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Integration of Communication and Social Network Modeling Platforms using ELICIT and the Wireless Emulation Laboratory

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Abstract:

Creating models and experiment platforms that study the relationships and interactions between composite networks will enable the design of tactical networks to maximize mission performance of an organization. Tactical environments can be conceptualized by complex networks, a composition of communication, social/cognitive, and information networks. We describe an approach to integrate ELICIT (Experimental Laboratory for Investigating Collaboration, Information-sharing and Trust) with an existing wireless emulation test bed, the Wireless Emulation Laboratory (WEL). These modifications enhance the capability to simulate more realistic communication models during trials of ELICIT experiments. Gaining an understanding of how communication network parameters affect decision-making performance in social networks will enable the design of tactical networks to optimally support mission operations. Experiments using the emulation environment will provide validation to the parameters in ELICIT used to simulate communication network parameters. Additionally, we study how specific ELICIT parameters can be used to represent both social and communication network concepts.

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Introduction

Tactical networks are comprised of many elements which interact dynamically to support Warfighter mission performance. Typically considered to include all military assets available to the Warfighter, the scope of the tactical scenario has expanded to include elements from other domains (i.e. culture, society, politics, and psychology). Tactical environments began to consider these elements to support Warfighter interactions with secondary groups such as local nationals and non-governmental agencies. Organizations such as the Department of Defense and the Department of Homeland Security have proposed strategies to deal with the increasing scope of their tactical situations. Information sharing is a crucial element of their organizational capability [1-2]. Each of these organizations recognizes the complexity of their situations calls for the consideration of networks with multidisciplinary elements such as culture, policies, coalition members, and technology. In many of these cases, the performance of the Warfighter is the primary interest. Understanding and being able to characterize the interactions between multidisciplinary networks will enable network design strategies to optimize Warfighter mission performance. A key tool for developing this understanding is the existence of a test bed that models all the characteristics of complex networks and can be used for research experiments.

The goal of this work is to improve the understanding of complex networks and provide a viable test bed to verify cross-layer network models. This paper first describes a command and control experiment platform called ELICIT (Experimental Laboratory for Investigating Collaboration, Information-sharing, and Trust) [18]. This platform has been used to model both organizational behavior constructs as well as communication networks. We use this platform to study the scope and range of parameters of complex networks involving communication networks and social/cognitive networks. We then describe current work that has improved the communication network modeling capability within the ELICIT platform. This involves the integration of ELICIT with a communications emulation platform called The Wireless Emulation Laboratory (WEL). Lastly, we present results to illustrate the increased fidelity of the communication models used in ELICIT experiments.

Complex Networks

Tactical networks can be represented and modeled through complex networks. *Network science* [3] is a research area intended to increase the understanding of complex networks, that is, networks that include communication, information and social/cognitive (CIS) networks. One of the major objectives of this field of study is to increase the understanding of the interactions between the constituent networks of the complex network. The majority of network research considers one of the constituent networks, while a characterization of the entire complex network may provide a more accurate representation of the increasingly complex scope of tactical networks. Figure 1 illustrates the concept of complex networks being comprised of social/cognitive, information and communication networks.

