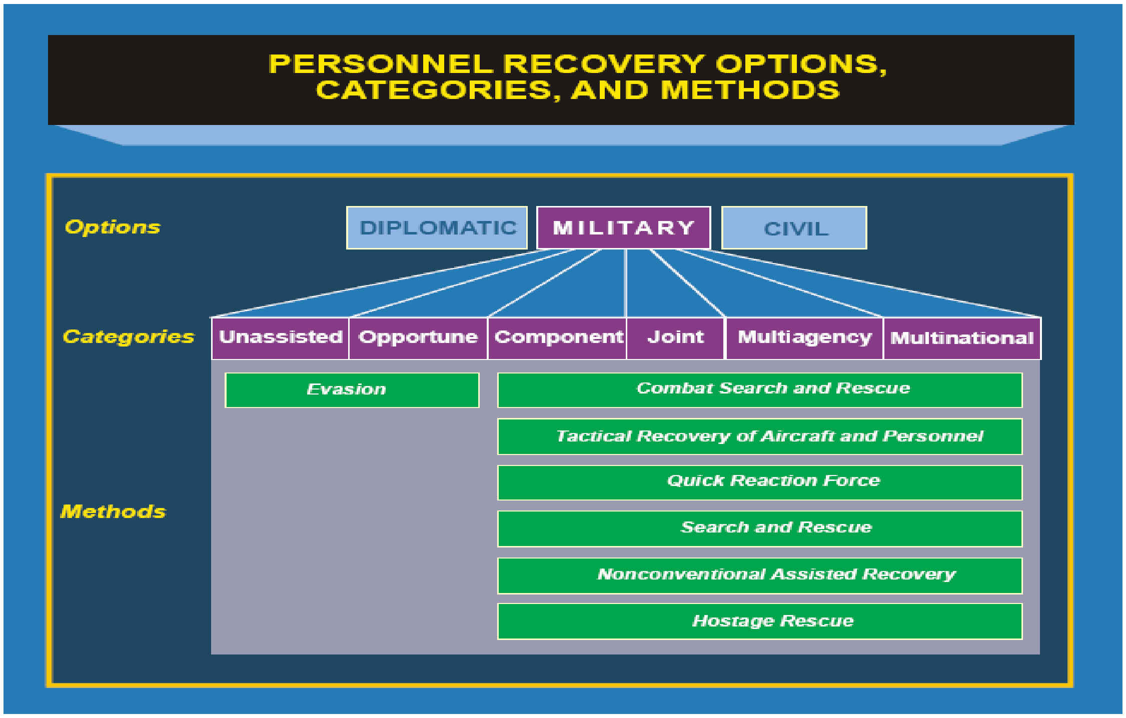
out of the range of the SAM batteries below. His parachute-landing fall was much softer than he anticipated as he landed on the hard Iraqi soil. Quickly securing his parachute, he made a dash for the nearest wadi and waited for the recovery he hoped would come soon. Because the PRC-112 is equipped with an Emergency Locator Transmitter (ELT), both the E-8C J-STARS (Joint Surveillance, Target Attack Radar System) aircraft operating in theater and one of the sixteen SARSATs (Search and Rescue Satellites) designed to locate ELTs would track his position. High above the downed pilot, a USAF RQ-1 (Predator B), equipped with an AN/APY-8 radar system was tracking Iraqi ground vehicles when the UAV (Unmanned Aerial Vehicle) operator in Turkey located BACH-21's hide sight. The Predator's optical systems quickly pinpointed his position and relayed the information to the J-STARS controllers working the situation. The J-STARS operator knew that unless BACH-21 was picked-up quickly, the local Iraqi paramilitary forces would sweep through and grab their first downed allied pilot of the war. A message was immediately relayed to the JFACC (Joint Force Air Component Commander) describing BACH-21's situation. A decision was immediately reached to utilize a new recovery technique developed by the USAF Special Operations School and UAV Battle Lab. A USMC Eagle Eye TRUS (Tilt Rotor UAV System) operating with a forward unit of the 1st Marine Division was immediately directed to BACH-21's location ninety miles to the north. Cruising at 200 knots, Eagle Eye was a low cost, composite tilt-rotor air vehicle using extensive off-the-shelf helicopter and common hardware parts. Using a technique originally developed for U.S. Army AH-64 and OH-58D aviators, the procedure involved a downed pilot "hooking" himself to a mooring clevis on the UAV by means of a "D" ring secured to the pilot's survival vest. This "James Bond" recovery technique, while unusual and very risky, gave allied pilots the chance to avoid becoming a POW (Prisoner of War) and a political pawn in the war with Iraq. Soon the Eagle Eye was hovering a few feet above BACH-21. He quickly secured himself to one of the mooring points on the side of the UAV and held on as the Eagle Eye turned and flew to an Army Special Forces A-Team operating sixty miles to the east. At 200 knots and barely 100 feet above the ground, BACH-21's ride was exciting to say the least. Skimming over telephone and electrical wires, dodging vehicles and villages, and generally avoiding high threat areas, the Eagle Eye safely dropped the pilot off at a pick-up site near the Special Forces Team. As the Eagle Eye returned to its original mission, the Team quickly secured BACH-21 and that night loaded the pilot on board an Army MH-47E "Chinook" helicopter flown from a base in Turkey. A few hours later, CNN and other news organizations flashed the news of the BACH-21 recovery around the world and was considered a major strategic boost to the allied war effort in Iraqi.

- 9 June 2005
U.S. News and World Report

Combat search and rescue (CSAR) is a specific task performed by rescue forces to affect the recovery of distressed personnel during war or military operations other than war. CSAR is an element of personnel recovery (PR).

Personnel recovery options, categories and methods are shown in Table 1.

Table 1.CSAR represents the Air Force's method of choice for PR in denied or hostile environments [4].



PERSONNEL RECOVERY OPTIONS, CATEGORIES, AND METHODS

Options

DIPLOMATIC
MILITARY
CIVIL

Categories

Unassisted
Opportune
Component
Joint
Multiagency
Multinational

Methods

Evasion
Combat Search and Rescue
Tactical Recovery of Aircraft and Personnel
Quick Reaction Force
Search and Rescue
Nonconventional Assisted Recovery
Hostage Rescue

The trend of a declining number of CSAR missions may lead some to question the rationale behind investing in and executing CSAR. There are four key reasons for retaining and improving the CSAR mission area. First, the U.S. Air Force places great value on the sanctity of human life. The U.S. military has a moral obligation to recover all of its personnel. Second, by assuring military members that we will do everything within reason to recover them, we sign an implicit contract with them. In return, they will exert their utmost in times of great stress. Third, the rescue and recovery of military members denies our enemies valuable sources of intelligence. Fourth, all trends are cyclical, and future combat may put more military personnel in isolated survivor status. We cannot discard CSAR as a valuable mission, because the future by its very nature is unknown [5].

The objective of Combat Search and Rescue (CSAR) operations is to protect downed/isolated personnel and reduce their threat level in order to allow recovery vehicles to pick them up [6]. We can divide CSAR missions into two categories. The first category involves missions that are immediate; survivors must be rapidly recovered after they are downed. The second category of missions is deliberate; an assessment of mission considerations may require delay for more detailed planning [6].

Combat Search and Rescue operations have four phases. They are Search, Ingress, Execution and Egress. These phases start after the downed/isolated personnel are reported to the CSAR Joint Force Commander (JFC). The CSAR JFC will establish a Combat Search and Rescue Task Force (CSARTF). The CSARTF generally consists of Rescue Escort (RESCORT) vehicles, Rescue Combat Air Patrol (RESCAP) vehicles, Survivor(s), and an Air Mission Commander (AMC). The RESCORT vehicles play the escorting role for the recovery vehicle. The RESCAP vehicles cross the Forward Line of Own Troops (FLOT), which is the most forward position of friendly forces in any kind of military operation at a specific time, to establish air superiority over the operation area and the ingress route [6]. The Airborne Warning and Control System (AWACS) plays a monitoring role for the entire mission. The CSARTF is shown in Figure 2.

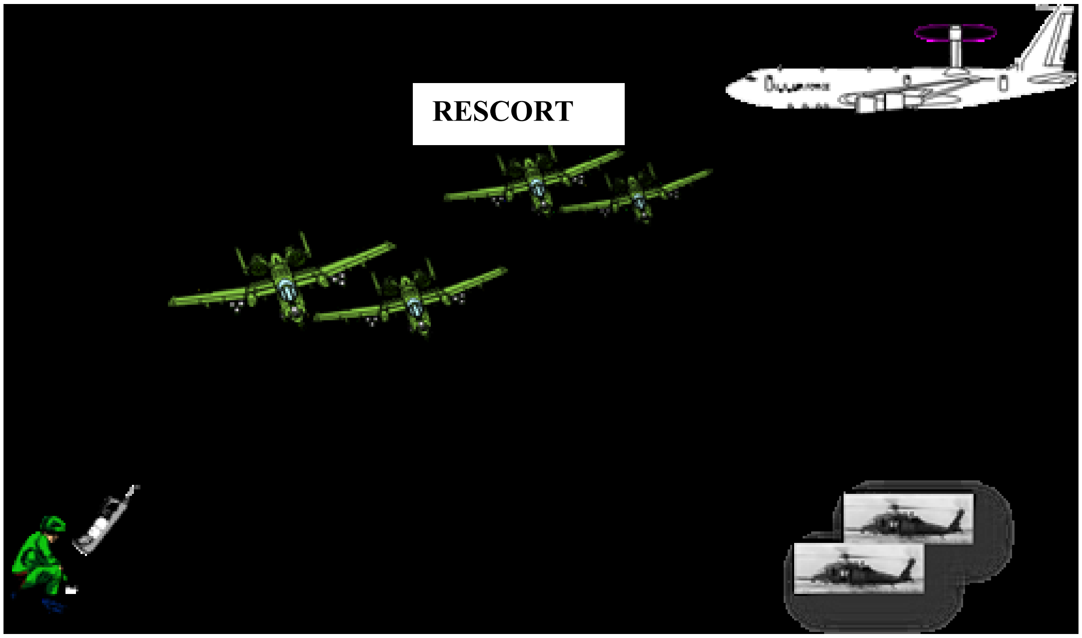


Figure 2. An Illustration of the Roles of the Parties Involved in CSAR Missions.

