Paper 023

20th ICCRTS
Theme: Organizational Concepts and Approaches
June 2015

Exploring Tipping Points and State Transitions in a Tactical Network

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Abstract

Today's military forces operate in a networked environment. Mission success depends to a significant degree, upon the ability to exercise effective command and control (C2) of this collection of inter-dependent networks, a multi-genre Composite Network that includes, but is not limited to, communication, information, and cognitive/social networks. C2 establishes not only the rules that govern and shape individual network behaviors (e.g., connectivity, access to information, and processes) but also create the conditions and constraints that give rise to the nature of the interactions that take place between and among these different networks. These network interactions create inter-dependencies that can result in effects cascades that impact individual and composite network performance. The hypothesis we explore in this paper is that stresses on a communications network will at some point create a tipping point that will results in a state change, specifically the difference between mission failure and furthermore that the adoption of a C2 Approach can change this tipping point.

Introduction

Mission success depends, to a significant degree, upon the ability of military organizations, often in partnership with a range of other organizations both military and civilian, to exercise effective command and control (C2) of a multi-genre Composite Network that includes inter-dependent communication, information, and cognitive/social networks.

In recognition of the above, The Network Science Collaborative Technology Alliance (NSCTA) is a collaborative research alliance between the US Army Research Laboratory (ARL), other government, industry and academic researchers. This alliance is exploring, creating and developing different methodologies and technologies with the notion to explore, identity, quantify and analyze composite networks and their ability to sustain performance in some form or fashion.

Within this research program is a subtask focused on advancing the science of multi-genre experimentation and validating basic network science under complex, military-relevant conditions. This experimentation tasks seeks to gain insights into cross-genre interactions on state transitions of various metrics [1]. In this paper, we will investigate the conditions that cause state transitions, defined by mission performance metrics that result from adverse impacts to the supporting communication network as a function of the design of the C2 / social network. This work illustrates the benefits of being able to have access to an experimentation infrastructure that is able to represent the dynamics interactions between and among two interdependent networks of different genres (composite network) – namely a communications and C2 / social network.

Without access to an instrumented composite network environment, individual researchers have tended to focus on a particular network genre and some confine themselves to a specific type of network (e.g. mobile communications). Recognizing that the behavior of their network of interest depends upon a variety of factors including the characteristics and behaviors of any interconnect network, they have been forced to posit a number of assumptions about the performance of interconnected networks without actually being able to simulate them in situ or to 'parameterize' key performance metrics associated with a related network in an attempt to understand important inter-dependencies. The availability of ARL's composite network experimentation environment will enable them to observed adaptive dynamic behaviors that are typical in Army composite networks.

The research reported upon here is but a very small and limited initial effort that in a planned multi-year multi-threaded campaign of experimentation is to improve our understanding of Composite Network behaviors and develop integrated designs that improve both the performance and agility of these networks and, by doing so, the ability to support missions.

While we limited this investigation to two inter-dependent networks, our findings are expected to contribute to validating some fundamental tenets of network science. For example, this research can be viewed as a 'proof of concept' demonstration of Barabási's assertion that

> "…despite the apparent differences, the emergence and evolution of different networks is driven by a common set of fundamental laws and reproducible mechanism. Hence despite the amazing diversity in form, size, nature, age, and scope characterizing real networks, most networks observed in nature, society, and technology are driven by common organizing principles"[2].

Hypothesis

Social and communications networks are significantly different from each other in a number of ways and their interactions are asymmetrical. Thus they 'qualify' as subjects that can be used to investigate Barabasi's proposition above. The general statement of our hypothesis is that, in the case of two inter-connect networks of different genres, the design of one can alter the tipping point of the other with relation to a given stress.

To investigate this hypothesis we employ a recently enhanced simulation capability of ARL's Network Science Research Laboratory (NSRL) that allows us to instantiate a C2 /social network and a tactical mobile communications network. The design parameter we selected for the C2 / social network is the C2 Approach. In military organizations, it is the C2 Approach that shapes the behavior of the social network and results in patterns of interactions between and among individuals in the organization[1]. The behaviors of individuals and organizations, in particular their information-related behaviors (access, processing, and sharing) places demands on the communications network. The ability of the communications network to support the social

[1] C2 is exercised in the context of warfighting doctrine and allows commanders to tailor their organization's behaviors to the mission and circumstance. A C2 approach is a region in a three dimension space whose inter-dependent dimensions consist of the allocation of decisions rights, the patterns of interactions, and the dissemination of information.