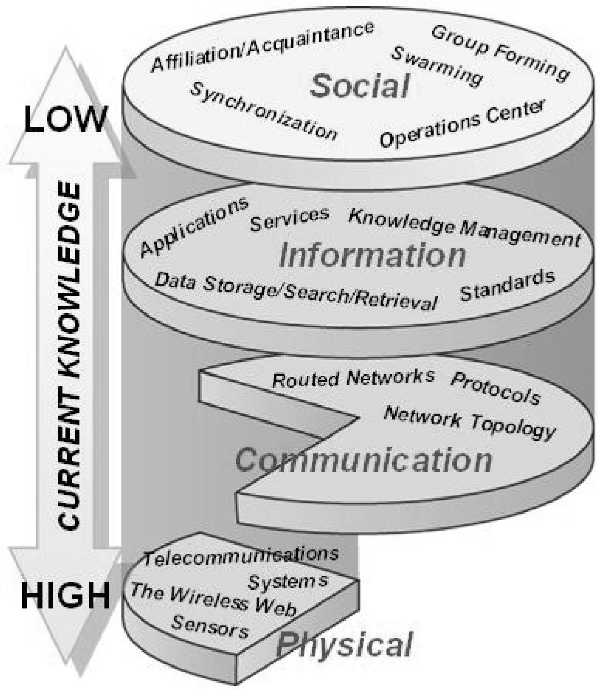

Figure 1. Complex network representation of CIS Networks

Studies considering the performance of communication networks tend to establish analytical measures of technical metrics (i.e. bandwidth, latency, throughput, or packet delivery rates) [4-8]. These studies do not emphasize the impact of the stakeholder. In tactical networks the stakeholder is the Warfighter. A naive approach to maximizing mission performance in communication networks is to provide full bandwidth and full resolution to all users all the time. From a communication resources perspective, this approach is extremely inefficient. Communications overhead must also be taken into consideration. *Strategies for the design of tactical networks must consider the efficiency of communication network resources*.

Social/cognitive networks research has generated numerous qualitative studies by developing models that aim to represent cognitive processes and social phenomenon [9-14]. In these studies, the communication models that are employed tend to be over-simplified. To date, much of the work has emphasized qualitative over quantitative data. Further, the studies involving human subjects are difficult to conduct, and it is even more difficult to gather accurate metrics and measurements during these experiments. The subjective nature of measurements and procedures used to gather this data often limits the significance of these studies. The generation of quantitative models that use software agents rather than humans will enable analysis of complex networks across multiple domains. *Strategies for the design of tactical networks must consider the efficiency of the decision-making ability of the Warfighter.*

The modeling of these networks may result in the emergence of tradeoffs between human (mission) performance metrics (social/cognitive network metrics) and the communications overhead (communication network). The Army has established a network science collaborative technology alliance which is a collaboration between government, industry and academic institutions to perform foundational, cross-cutting research for a fundamental understanding of interactions, interdependencies, and common underlying science among social/cognitive, information, and communication networks. The aim of network science is to model the interactions of complex networks which include communication, information and social/cognitive networks [3]. A goal of the Army is to maximize the mission performance of the Warfighter. By using concepts of network science to represent tactical environments, it is possible to develop cross-network models to enable the prediction and analysis of the performance of the Warfighter in these situations.

In command and control (C2) research, *complex endeavors* are defined as situations that are "characterized by complex, multi-dimensional effects spaces" [15]. The study of complex endeavors enable military planning approaches by considering the interactions of the military units with coalition military partners and other non-military organizations. These interactions are dynamic and unpredictable in nature. The C2 maturity model / approach space was proposed [16] to represent the state and capability of organizations. The approach space is defined by a function of three non-orthogonal axes/variables: allocation of decision rights, distribution of information and patterns of interaction. Five organizational operating states are then mapped to this three-dimensional C2 approach space: conflicted, deconflicted, coordinated, collaborative, and edge. The C2 approach space is shown in Figure 2. Based on the mission, one of the five operating states may be optimal performance-wise. It is not necessarily the case that the edge organization is universally optimal.

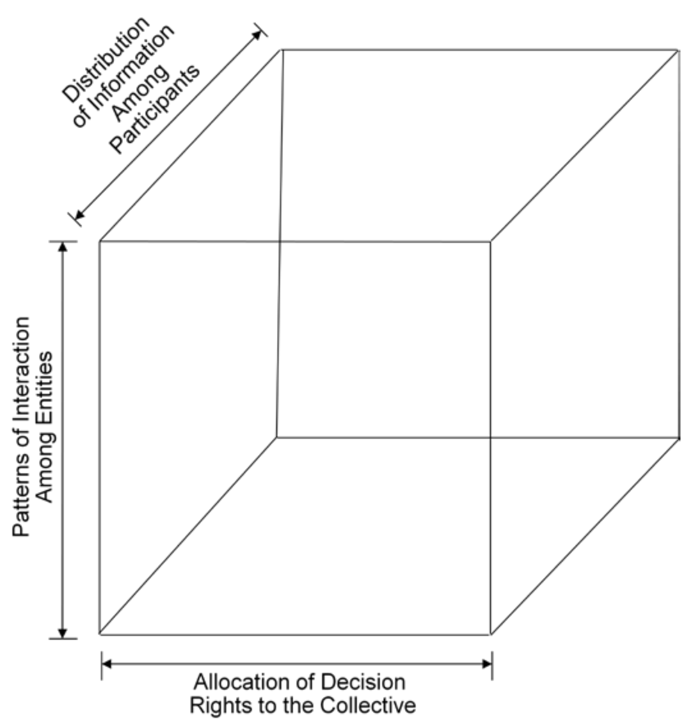

Figure 2. C2 Approach Space (CCRP)