In order to see how the NTO provides benefit to this research, we have to look the four phases of CSAR missions.

1. SEARCH PHASE

In this phase the aim is to find the rough location of the survivor(s). Usually this is done through one or more of the following means:

- a. Position reported by wingman.
- b. Activation of aircraft emergency beacon.
- c. Last known position from AWACS, Satellite.

RESCAP vehicles, called Sandy1 and 2, locate and sanitize the survivor. At the same time RESCORT vehicles, called Sandy 3 and 4, bring the Recovery vehicles, called Jolly 1 and 2, to the rendezvous point [6].

Search phase snapshot is depicted in Figure 3.

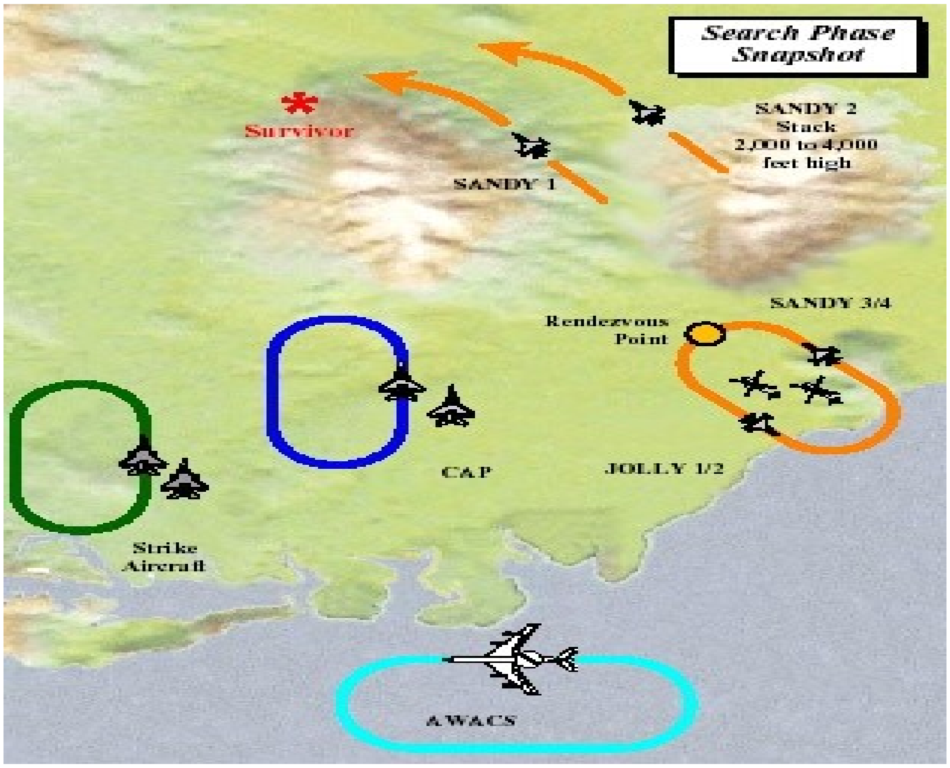


Figure 3. Search Phase Snapshot [6].

Use of the NTO can be beneficial in many ways in this phase. Positions reported by the wingman can be routed directly to the CSAR JFC as high priority information.

2. INGRESS PHASE

After the survivor(s) approximate position has been determined, all of the CSARTF assets will check-in with AMC. RESCAP vehicles will cross the FLOT and gain local air superiority over the Operation Area and ingress route. RESCORT vehicles and recovery vehicles will be launched and repositioned in a holding area close to FLOT where the handover will take place between RESCORT and RESCAP vehicles [6]. An ingress phase snapshot is depicted in Figure 4.

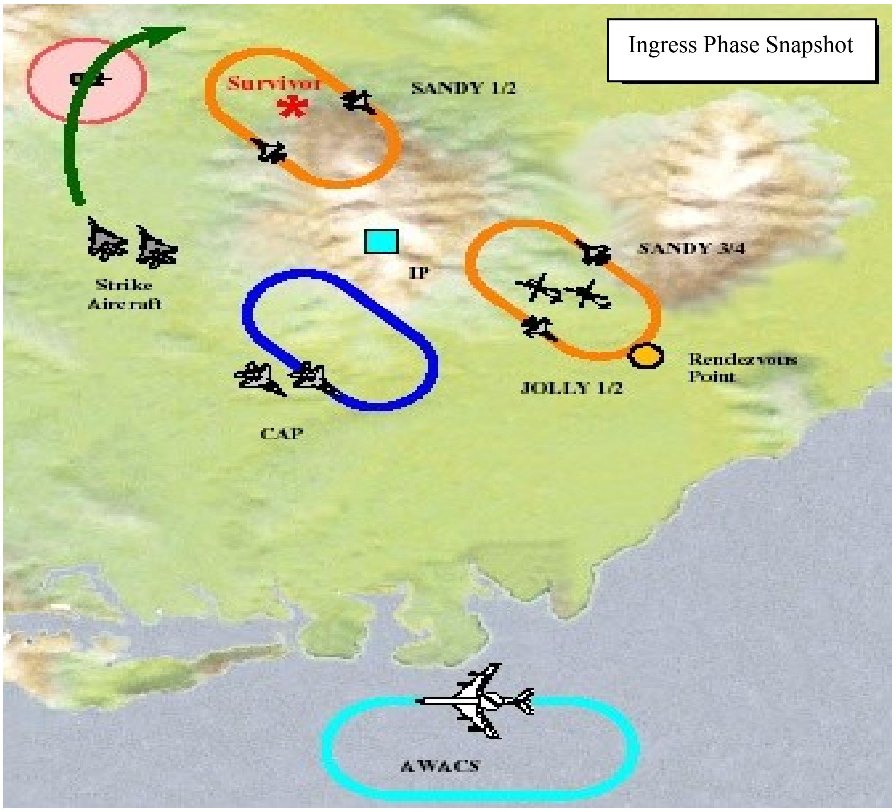


Figure 4. Ingress Phase Snapshot [6].

3. EXECUTION PHASE:

This phase begins with finding the survivor(s). Once the survivor(s) have been precisely located and mission is considered feasible by the RESCAP vehicles after a threat assessment has been completed, the RESCORT vehicles will hand over the recovery vehicles to RESCAP vehicles at the Holding Point (HP) [6]. The RESCAP vehicles will lead the recovery vehicles using Spider Points (SP) to the survivor. This is shown in Figure 5.

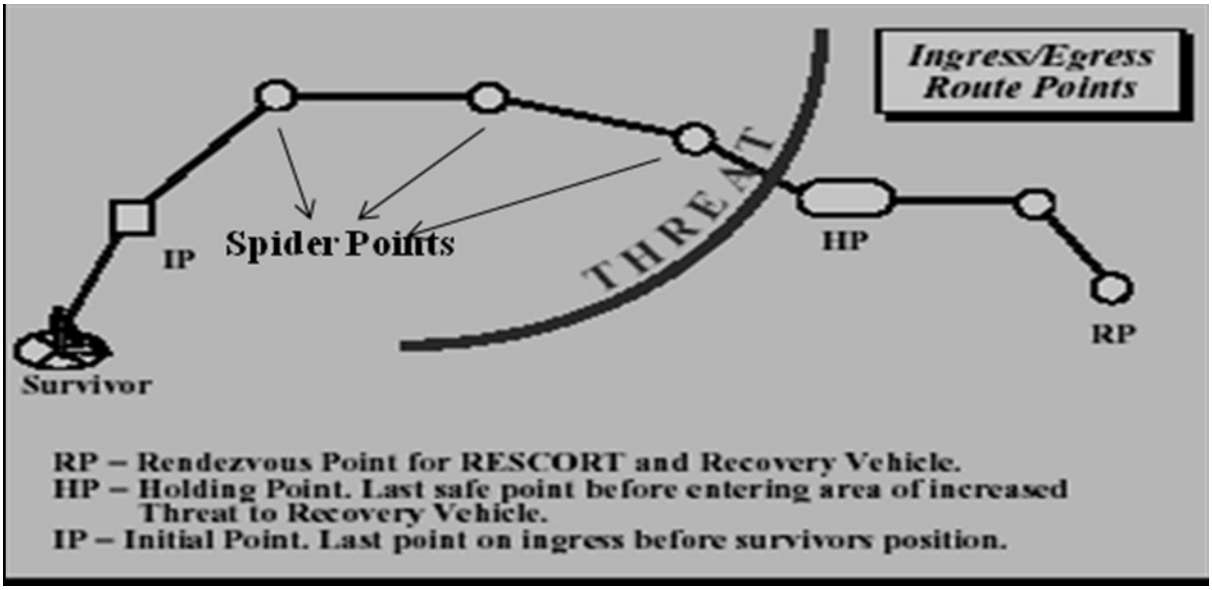


Figure 5. Interaction of the RESCORT and RESCAP vehicles via Spider Points [6].

All assets should be aware that this is the most critical part of the mission, and therefore, they should minimize radio transmission. With that said, in this part of the mission there will be regular radio transmissions between the survivors, RESCAP, and the recovery vehicles. Also, the Mission Commander should be ready to copy the radio transmissions and to relay them to CSARTF if line of sight communication between the RESCAP vehicles and recovery vehicles is not possible [6]. However in this research we are assuming the transmission is done in a wireless manner via JTRS.