(task oriented) network is a function of many things, among them the available bandwidth. The stress we have selected serves to restrict available bandwidth. In specific terms, our hypothesis is that the stress induced tipping point will result in a state change (mission success to mission failure) and that this tipping point will be moved (along the stress axis) if the C2 Approach is changed.

As previously mentioned, our ability to successfully undertaken this experiment demonstrates that, with the enhancements made to ARL's NSRL, researchers can explore the complex behaviors inherent in Composite Networks with greater granularity and realism.

Key Concepts and Terms

In this section we briefly discuss the nature of a military composite network that is required to support mission-defined operations including its design parameters, performance metrics and how we determine mission success as well as our use of the term 'tipping point' in the context of our hypothesis.

Army Composite Networks

Since the 1990s the Army has recognize the importance and role of networks as evidenced from the development of a 'new theory of warfare' referred to as Network Centric Warfare [2]. The tents of NCW (see Figure 1) and its relationship to a composite network (Figure 2) suggest that new approaches to Command and Control, ones that enables self-synchronization, are 1) required to take full advantage of the opportunities provided by networking capabilities and 2) constitute a design challenge for composite networks.

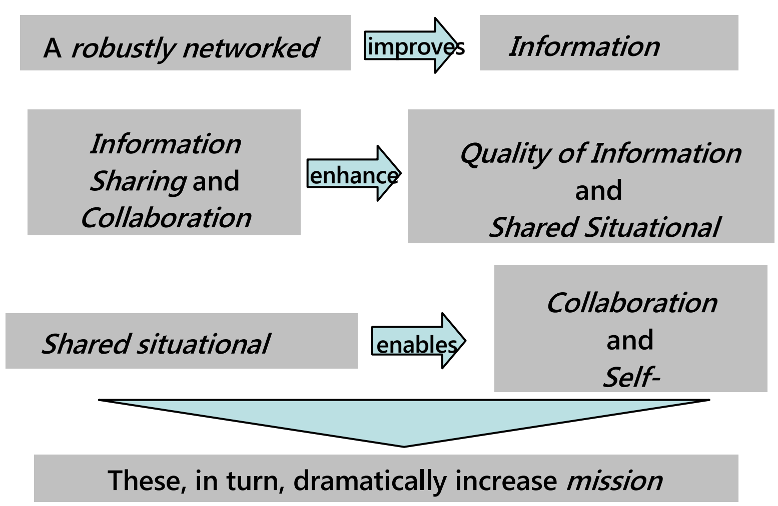

Figure 1: Tenets of NCW

[2] See seminal publication on Network Centric Warfare at http://dodcccrp.org/files/Alberts_NCW.pdf