To apply the C2 approach space to the dynamics of tactical networks, the concept of agility in organizations was proposed as a measure of how to adapt to a given network state [15]. Rather than attempting to predict network conditions and determine which C2 approach space would optimally handle the mission given the network state, it is proposed that the more effective network is one that is able to successfully cope with changes in the environment (system). The organization would effectively handle degradation/loss of capability, change in objectives, and change in the conditions of the coalition/individuals. The goal of agility is to maintain acceptable performance, effectiveness and efficiency (thus requiring timely recognition, appropriate response, and timely response). The concept of *agility* can be applied to people, C2 approaches, organizations, processes, systems, architectures, policy, doctrine, tactics, and acquisition [17].To establish an abstract model that combines network science and concepts of command and control research, the parameters of communication, information, and social/cognitive networks can be combined to describe the network effects complex endeavors encompass. In this model, C2 Maturity is a set of operating states of a social/cognitive network, and C2 agility is the ability of a complex network to adapt. Network science research is currently focused on creating models of these interactions and has not necessarily identified specific strategies to demonstrate or implement agility within complex networks.

The joint consideration of network science and command and control research concepts inevitably brings together concepts from multiple disciplines which do not have a shared vocabulary. In addition, there are common parameters in each of the CIS networks of the complex network approach that can have different range and scope of value. For instance, a processing delay in communication networks may have a scope of 10-100 ms while the analogous delay in social networks may have a range of 10-20 s. This mismatch in representation may dilute the sensitivity of experimental results with respect to the common parameter. Being able to individually express these parameters in a test environment may result in the emergence of tradeoffs or optimal operating values for these parameters within CIS networks.

ELICIT Platform

ELICIT was developed by the United States Department of Defense Command and Control Research Program (CCRP) of the Office of the Assistant Secretary of Defense for Networks and Information Integration (OASD/NII) as part of their initiative to develop and test principles of organization that enable transformation from traditional hierarchy-based command and control practices toward more agile practices that transfer more power and decision rights to the edge of the organization [19]. Considerable research has been conducted to date using ELICIT including [21-23].

This ELICIT platform has configurable scenarios that enable groups to focus on the task of identifying the “who”, “what”, “where”, and “when” of a fictional insurgent threat. Specific packets of partial information in the form of “factoids” are provided periodically to each of the participants during an experiment session. The factoids and their distribution are structured so that no one participant receives all the information necessary to perform the task; thus, information sharing is required in order for any participant to be able to determine a solution to the ELICIT problem.

A web-based ELICIT session starts with the factoids being randomly seeded to the participants in the trial. Participants must then share and receive this information with other participants to gain knowledge of the threat. Additionally, participants may have access to a set of centralized information sources called websites that allow participants either to post or pull factoids from

these websites. Periodically, the participants can send their knowledge of the threat to the ELICIT administrative system. ELICIT provides an instrumented task environment that captures and time stamps participants' information sharing activities.
To measure their performance, we use a measure called correctness. Correctness is a measure that represents the level of situational awareness within this scenario. Correctness is measured by the accuracy of the participant's knowledge of the "who", "what", "where", and "when" and has a scale from 0 to 1. The details "who", "what", and "where" are scored with 0 or 1, and "when" has a score of {0, 0.25, 0.5, 0.75 and 1.0}, allowing for partial correctness. The overall correctness score, *C*:

$$C = 0.25\,(WHO + WHERE + WHAT + WHEN).$$

Sensemaking agents were developed for use in ELICIT (abELICIT) [24, 25], enabling campaigns of experiments involving agents, either in lieu of or in conjunction with human participants. The sensemaking agent software instantiates semi-intelligent, configurable agents that are designed to behave like humans. These agents are able to take the place of human participants in ELICIT experiments, and form a mental model of the information in the factoids received and of the members of the group in which they operate. That is, as an agent participates in an experiment it generates scenario specific situational awareness that can be drawn upon to make decisions about behavior. The sensemaking agent is able to formulate ELICIT messages based on awareness and understanding of the factoids to which it has been exposed.