4. EGRESS PHASE:

After the survivor is evacuated, RESCAP and recovery vehicles will follow the Spider Points that are more secure, as was determined during the INGRESS phase. The Spider Points used could be same ones employed in the INGRESS phase or they could be different ones. The handover will take place at the HP. This is shown in Figure 5.

2.4 Joint Tactical Radio System

The Joint Tactical Radio System (JTRS) often pronounced "jitters" is the next-generation software defined radio for use by the U.S. military in field operations after 2010 [8]. The JTRS program originated in the mid-1990s and was intended to replace the 25 to 30 families of radio systems used by the military — many of which could not communicate with each other — with software-based radios that could operate across the entire radio frequency spectrum [7]. The idea behind JTRS is to create a family of radios for troops, vehicles, ships, etc. that all share a similar underlying architecture, can use the Internet Protocol for data, and is a “software-defined” platform that relies on software rather than hardware to handle communication protocols [8].

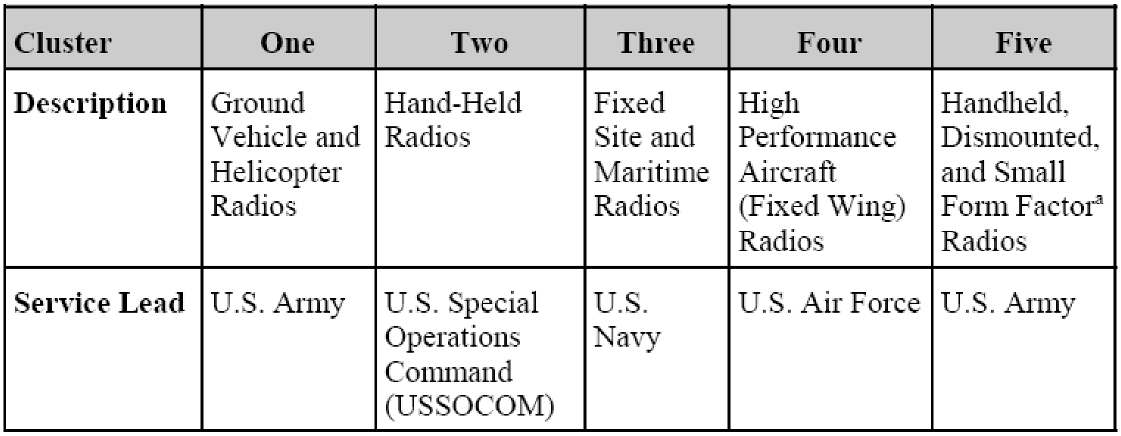
The Joint Tactical Radio System family of radios will range from low cost terminals with limited waveform support to multi-band, multi-mode, multiple channel radios supporting advanced narrowband and wideband waveform capabilities with integrated computer networking features [9]. JTRS will develop a family of affordable, high-capacity tactical radios to provide both line-of-sight and beyond-line-of-sight C4I capabilities to the warfighters. This family of radios will cover an operating spectrum from 2 to 2000 MHz, and will be capable of transmitting voice, video and data. However, JTRS is not a one-size-fits-all system. Rather, it is a family of radios that will be interoperable, affordable and scalable [8]. This will make JTRS more attractive because in the near future NTO will be applied not only to air assets but also ground assets.

JTRS will work with many existing military and civilian radios. JTRS is intended to permit the Services to operate together in a “seamless” manner via wireless voice, video, and data communications through all levels of command, including direct access to near real-time information from airborne and battlefield sensors [9]. It includes integrated encryption and Wideband Networking Software to create mobile ad-hoc networks (MANETs).

JTRS is a Department of Defense (DOD) program that promises to play a significant role in the U.S Army's proposed Future Combat System (FCS) [10]. JTRS, envisioned as a family of software programmable radios, has been described as the "backbone" of the FCS.

The JTRS program was originally broken into five clusters with each cluster having a particular Service "lead" [10]. This is shown in Table 2.

Table 2. The JTRS Program's Clusters [10].



Cluster	**One**	**Two**	**Three**	**Four**	**Five**
Description	Ground Vehicle and Helicopter Radios	Hand-Held Radios	Fixed Site and Maritime Radios	High Performance Aircraft (Fixed Wing) Radios	Handheld, Dismounted, and Small Form Factor[a] Radios
Service Lead	U.S. Army	U.S. Special Operations Command (USSOCOM)	U.S. Navy	U.S. Air Force	U.S. Army

In early 2004, DoD merged Clusters Three and Four into a single program — the Airborne, Maritime, and Fixed Station Program (AMF JTRS) — jointly managed by the Navy and the Air Force — because studies suggested that developing the clusters together would result in a more efficient procurement process and a better overall product [11].

Due to security, interoperability with legacy radio systems, and due to the issues of size, weight, and limited range constraint of the radios in Cluster five, the timeline of the JTRS effort has been hampered [10].

Despite encountering some significant programmatic and technical issues, the JTRS Program continues to be a key DoD transformational program. The JTRS Program is intended to provide foundational support for the DoD objective of information superiority on the battlefield, meeting the growing demand of War-fighters' communications needs with the help of NTO [14].

2.5 Summary

This chapter presented the recent research and fundamental concepts in the areas of NTO, ATO, JTRS and CSAR. First, ATO and NTO interaction was introduced. Second, phases of CSAR were explained with the necessity of NTO in CSAR missions. Finally, the JTRS was explained.

III. Methodology

3.1 Introduction

This chapter presents the method used to compare the respective benefits of two different CSAR mission scenarios. First examined is the problem definition, goals, hypothesis and approach. Next, system workload is described, along with the performance metrics, parameters, and factors used. The evaluation technique, simulation environment and experimental design are then discussed. Lastly, a summary is given of the analysis and interpretation of the data.

3.2 Problem Definition

3.2.1 Goals and Hypothesis

For CSAR missions to be accomplished they must be facilitated by good radio communication. It is important to note that this research assumes that JTRS will be used instead of standard radio communication. Chapter 2 discussed several aspects of the JTRS radio system. Networking and communication in CSAR missions must be a top priority in order to achieve those missions. Without such considerations, CSAR mission can fail needlessly, which can cause personnel and asset losses. With that said, the cost of implementing an NTO, in terms of its limited resources, needs to be efficient and scalable so the all air missions, including those involved in CSAR, can be achieved effectively. When only considering air assets' networking relations among a few assets in a subset of an ATO, this problem is not very complex. On the other hand, implementing an NTO for large groups of air assets involves significant complexity.

The focus of this thesis is on one particular aspect of an NTO, which helps to provide more insight into the use of air missions when planning CSAR mission from a networking perspective.

Primary goals of this research are listed below:

- To investigate the viability of using the NTO in CSAR missions that could lead to its use in other ATO missions.
- To assess the NTO performance end-to-end delay based on two OPNET simulations.

One hypothesis is that the ATO architecture can be effectively adapted to NTO architecture. Furthermore, it is hypothesized that JTRS can be used instead of current technology for effective military networking. Finally, it is hypothesized that weather and environmental factors will not hamper the missions in the ATO.

3.2.2 Approach

A CSAR scenario has been created using the OPNET Simulation MODELER(14.0) by adapting phases of the CSAR mission described earlier. Only a subset of a CSAR mission, execution phase, is simulated since an entire CSAR mission can take a long period of time.

The CSAR execution phase is simulated under two different scenarios. These scenarios are used to illustrate the NTO's benefits in the context of CSAR missions. Both scenarios will reflect the dynamics of a typical CSAR mission using JTRS.

Here the two scenarios are described. First, the downed pilot is located by a satellite. Second, image of the place and coordinate of the downed pilot will be sent to the headquarters. This data (location and image of the place) is sent to the recovery vehicle under two different circumstances, which make up our two scenarios.

The overall architecture is shown in Figure 6. The steady line shows the data (location and image of the place) flow from survivor to the Headquarters.

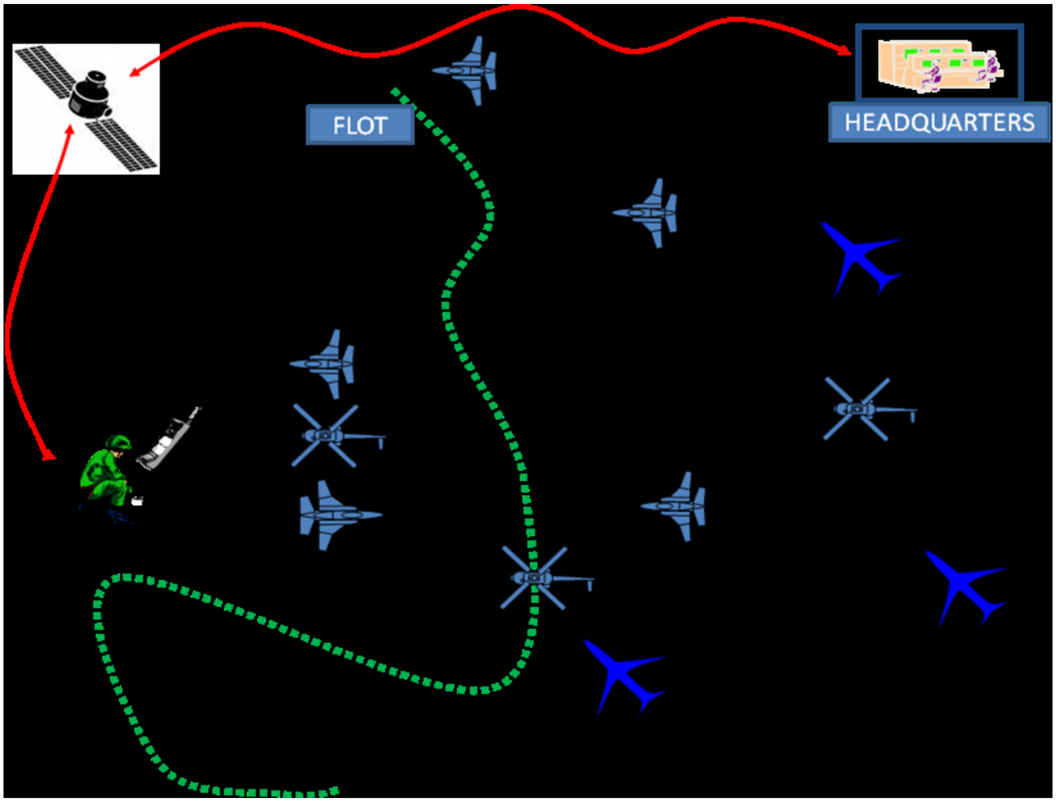


Figure 6. Snapshot of Air Space

The data will be sent to all nodes in the network in order to reach the survivor. This is what we will call the "CSAR without NTO knowledge" scenario.