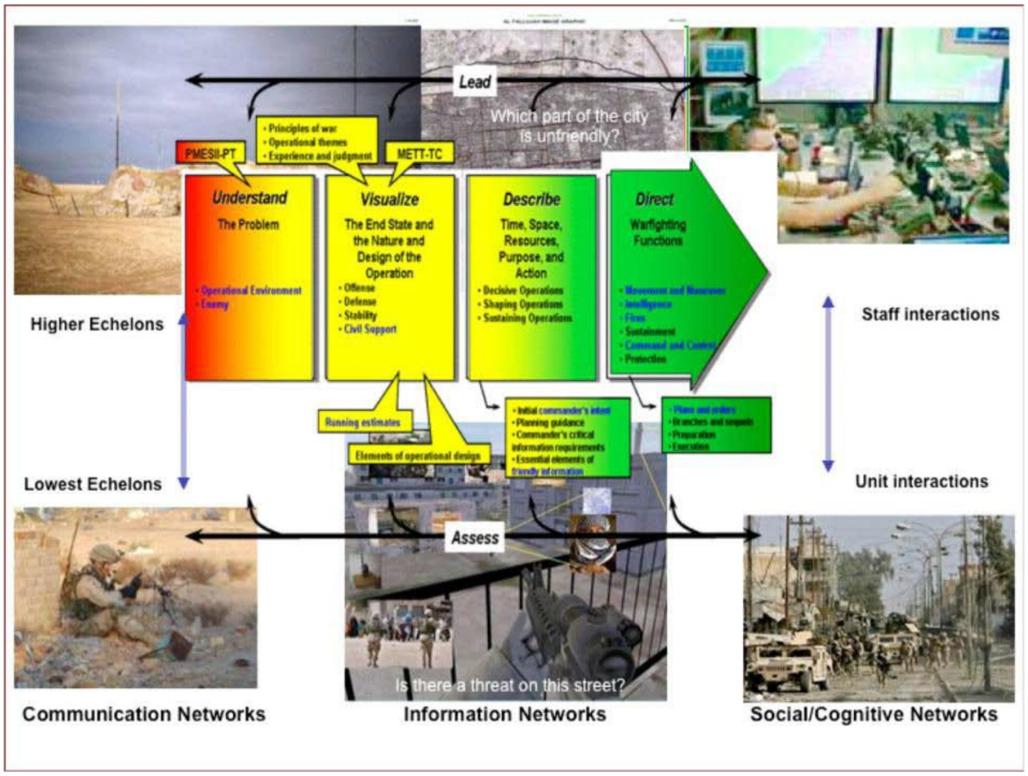

Figure 2. Network Science and Network-Centric Warfare

In military organizations the social network is shaped and constrained by the approach to C2 that is adopted. In NCW terms, different C2 approaches will result in more or less shared awareness as a function of time. There is no 'one size fits all' approach to C2 that is appropriate for all missions and circumstances. The fitness of a given approach also depends upon the characteristics and performance of the information and communications network. Evidence shows that no specific approach or set of approaches defines what Command and Control means. This paper is considers two very different C2 Approaches, a traditional hierarchical organizational approach (pre-NCW) and a highly decentralized C2 approach (Edge organization) that pushes the self-synchronization idea at the heart of NCW to its logical conclusion and allows the force at each echelon to have many degrees of behavioral freedom [Alberts and Hayes 2003].

Enabling interactions between and among the nodes of a distributed social network is a communications network. The communication network used in a tactical environment is radio-based and is challenged by connectivity and bandwidth limitations [3].

Figure 3 identifies design and performance parameters and characteristics of the Endeavor Space[3] that impact behaviors and performance of each of the three single genre networks as well as the Composite Network. It also identifies a measure of performance for the composite mission network and the Endeavor Space dimensions that impact Composite Network Performance for each of the three network genres in a military composite network and for the composite mission network, of interest.

Network	Design	Performance	Endeavor Space
Composite	Integrated Design	Task Accomplishment	Mission Challenges Mission Requirements
C2 (Social)	C2 Approach Sharing Policies Team Composition	Shared Awareness	Cognitive Load Trust
Information	Compression Smart Query Pacing	Information Dissemination	Signal to Noise Damage to Sources Mis-Information
Communications	Topology Bandwidth Power	Message Delivery	Damage to Links Message Size Available Bandwidth

Figure 3. Description of multi-genre network layers

[3] The term Endeavor Space refers to a multi-dimensional space whose dimensions represent the important characteristics of missions, environmental conditions and stresses as well as the state of 'self' contained in this space are the range of challenges that an enterprise could be called upon to meet. Enterprise Agility is measured by the volume of this space where an enterprise can operate successfully.

Tipping Point

The term "Tipping Point" is used differently by different researchers. One use is that a tipping point exists when the state of a system changes as a result of the value of a parameter exceeds some level [4]. Others, for example, in the study of social networks consider a scenario where a percentage of the population, who holds a minority opinion, yet unshakable belief, becomes by the majority [5]. We are using tipping point in the former construction to refer to a threshold of mission success or failure as a function of various parameters in this tactical network.

Experiment

This experiment involves the employment of an integrated experimentation environment that uses ELICIT to represent the C2 or social network as well as task that involves finding the solution to four part problem and EMANE to emulate a tactical network. All communications between and among social network nodes (agents) go thru the tactical network.

Simulating the Tactical Network

The topology of the tactical network is representative of the network that would be necessary for a tactical military scenario involving a Company, its Platoon and Squad that reports to a Battalion level headquarters.

We consider various communications link bandwidths in our scenario that are representative of actual radio waveforms. The radio model used at the squad level to deliver information to the team leader and the platoon is an AN/PRC-148 (MBITR) [6]. This radio has a bandwidth of 16 kbps. The radio model that will be used by the platoon to the company, at the outpost, will be the AN/PRC-119 (Man Pack SINCGARS). This radio has bandwidth of 16 kbps. The AN/VRC-92 (Vehicle SINCGARS) radio will be used by the company at the outpost to deliver information to the higher echelon [7].

We envision that the task at hand will require different services, all in support of the network to perform the mission. The requirements could be streaming video, real-time messaging, and/or Voice-over-IP. These services are run over networks with limited computing and networking resources. The communications in our simulations are representative of these data services as we consider several message sizes. Also, we simulate background traffic to model these service/information flows and determine if the network with different C2 Approaches (hierarchical, edge) and apportioned link bandwidths produce any change in the threshold for mission success.