In addition to having this awareness or sensemaking capability, the agents have additional configurable variables to define their personalities, capabilities and styles of social interaction with the other experiment participants. Using these variables, agents can be configured to operate in human timeframes, show human levels of variability and human personality traits such as tendencies to hoard information, reciprocate favors and trust team members (among others).
In terms of architecture, Figure 3 delineates a high-level view of the sensemaking agent logic flow. The sense making agent explicitly models the major mental steps that humans take when performing ELICIT tasks. The model accounts for people taking these steps in differing orders and in varying time frames. Interested readers are directed to [24] for details.

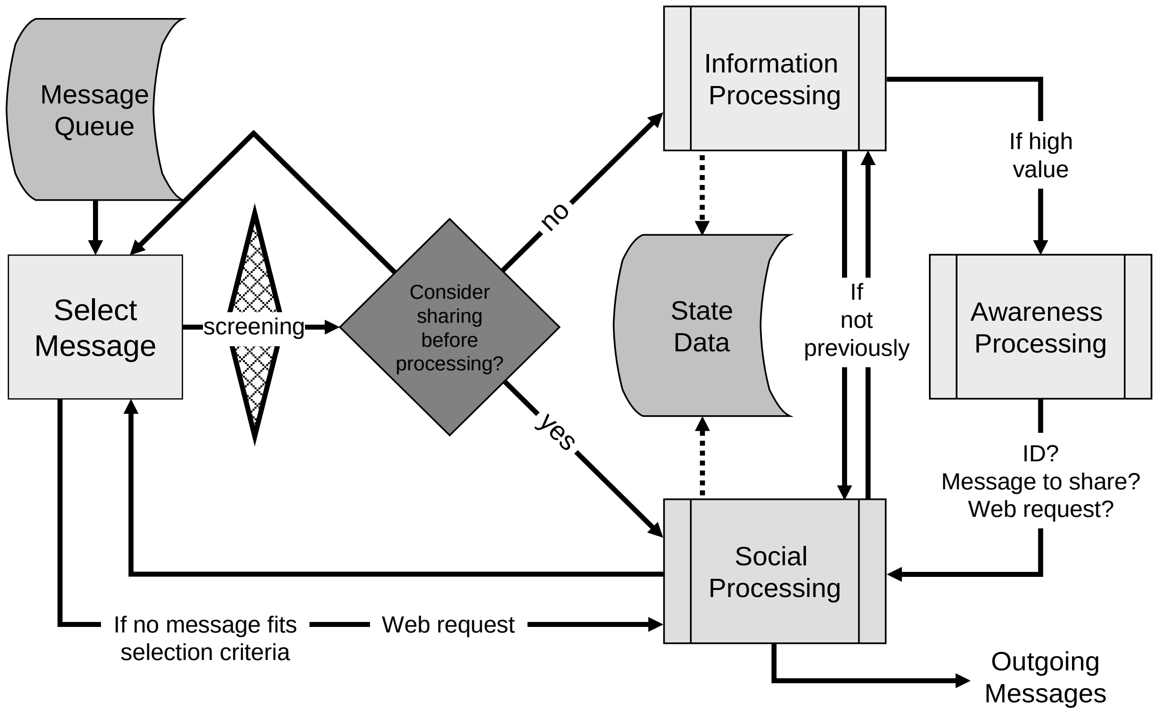

Figure 3. High-Level View of Sensemaking Agent Logic Flow.

It is important to note that the sensemaking agent behaviors have been validated and calibrated in part through comparison with human behaviors in numerous ELICIT experiments. Indeed, previous ELICIT based experiments provide a rich set of data on which to model agent behavior. These data include transaction logs that record and timestamp every action taken by each participant, scratch paper used by experiment participants, and information gleaned from participants in post experiment discussion sessions. This information and experience provide a strong basis for modeling human information-sharing and information-processing behaviors and illuminate insight into the mental models used by people when participating in the experiments. The abELICIT implementation includes about 50 configurable parameters that can be used to tailor the sensemaking agents' behavior. Thus, ELICIT is able to model the social cognitive elements of human decision making in various network configurations. Its ability to model the dynamics of communication networks is limited.