The data will be sent to specific nodes that were determined using the NTO in order to reach to the survivor. This is called the "CSAR with NTO knowledge" scenario.

Since JTRS and the NTO are still in the concept stage, it is important to ensure that the technology exists to allow the proposed communication architecture to be applied. However in this research JTRS cannot be used since it is not in the OPNET Modeler. For simulation purposes, the radio link communication in OPNET Modeler will be used. By using current radio technology, it is assumed that the communication range between air assets is feasible.

There are two hypotheses that will be considered throughout the simulation.

- The end-to-end delay will be longer for CSAR without NTO knowledge when compared to the CSAR with NTO knowledge in high background traffic situations.
- The end-to-end delay will be longer with the CSAR without NTO knowledge when compared to the CSAR with NTO knowledge in low traffic situations.

In this simulation study, the baseline of the two scenarios will be the ones without NTO knowledge. The comparison will try to search if any of the NTO knowledge scenarios does have a significant impact on the end-to-end delay.

3.3 System boundaries:

The CSAR Group Networking System is the System Under Test (SUT) and involves the following components: The NTO architecture, wireless network and aircraft specified in the ATO. The NTO architecture is the component under test (CUT). The NTO architecture is compared to baseline architecture which can be called the “without NTO” architecture.

Inter-arrival time is the only workload parameter. The system parameters are the transmission range, bandwidth, network speed and radio power. Section 3.7 discusses these parameters in more detail. The metric of the system is the end-to-end delay. Figure 7 shows the block diagram of the SUT.

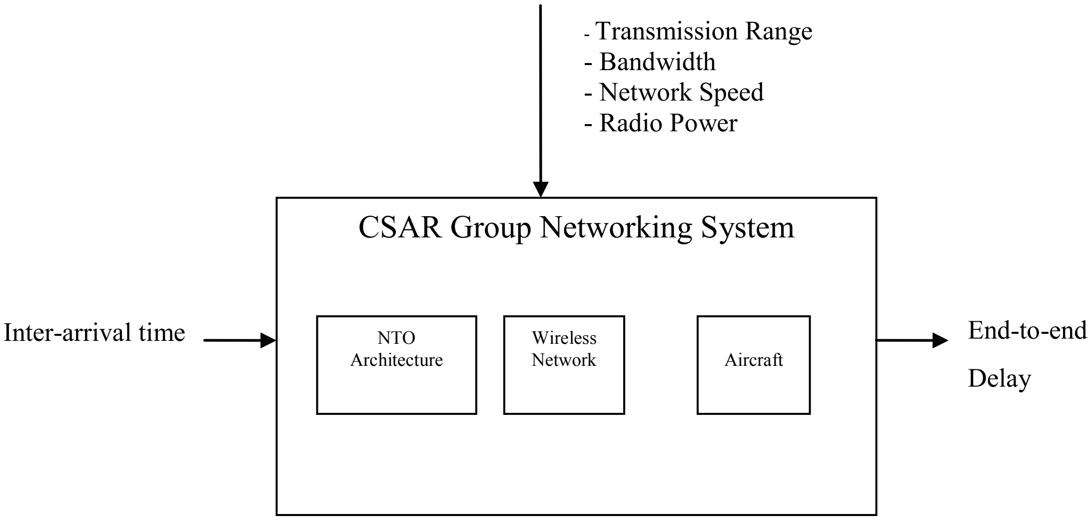


Figure 7. CSAR Group Networking System

This study assumes there are no obstacles to aircraft travel or communication. Another assumption is that the aircraft are equipped with modern transceivers and receivers that can communicate successfully over the needed transmission range and the region.

3.4 System Services

The CSAR Group Networking System might offer a communication network service for aircraft flying over a region based on the ATO. When all traffic generated by the source reaches all intended nodes and only those nodes, then the service can be considered successful. For this to happen, the underlying NTO architecture must successfully route traffic to intended members through the intended routes

3.5 Workload

Reducing the end-to-end traffic delay associated with NTO architecture is the primary focus of this thesis. The workload of the SUT is finally the amount of traffic that needs to be routed. Thus, the amount of routed traffic related to the NTO depends upon several parameters including the size of the data, size of the packets, the inter-arrival time, the number of hops, and scale of the network. The study narrows down the possible network workload to a hypothetical fixed range since neither JTRS nor the NTO are in real life usage. The aim is to show the feasibility of NTO in order to envision the future wars command, control and communication (C3). To do so, the workload to the SUT is generated by varying the inter-arrival parameter.

3.6 Performance Metrics

The ultimate target of this thesis is to assess the performance of the networking service with the NTO architecture along with the without the NTO architecture. The study focuses on the performance impact of an NTO on end-to-end delay. The end-to-end delay could be one of the most complex and important pieces of information on the network. As a result, the performance metric should determine how efficient the NTO architecture is in terms of end to end delay. Hence the following performance metric is defined:

- *End-to-end Delay*: The average amount of time by an aircraft to send packets from source and received by sink during the simulation period.

This metric has utmost importance in a situation such as a large group of aircraft where network bandwidth can be limited and costly. However in this research due to time constraints, the network will be tested with a limit of six aircraft.

3.7 Parameters

The parameters are the properties of the system. When the parameters altered, it can affect the performance of the system. The system parameters characterize the system, and workload parameters characterize the workload. Further description of the system parameter and the workload parameter can be found below. The fixed experimental parameters are displayed in Table 3.

Table 3. Fixed Parameters

Parameter	**Scenario 1 Value**	**Scenario 2 Value**
Data Rate	90,000 bps	90,000 bps
Packet Size, Distribution	5000 bits, Constant	5000 bits, Constant
Number of Aircraft	6	6
Channel Bandwidth	20 kHz	20 kHz
Channel Min Frequency	400 MHz	400 MHz
Aircraft Ant. Power	15 Watt	15 Watt
Simulation Length	2750 time steps (45 min.)	2750 time steps (45 min)

3.7.1 System Parameters

- <u>Transmission Range</u>: The maximum distance that two nodes can successfully communicate without losing packets.
- <u>Data Rate</u>: This attribute is the rate at which information may be forwarded over the data transmission channel.
- <u>Channel Bandwidth</u>: This attribute specifies the bandwidth of the channel.

- Packet Size: This attribute specifies the distribution name and arguments to be used for generating random outcomes for the size of generated packets (specified in bits). IEEE 802.11a is a widely known technology and the packet size is 4095(payload)+13(other bits) = 4108 bits which is approximately 5,000 bits.
- Channel Frequency: This attribute specifies the base frequency of the channel. This value overlaps with the UHF radio spectrum.
- Aircraft Antenna Power: This attribute specifies the transmission power allocated to packets transmitted through the channel. Average aircraft radio power is taken to equal 15 watts.

3.7.2 Workload Parameters

- Packet Inter-arrival Time : In this study the inter-arrival specifies the distribution name and arguments to be used for generating random outcomes for times between successive packet generations.

3.8 Factors

Factors are selected from the workload parameters. In this research there is only one workload parameter .This factor is varied to verify the effect on the performance of NTO architecture evaluated in terms of end-to-end delay. Table 4 summarizes the parameter of factor chosen for Scenario 1 and Scenario 2. The level 1 and 2 inter-arrival times are chosen to simulate the high and low traffic network schemes. This is explained in Appendix A.

Table 4. Factor Levels Scenario 1 and Scenario 2

Factor	Level 1	Level 2
Packet Inter-arrival time	0.0625 sec.	0.166667 sec

3.9 Evaluation Technique

The NTO is currently a conceptual construct. The NTO does not yet exist, so measurements of an actual system are not realistic for this study. Throughout the literature search it has not been possible to find any research regarding an NTO analytical model. Since a model that can be adapted to this scenario doesn't exist; therefore using an analytical model is not an option.

A simulation is the best evaluation technique for this study. OPNET Modeler and MATLAB tools were questioned for carrying out the simulation. Due to the fact that this study is specifically concerned with parameters involving data transmission, packets, end-to-end delay and routing, OPNET is the best choice to perform the simulation for this study.

The performance of the NTO architectures in terms of end-to-end delay is evaluated by discrete event computer simulations developed by OPNET (version 14.0). The attributes of the aircrafts are modeled in OPNET node models, which are initialized based on real aircraft specifications. First end-to-end delay performance metric is tracked and output to Excel files. Second the Excel files are imported into Minitab where plots and figures are gathered for simulation analysis. The simulations created throughout this thesis can be reproduced on any workstation with OPNET version 14.0.

3.10 Simulation Environment

The simulation environment is a solely designed for this simulation. Therefore a detailed description of the original simulation environment is explained thoroughly below.