The software tool we used to generate traffic is MGEN (Multi-Generator). Developed by the Naval Research Laboratory, MGEN is open source software that provides the ability to perform IP network performance tests and measurements using TCP and UDP/IP traffic [8]. The software infrastructure used to simulate/emulate tactical communications is the Common Open Research Emulator (CORE). CORE provides a graphical user interface; with the Extendable Mobile Ad-hoc Network Emulator (EMANE) framework that provides radio models and scenarios [9].

Simulating the C2 / Social Network and Determining Mission Success

abELICIT[4] was used to instantiate both a traditional military Hierarchy and an Edge organization. The problem to be solved was the standard "Industrial Age" ELICIT challenge problem (68 factoid set containing a 'normal' amount of noise). Two different C2 Approaches were simulated – a traditional hierarchy and an edge organization.

Mission success was defined as the development of a correct overall solution, that is the identification of the "Who What Where and When" of a terrorist attack within the timeliness requirement of the mission. For this paper, we do not consider the level of shared awareness developed (the number of individuals with the correct overall solution) since this paper's objective is to illustrate a tipping point experiment using a composite network. ARL researchers plan to conduct additional runs to further explore the incorporation of shared awareness requirements into an analysis of tipping points for communication network performance.

[4] ELICIT – Experimental Laboratory for the Investigation of Collaboration, Information-sharing and Trust is a DoD develop instrumented environment see http://www.dodccrp-test.org/elicit abELICIT refers to the employment of agents to represent human behavior in this environment.

Results & Analysis

Figure 4 compares the points at which a Traditional Hierarchy and a share-only Edge C2 Approach cannot meet timeliness requirements for a selected mission timeless requirement.

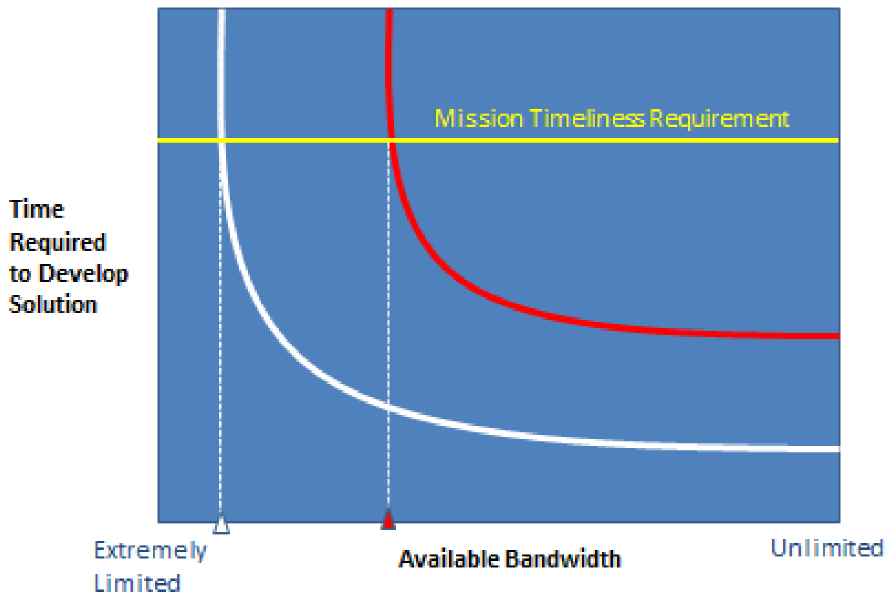

Figure 4: Mission Success as a function of Bandwidth Availability: Traditional Hierarchy v. Share-Only Edge

As expected, the time required to develop a complete solution increases as available bandwidth is reduced. At some point, neither C2 Approach is able to solve the problem. A more typical 'post-only' Edge was not supported by the experimentation environment, but we expect to be able to add these results at a later date. From Figure 4, we see that the bandwidth tipping point depends upon the adoption of a specific C2 Approach. Thus commanders would be well advised to, in addition to considering all of the pros and cons of different approaches to C2 consider bandwidth availability in the selection of a C2 Approach.

****** At the time this draft paper is being submitted to ICCRTS, testing of the environment is continuing.   We will update this section of the paper in both the final submission and in the actual presentation (if accepted).*

Future Work

The identification of the tipping points of mission success within a tactical communication network can be used to help with the identification of tipping point in a composite (multi-genre) networks. We can also begin to study on the robustness, resilience and redundancy in a network and how we can use NSCTA tools like QoI, DTN and other functionalities to enhance the communications network robustness based upon parameters of other networks such as social and information networks. These can be tested to see how composite networks can be designed to maintain mission performance in the presence of sophisticated environmental constraints of this composite network.

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