While flying over enemy region, one of the two aircraft is downed by a hostile forces Surface to Air Missile. The pilot landed safely to the soil, but he had some injuries and he cannot move. Since he cannot move, his exact position is very important to the CSARTF and the reaction time must be fast. The pilot's position is in a deep wadi (valley) so that, other than using a satellite system, it is not possible to detect the downed pilot. The downed personnel sends a beacon signal and this is located by national satellite. Likewise, the location of the survivor and an image of the place is taken by satellite and sent to the headquarters. As soon as the downed aircraft is reported to CSAR JFC, CSARTF is deployed for the mission without knowing the exact location. The Headquarters is trying to send the exact location to CSAR mission assets so that CSARTF can accomplish the mission safely and efficiently.

While the exact location and image update of the pilot are being sent, CSARTF is deployed to the area and CSARTF is in the execution phase. For this research it is anticipated that this CSAR mission requires immediate planning.

In Figure 8, data sent to the Headquarters is trying to be sent to the survivor through the network. Since we don't have the network connectivity among air assets, this data have to be broadcast in order to be reached by the survivor. The CSARTF is trying to get to the surviving downed personnel and in order to accomplish this they are flying though the spider points. The spider points are located in hostile territory. RESCAP vehicles protect the recovery vehicle from all the threats along the spider points. Besides CSAR missions there are Air-to Air refueling missions and Close Air Support missions in the ATO. This will be loaded at the start of the simulation. We can say that the highly planned missions can be an advantage in relaying information in bandwidth and end to end delay.

In the first scenario, the data sent by the headquarters to the AWACS are broadcast to the recovery vehicle through every asset in the ATO. In Scenario 1, 45 minutes, represented by 2750 discrete time steps, of flooding and 4 different routes designated by the NTO are simulated. This is depicted in Figure 8. However, broadcasting data creates a lot of congestion and results in more bandwidth use for the entire network. From the figure, we cannot assume that the only obstacle will be in range for this networking broadcast method. In this research, the environment (mountains and Electronic Warfare) is not taken into account.

In Figure 8, the headquarters is trying to send the image update to every single plane. In the figure, the black arrows show the information paths used to reach the other aircraft. The red line is the route that the RESCAP and RESCORT vehicles are following via the spider points. Spider points are shown with blue squares. The green dotted line represents the FLOT (Forward line of Troops). Every asset's mission is to get the information to the RESCAP vehicles. Routes designated by the NTO are shown as Route1, Route2, Route3 and Route4, respectively.

In scenario 1, during each simulation run, all fixed parameter values are held constant, however the packet inter-arrival time is 0.0625 second and has a Poisson process distribution. The metric of *end-to-end delay* is tracked throughout the entire simulation

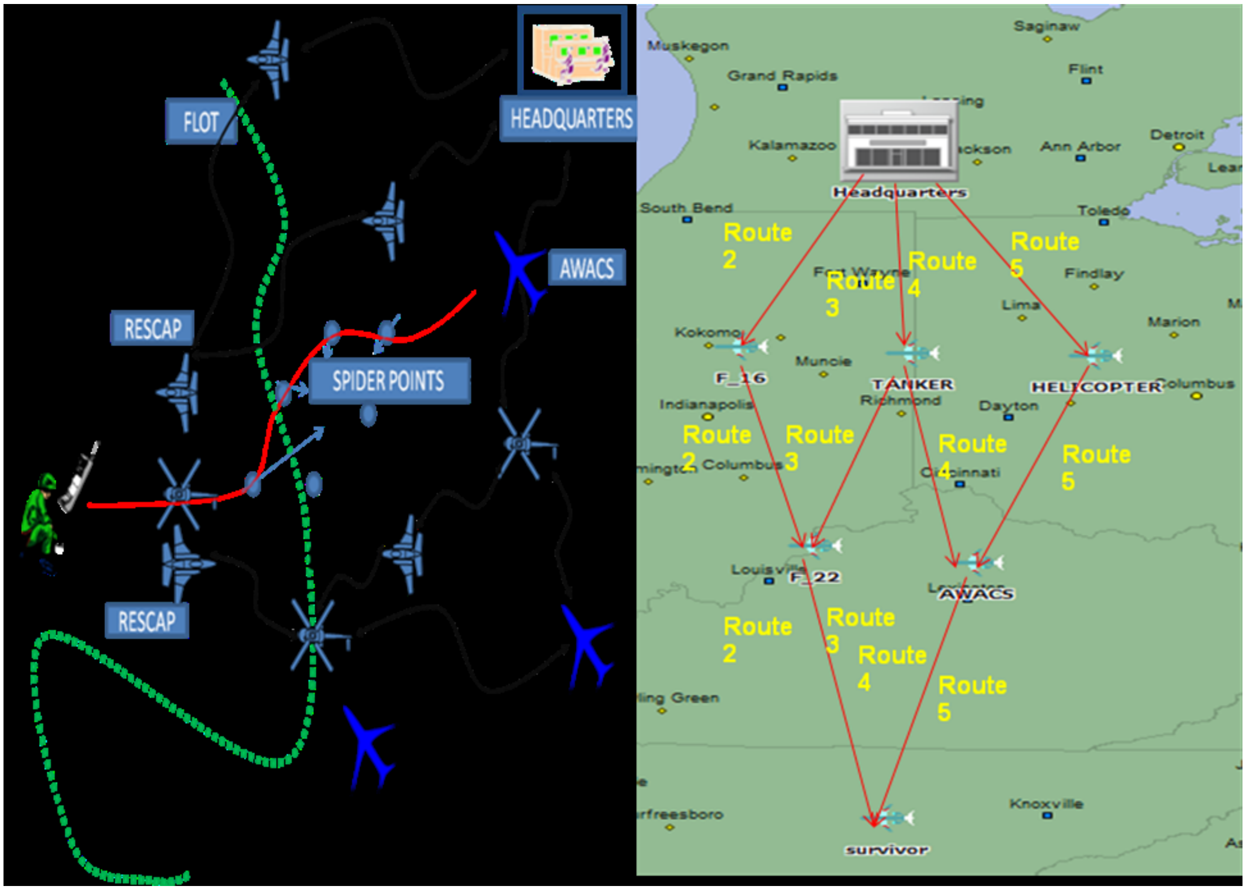


Figure 8. Scenario 1 Scenario with high traffic load

In Scenario 2, 45 minutes, represented by 2750 discrete time steps, of flooding and 4 different routes designated by NTO are simulated. During each simulation run, all fixed parameter values are held constant, however the packet inter-arrival time is 0.1667 second and has of Poisson distribution. The metric *end-to-end delay* is tracked throughout the entire simulation.

In both scenarios the time span for simulation is limited to 45 minutes. There are two reasons; first, the CSAR Execution phase lasts 30 or 45 minutes, second, the simulation is run for long hours and after 45 minutes it becomes stable.

3.11 Experimental Design

For this study, two experiments each with 10 repetitions are simulated with tho factor levels mentioned above. The first experiment, which simulates 5 different routes under high traffic load, has 10 repetitions for each design (scenario 1: 10+10+10+10+10 = 50). The second experiment, which simulates 5 different routes under low traffic routes, has 10 repetitions for each design (scenario 2: 10+10+10+10+10 = 50). The total experiment runs for the entire research is 100. For each route, different prime number seed is used.

3.12 Analysis and Interpretation of Results

As mentioned earlier, there are two hypotheses that will be considered throughout the simulation.

- The end-to-end delay will be longer with the CSAR without NTO knowledge when compared to the CSAR with NTO knowledge in high traffic situations.
- The end-to-end delay will be longer with the CSAR without NTO knowledge when compared to the CSAR with NTO knowledge in low traffic situations.

The analysis of the data supports half the goals of this research. It supports the high traffic assertion, but it does not support the low traffic hypotheses. In high traffic simulations, end to end delay with the NTO architecture is shorter than without the NTO. On the other hand, in low traffic simulations, the end-to-end delay with the NTO is not shorter than without NTO, as we expected. Each experiment is replicated 10 times, as stated above, to get a better depiction of the system's performance in terms of end-to-end delay. Confidence intervals of the 45th minute snapshot are used to evaluate the performance of the NTO architecture in terms of end-to-end delay. If the confidence intervals for end-to-end delays do overlap, the end-to-end delay cannot be considered statistically dissimilar. If not, the end-to-end delays are said to have a noteworthy statistical dissimilarity, therefore it can be concluded that the end-to-end delay with the NTO does perform better or worse than the other.

To allocate the variation in *end-to-end delay*, an Analysis of Variance (ANOVA) is performed on the metric. This shows if the variance in performance is due to experimental error or real differences in the changing factor. In order for the results of the ANOVA to be valid, several assumptions must hold. The assumptions of the ANOVA are: the errors are randomly, independently, and normally distributed with a mean of zero, and have a common variance. These assumptions can be verified by examining residual plots including a normal probability plot, a residual versus fits plot, a histogram of the residuals, and a residual versus order of the data plot [13].

3.13 Summary

In Chapter 3 the methodology used to evaluate the end-to-end delay performance of the NTO architecture applied to a CSAR mission is discussed. This research is evaluated via OPNET performed simulations, rooted in the NTO performance metric in terms of *end-to-end delay*. All experiments are repeated ten times. Experiments are performed on two different scenarios to evaluate the impact of the NTO architecture on 5 different routes in terms of end-to-end delay performance metrics.

IV. Results and Analysis

4.1 Introduction

The experimental results are presented and analyzed in this chapter. Primarily, the end-to-end delay results of Scenario 1 are presented. Subsequently the end-to-end delay results of Scenario 2 are presented. Lastly, the result overall analysis is provided.

4.2 Results and Analysis of Performance Metrics

In this section the related data collected from the simulations are analyzed. The end-to-end delays of two scenarios tested are analyzed by two means. First the overall end-to-end delay of the tested scenario is presented. Second the confidence interval of 45th minute snapshot end-to-end delays is evaluated. Finally the ANOVA is performed in order to show that the variance in performance is a real difference in the changing factor instead of experimental errors.

Primarily results from Scenario 1 are analyzed. After that the results from Scenario 2 is analyzed. Several graphs of end-to-end delays and confidence intervals of end-to-end delays are presented in the following sections.

4.2.1 Analysis of Scenario 1

This section analyzes Scenario 1 results. Scenario 1 represents NTO architecture where 4 different routes are designated to relay the image update or to flood network under high traffic load. The overall end-to-end delay for the scenario 1 is shown in Figure 9. Route 1 indicates the end-to-end delay for the without NTO architecture. Route 2 through 5 shows the end-to-end delay for the with NTO architecture. By visual inspection the end-to-end delay for Route 2 and 3 and also Route 4 and 5 overlap each other.

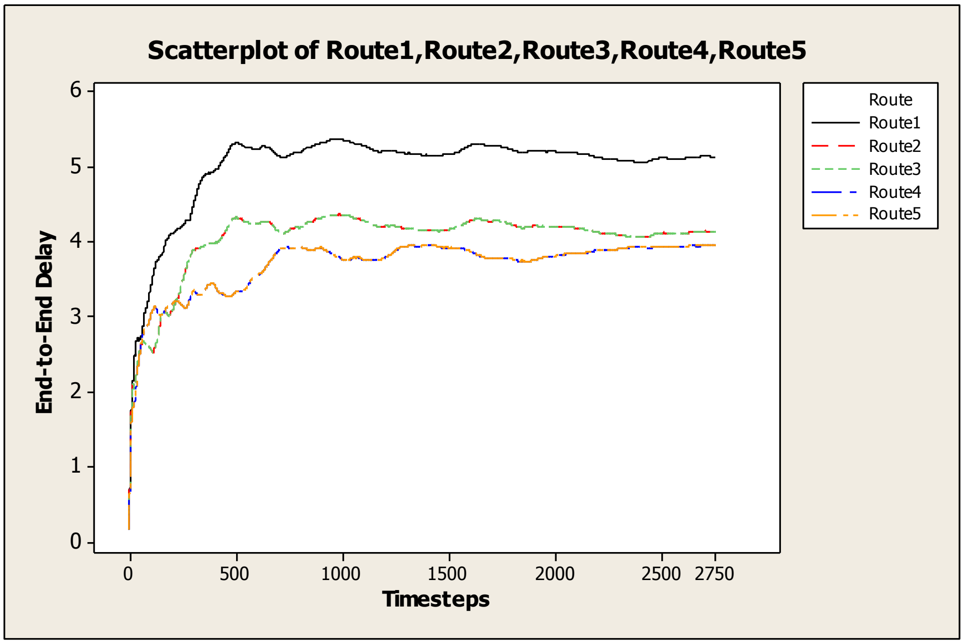


Figure 9. Overall End-to-End delay for Scenario 1

4.2.1.1 Analysis of *End-to-End Delay* for Scenario 1

This section analyzes end-to-end delay performance metric of Scenario 1. Since the NTO designated routes end-to-end delay is shorter. It gives an idea of the feasibility of the NTO architecture under high traffic load. The shorter end-to-end delays are important in terms of achievability of NTO architecture. As expected the end-to-end delay is shorter with NTO designated routes under high traffic load. By inspecting Figure 9, it can be seen that NTO architecture routes have statistical differences compared to the without NTO route. This difference is shown on the detailed plot containing confidence intervals of 45th minute snapshot in Figure 10. Route 1 shows the route without NTO architecture. Routes 2 through 5 show the routes with NTO architecture. NTO designated routes do not have statistical differences compared among each others. In order to show this Tukey's method is applied and results are shown in Appendix B.

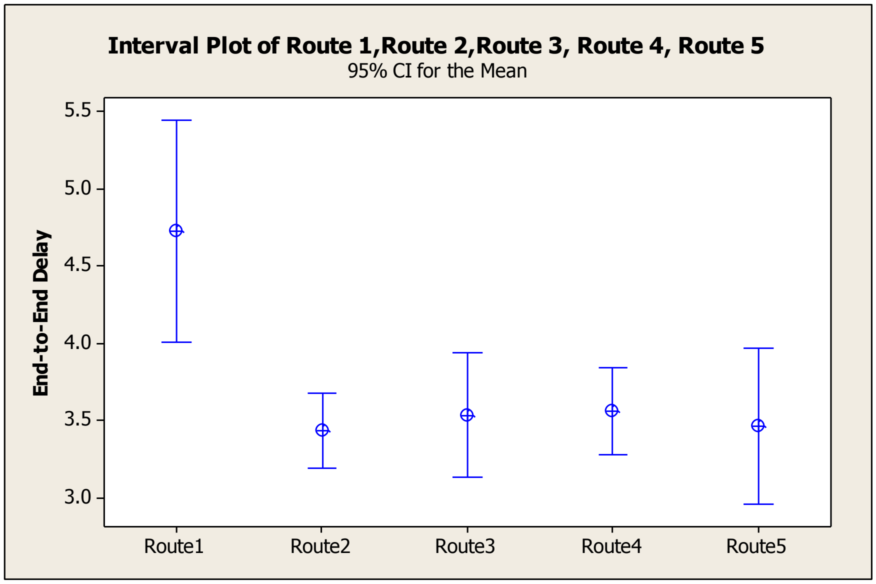


Figure 10. 95 % CI for End-to-End Delay under High Traffic Load

The validity of the ANOVA can be confirmed by visually inspecting the residual plots in Figure 11. The normal probability plot and the histogram show the residuals reasonably fit a normal distribution with a mean of zero. The versus fits plot shows residuals evenly distributed above and below the center line with no apparent trends confirming the errors are independent [13].

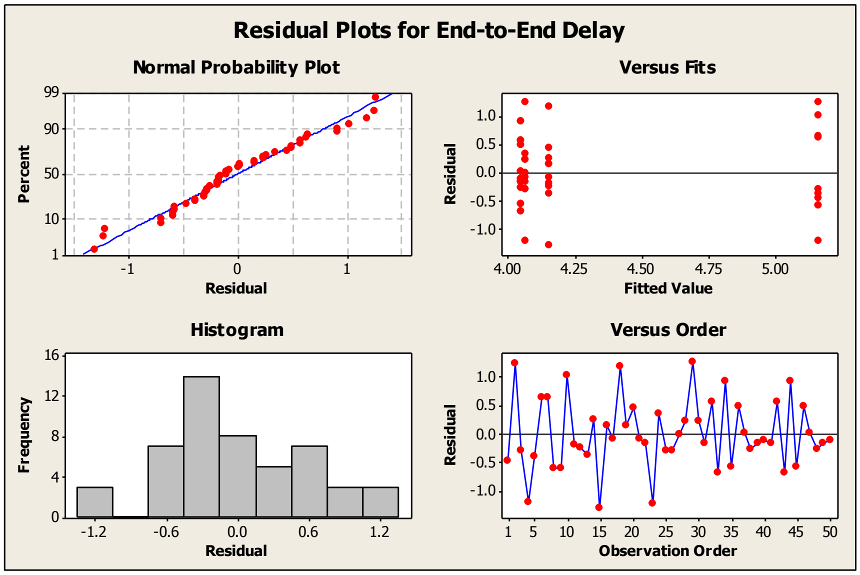


Figure 11. Plots for Verifying the Assumptions of the End-to-End Delay ANOVA

The results of the ANOVA using the *end-to-end delay* are displayed in Table 5. Since small p-value indicates null hypothesis is incorrect, p-value 0.001 shows that one (or more) of the means of the end-to-end delays are different.

Table 5. Results of Using an ANOVA on End-to-End Delay under High Traffic Load

Source	DF	SS	MS	F Ratio	P
Routes	4	9.404	2.351	5.85	0.001
Error	45	18.082	0.402		
Total	49	27.486			

4.2.2 Analysis of Scenario 2

This section analyzes Scenario 2 results. Scenario 2 represents NTO architecture where 4 different routes are designated to relay the image update and to flood the network under low traffic load. The overall end-to-end delay for the scenario 2 is shown in Figure 12. Route 1 indicates the end-to-end delay for the without NTO architecture. Route 2 through 5 shows the end-to-end delay for the with NTO architecture. By visual inspection, the end-to-end delay for Route 2 and 3 overlap each other, also the end-to-end delay for Route 1 is shorter when compared Routes 2 through 5.

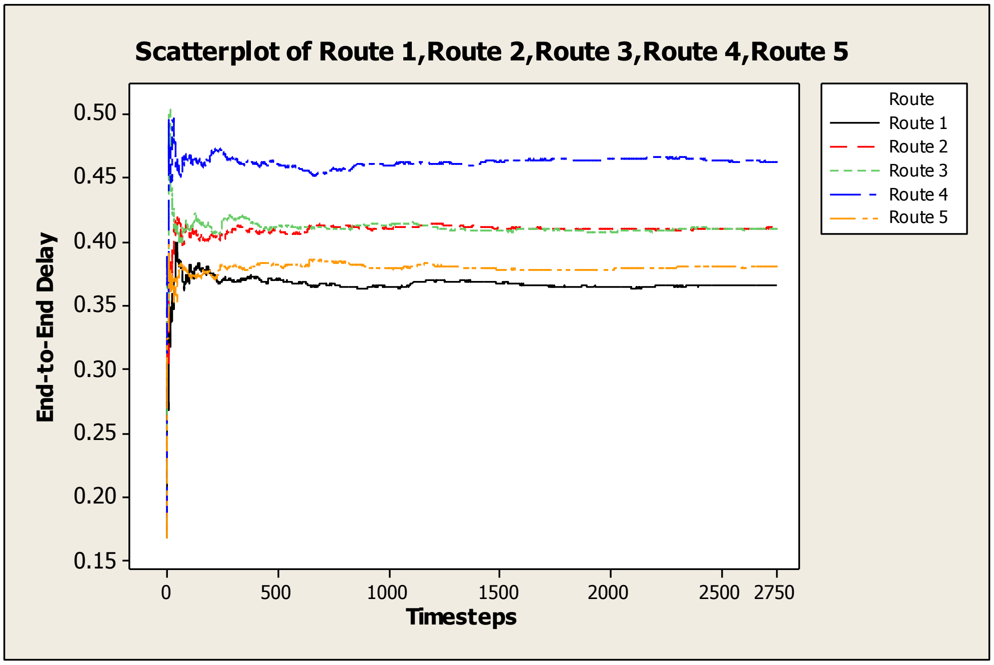


Figure 12. Overall End-to-End Delay for Scenario 2

4.2.2.1 Analysis of *End-to-End Delay* for Scenario 2

This section analyzes end-to-end delay performance metric of Scenario 2. As stated above, the end-to-end delay with NTO architecture is expected to be shorter compared to the one without NTO architecture, although the results show that without the NTO architecture end-to-end delays are shorter when compared to the with the NTO architecture under low traffic load. By visual inspection it can be seen that without NTO architecture route has significant statistical difference compared to the with NTO architecture route. These differences are verified by the numerical data, which is shown on a detailed plot containing confidence intervals in Figure 12. Route 1 shows the route without NTO architecture. Route 2 through 5 shows the routes with NTO architecture.

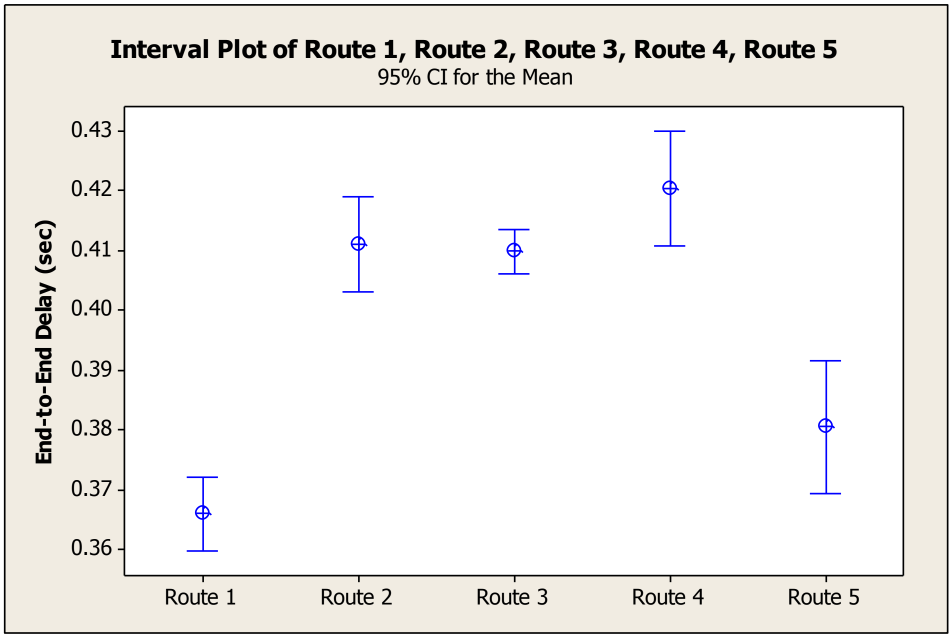


Figure 13. 95 % CI for End-to-End Delay under Low Traffic Load

NTO designated routes do have statistical differences compared among each others. In order to show this Tukey's method is applied and results are shown in Appendix C. However in this research the aim is not showing the end-to-end delay differences between NTO designated routes.

The validity of the ANOVA can be confirmed by visually inspecting the residual plots in Figure 14. The normal probability plot and the histogram show the residuals reasonably fit a normal distribution with a mean of zero. The versus fits plot shows residuals evenly distributed above and below the center line with no apparent trends confirming the errors are independent [13].

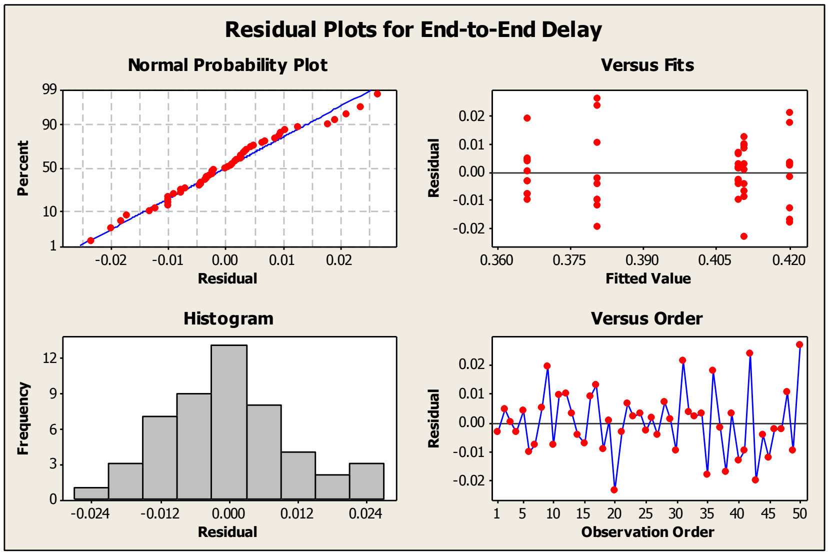


Figure 14. Plots for Verifying the Assumptions of the End-to-End Delay ANOVA

The results of the ANOVA using the log *end-to-end delay* are displayed in Table 6. Since small p-value indicates null hypothesis is incorrect, p-value 0.000 shows that one (or more) of the means of the end-to-end delays are different.

Table 6. Results of Using an ANOVA on End-to-End Delay Under Low Traffic Load

Source	DF	SS	MS	F Ratio	P
Routes	4	0.021185	0.005296	41.14	0.000
Error	45	0.005793	0.402		
Total	49	0.026978			

4.3 Overall Analysis

The conclusions drawn from the simulations are presented in this section. Primarily, from the aspect of first hypothesis, the statistical analysis confirms that end-to-end delay will be longer with the CSAR without NTO knowledge when compared to the CSAR with NTO knowledge in high background traffic situations. However the second hypothesis, end-to-end delay will be longer with the CSAR without NTO knowledge when compared to the CSAR with NTO knowledge in low traffic situations, can not be confirmed with the results of scenario 2. The NTO architecture end-to-end delay under high traffic load provides statistically significant performance gains over the without NTO architecture. Using the data from scenario 1, the following summarizes the performance gain achieved by the with NTO architecture routes compared to the without NTO architecture route:

- 19.5 % less end-to-end delay time via Route 2
- 21.1 % less end-to-end delay time via Route 3
- 21.5 % less end-to-end delay time via Route 4
- 21.4 % less end-to-end delay time via Route 5

Using the data from scenario 2, the following summarizes the performance loss achieved by the with NTO architecture compared to the without NTO architecture:

- 12.2 % higher end-to-end delay time via Route 2
- 12.8 % higher end-to-end delay time via Route 3
- 14.7 % higher end-to-end delay time via Route 4
- 3.9 % higher end-to-end delay time via Route 5

From the above results it is concluded that there is a big difference of end-to-end delays under high and low traffic load. At first it may be seen that NTO architecture does not provide any efficiency in Scenario 2. When we look at end-to-end delays, with NTO architecture performs poorly ranging 3.9% to 14.7% compared to without NTO architecture under low traffic load. However in real life scenarios the NTO architecture will never be lightly loaded. In scenario 2, the tradeoff is between bandwidth and speed.

Without the NTO you will get shorter end-to-end delays ranging from 3.9% to 14.7%however you will end up using more bandwidth.

Since the end-to-end delay with NTO architecture routes under high traffic load is less than without NTO architecture routes. The comparison between scenario 1 and 2 can be looked at from different aspects. The gain of the 1st Scenario is on average 20.9%, on the other hand the loss of the second scenario averages 10.9%. Likewise under low traffic load if the data intended to send is a must-send and critical-time data, then the best option will be flooding the network.

4.4 Summary

In Chapter 4, the data from two different scenarios are presented and analyzed. First, the performances of each with and without NTO architecture routes were statistically analyzed in terms of end-to-end delay. Finally, a general analysis was provided.

V. Conclusions and Recommendations

5.1 Introduction

In Chapter 5 the conclusion of the research is outlined. First the main conclusion is given. Next, the importance of this research is discussed. Finally the possible recommendations for future work are described.

5.2 Conclusions of Research

These experiments clarify that the NTO architecture can be applied to the air assets that appear in the ATO. Since ATO is highly preplanned, taking advantage of this will give better performance in terms of end-to-end delay. The main conclusion is that decision-makers can gain insight into the network coverage of the air space with the aid of NTO knowledge. Additionally, the results determine that the NTO architecture significantly outperforms without the NTO architecture studied in terms of reducing *end-to-end delay* under high traffic load.

From the low traffic load perspective the end-to-end delay did not outperform the high traffic load, as expected. However the overall gain can be summarized as follows. Assuming that critical data will be sent under low traffic load, the options will be either flooding the network or choosing the routes designated by NTO. The first option, flooding the network, will give a shorter end-to-end delay, more bandwidth usage and almost 99% guaranteed delivery. The second option, choosing the designated routes by NTO, will give longer end-to-end delay, less bandwidth usage and lower delivery percentage than flooding. This will be a tradeoff under low traffic load. We can easily conclude that important traffic that has to sent will be sent without the NTO architecture under low traffic load.

The experiments in this research advocate the use of an NTO to achieve wider network reliability and robustness than is possible without using an NTO. In order to shape the FCS, every asset using JTRS must be able to react to rapid changes in the battlefield. By taking advantage of the highly preplanned network coverage in an NTO, reliable and high quality transfers can be achieved. In this research we have described the benefits of the NTO in the context of CSAR missions. This can be expanded to all missions. Both JTRS and the NTO are new, and the idea of joining them can emerge easily since they seem to overlap each other.

5.3 Significance of Research

This research is the first effort to provide a constructed mission using an NTO architecture, which was designed in the context of CSAR group communication. Also, this thesis is among the first to address end-to-end delay performance metric in CSAR communication. By taking advantage of highly preplanned missions can provide highly reliable network coverage and in the near future these planes can act as a satellite.

One of the most challenging issues in the battlespace is the communication in every aspect. If the communication is not achieved well, there will be a shortfall in the C3 (Command Control and Communicate) systems. From that perspective the NTO will help C3, since communication will be done by networking manner with the joint of NTO and JTRS.

This research can lead the new era of communication not only in military applications but also in civilian applications. The NTO can be applied also for the civilian airliners. Since in the near future the flights will be more frequent and the airliners routes are highly planned, the planes can act as a router throughout its entire route. This could give communication industry a big chance in the ways of deployable communication.

Also the JTRS is still in progression phase and if it is going to replace the current radio technology and be above it, along with the JTRS progression phase, there has to be input from NTO to JTRS.

5.4 Recommendations for Future Research

This research presents an interesting and new area using the, so called NTO, which can take advantage of highly planned air assets for managing relaying information throughout longer ranges. This research is limited in that it focuses on performance in terms of reducing end-to-end delay with and without NTO architectures under different traffic loads. So, there are several ways that could be expandable for future research.

One recommendation for future work is to implement this scenario under multiple different performance metrics such as packet loss, SNR ratio between assets, reception power, transmission range and throughput after the implementation of JTRS is finished.

JTRS has a long way to go. Since NTO is in the concept stage, these two can be combined for the networking of the Net-Centric operations. One could research the overlapping parts of NTO and JTRS and can input the NTO information into the JTRS and can design the Graphical User Interface for the NTO in JTRS architecture.

Finally one could expand the scenario presented in this research where there can be other assets like troops, tanks or airplanes playing a jammer role for the entire network. This could be done after JTRS has fully implemented. This will give a better understanding of NTO with a more realistic scenario.

5.5 Summary

In Chapter 5 the conclusion was presented. The importance of the research was discussed. The possible recommendations for future research are provided.

Appendix A. Traffic Separation for Low and High Traffic Load

For high traffic load it is assumed that it is being sent at 5 Mbps picture update. The packet length is 5000 bits. Then the number of packets will be 1000. When the number of packets is divided into 60 seconds, the number of packets sent per second will be 16.6667. I assumed 16 packets per second roughly. In order to plug into OPNET, 16 packets per second is divided by 1. The inter-arrival time is 0.0625 s.

For low traffic load it is assumed that it is being sent 2 Mbps picture update. The packet length is 5000 bits. Then the number of packets will be 400. When the number of packets is divided into 60 seconds, the number of packets sent per second will be 6.3. I assumed 6 packets per second roughly. In order to plug into OPNET, 6 packets per second is divided by 1. The inter-arrival time is 0.1667 s. This is shown below.

High Traffic Load

λ= Picture Size/(Packet size*60)

λ= 5 Mb/5000 bpp*60sec

λ= 16.667 ≈16 pps

μ = Data Rate/ Packet Size

μ = 90 000 bps/ 5 000 bpp

μ = 18 pps

$\rho = \lambda / \mu$

ρ =16 pps/ 18 pps

ρ = 88%

Low Traffic Load

λ= Picture Size/(Packet size*60)

λ= 2 Mb/(5000 bps*60sec)

λ= 6.667 ≈6 pps

μ = Data Rate/ Packet Size

μ = 90 000 bps/ 5 000 bpp

μ = 18 pps

$\rho = \lambda / \mu$

ρ =6 pps/ 18 pps

ρ = 33%

Appendix B Tukey 95% Simultaneous Confidence Intervals

```
All Pairwise Comparisons among Levels of Route

Individual confidence level = 99.33%


Route = Route 1 subtracted from:

Route      Lower   Center    Upper  ----+---------+---------+---------+-----

Route 2  -1.8139  -1.0081  -0.2022   (---------*---------)

Route 3  -1.8978  -1.0919  -0.2861  (---------*---------)

Route 4  -1.9171  -1.1113  -0.3055  (---------*---------)

Route 5  -1.9149  -1.1091  -0.3032  (---------*---------)

                                   ----+---------+---------+---------+-----

                                     -1.60     -0.80     -0.00      0.80


Route = Route 2 subtracted from:


Route      Lower   Center   Upper  ----+---------+---------+---------+-----

Route 3  -0.8897  -0.0839  0.7220            (---------*---------)

Route 4  -0.9091  -0.1032  0.7026            (---------*---------)

Route 5  -0.9068  -0.1010  0.7048            (---------*---------)

                                    ----+---------+---------+---------+-----

                                      -1.60     -0.80     -0.00      0.80
```

```
Route = Route 3 subtracted from:


Route      Lower   Center   Upper  ----+---------+---------+---------+-----
Route 4  -0.8252  -0.0194  0.7865              (---------*---------)
Route 5  -0.8230  -0.0171  0.7887              (---------*---------)
                                   ----+---------+---------+---------+-----
                                    -1.60     -0.80     -0.00      0.80
```

```
Route = Route 4 subtracted from:


Route      Lower  Center   Upper  ----+---------+---------+---------+-----
Route 5  -0.8036  0.0022  0.8081              (---------*---------)
                                  ----+---------+---------+---------+-----
                                   -1.60     -0.80     -0.00      0.80
```

Appendix C Tukey 95% Simultaneous Confidence Intervals

```
All Pairwise Comparisons among Levels of Route

Individual confidence level = 99.33%


Route = Route 1 subtracted from:

Route      Lower   Center    Upper  -----+---------+---------+---------+----

Route 2  0.03042  0.04484  0.05927                  (---*---)

Route 3  0.02923  0.04365  0.05807                  (---*----)

Route 4  0.03968  0.05411  0.06853                    (---*----)

Route 5  0.00006  0.01448  0.02891              (---*---)

                                   -----+---------+---------+---------+----

                                     -0.035     0.000     0.035     0.070

Route = Route 2 subtracted from:


Route       Lower    Center     Upper  -----+---------+---------+---------+----

Route 3  -0.01562  -0.00119   0.01323             (---*---)

Route 4  -0.00516   0.00926   0.02369              (---*---)

Route 5  -0.04478  -0.03036  -0.01594         (---*---)

                                       -----+---------+---------+---------+----

                                         -0.035     0.000     0.035     0.070
```

Route = Route 3 subtracted from:

```
Route      Lower    Center     Upper  -----+---------+---------+---------+----
Route 4  -0.00397   0.01046   0.02488              (---*---)
Route 5  -0.04359  -0.02917  -0.01474    (---*---)
                                      -----+---------+---------+---------+----
                                      -0.035     0.000     0.035     0.070
```

Route = Route 4 subtracted from:

```
Route      Lower    Center     Upper  -----+---------+---------+---------+----
Route 5  -0.05405  -0.03962  -0.02520  (---*---)
                                      -----+---------+---------+---------+----
                                       -0.035     0.000     0.035     0.070
```

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 074-0188*

1. REPORT DATE *(DD-MM-YYYY)* 27-03-2009	**2. REPORT TYPE** Master's Thesis	**3. DATES COVERED** *(From – To)* May 2007-March 2009

4. TITLE AND SUBTITLE The benefits of a Network Tasking Order in Combat Search and Rescue Missions	**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Gocmen, Murat, 1st Lt., TUAF	**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S) Air Force Institute of Technology Graduate School of Engineering and Management(AFIT/EN) 2950 Hobson Way WPAFB OH 45433-7765 DSN:785-3636	**8. PERFORMING ORGANIZATION REPORT NUMBER** AFIT/GCE/ENG/09-01
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE:DISTRIBUTION UNLIMITED

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Networked communications play a crucial role in United States Armed Forces operations. As the military moves towards more network centric (Net-Centric) operations, it becomes increasingly important to use the network as effectively as possible with respect to the overall mission. This thesis advocates the use of a Network Tasking Order (NTO), which allows operators to reason about the network based on asset movement, capabilities, and communication requirements. These requirements are likely to be derived from the Air Tasking Order (ATO), which gives insight into the plan for physical assets in a military mission. In this research we illustrate the benefit of an NTO in a simulation scenario that centers on communication in a Combat Search and Rescue (CSAR) mission. While demonstrating the CSAR mission, we assume the use of the Joint Tactical Radio System (JTRS) for communication instead of current technology in order to mimic likely future communication configurations. Our premise is that the knowledge in an NTO can be used to achieve better CSAR missions and yield better decision-making opportunities to the mission commanders. We present a scenario that hinges on the transmission of a critical image update from the headquarters to the survivor in the context of a CSAR mission. We attempt to transmit the image with the aid of an NTO and then without the use of an NTO under high and low traffic loads. Our results show that the end-to-end delay with the aid of an NTO in high traffic conditions is shorter when compared to operations without the aid of an NTO and bandwidth requirements are also lower. In low traffic conditions, the end-to-end delay is shorter without the aid of an NTO, but at the cost of higher bandwidth utilization.

15. SUBJECT TERMS
Combat Search and Rescue, Air Tasking Order, Network Tasking Order and Joint Tactical Radio System

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Kenneth Hopkinson,PhD,ENG
REPORT U	**ABSTRACT** U	**c. THIS PAGE** U	UU	66	**19b. TELEPHONE NUMBER** *(Include area code)* (937) 255-6565;email:Kenneth.hopkinson@afit.edu