Multi-disciplinary concepts

Studies in network science / complex endeavors involve concepts from multiple disciplines. Difficulty in creating cross or multi-disciplinary models is caused in part by non-shared vocabularies. Models of complex networks will need to distinguish between similar concepts in different network layers. For example, transmission delays in communication and social networks should not be represented by a single delay parameter. The goal of this work within network science and C2 agility research is to develop models and strategies that will maintain acceptable performance in the presence of the set of expected network conditions spanning the entire complex network space. A more specific goal of this paper is to develop a comprehensive network model that bridges social/cognitive network and communication network models. Our approach is to survey a set of parameters common to each of the constituent network models in complex networks. We perform this survey by using parameters found in the agents designed for the ELICIT experiment platform.

In related work, Nissen and Alberts [27] connect the C2 maturity and agility models to concepts in organization and management theory. Connections are drawn between agility and contingency theory. C2 maturity models are compared to organizational archetypes. Parallels between organizational design factors and C2 field concepts are drawn. The outcome of [27] is a preliminary work providing a “Rosetta Stone” between C2 and organizational management theory. A method to jointly characterize organizations using C2 and organizational management theory concepts is also proposed.

When establishing connections between social/cognitive networks and communication networks, existing work tends to evaluate social networks and communications between entities using social network analysis tools that make over simplified assumptions with regard to communications. Analysis of social structures typically employs sociograms, which can illustrate interactions or the volume of interaction between nodes in the network. Sociograms can be established by measurement of email communications [14, 28]. However, in these studies, the quality of the communications links is not considered. Email interaction provides a coarse representation of the interaction as well as the quality of the network. Sociograms can be used to study social network analysis metrics such as centrality, betweenness, and social tie strength. Studying the interactions represented in sociograms and the quality of the interactions by investigating the dynamics of communications with finer resolution may provide further insight into interactions within complex networks.

This section identifies parameters of complex networks and the established meanings from the communication network and social/cognitive network domains. We use ELICIT parameters as the common thread to bridge the two models. With the over 50 parameters of the sensemaking agent, we have identified a subset of these parameters that have meaning in both communication and social/cognitive domains. The objective of this study is to define the dual use of the parameters in both domains to allow meaningful experimentation of complex networks. Table 1 provides a list of the ELICIT agent parameters and their meaning in both the communication and social/cognitive domains.

Communication Network	Social/Cognitive Network	ELICIT Parameter
	Inbox details	
Buffer size	Working memory, Memory capacity	`messageQueueCapacity`
TTL, timeout	Memory	`messageQueueTimeRemainInQueue`
message stack, FIFO	Message reading strategy	`messageQueueNewerBeforeOlder`
	Message Sending	
message forwarding	Share before reading	`shareBeforeProcessing`
information loss	Broadcast information	`postFactor`
information loss	Selective forwarding	`shareWithFactor`
information loss	Information seeking	`pullFactor`
information sharing rate	Technology preference	`SharingModality`
	Delays	
	message preference	`screeningSelectedMessageDelay`
Encoding, encryption, decoding	cognitive processing delay (event-related potential)	`informationProcessingDelay`
Packet formatting, circuit establishment, session	Workload (social)	`socialProcessingDelay`
Transmission, post latency	Workload (social)	`sharingPostingMessageDelay`
Local topology assessment (1-hop neighbors)	Workload (cognitive)	`awarenessProcessingDelay`
Message latency	Human-computer interaction	`webRequestDelay`
Availability, connectivity	Human-computer interaction	`pullBetweenSitesDelay`
	Human-computer interaction	`postBetweenSitesDelay`
Memory access	Human-computer interaction	`selectMessageFromQueueDelay`
	Social Processing	
Topology	Organizational structure	`accessibleAgents`
Topology	Organizational structure	`accessibleSites`
Message control	Curiosity, Workload	`propensityToSeek`
Message control	Workload	`minTimeBetweenPulls`
Message control	Workload	`minTimeBetweenShares`

Trust in Network	Trust in Individuals	`trustInIndividuals`
Trust in Network	Trust in Information/Technology	`trustInWebSites`
Topology	Mission assignment	`Primary`
Topology	Mission assignment	`Secondary`
	Innovation, Exploration	`propensityToShareExternal`

Table 1: Relationships between Communication Network Variables, Social Cognitive Network Variables and ELICIT Parameters

See also Appendix 1 for a complete listing of the ELICIT 2.5 sensemaking agent parameters and the baseline values used for this effort.

Wireless Emulation Laboratory (WEL)

The Army Research Laboratory has developed the Wireless Emulation Laboratory (WEL) [29-30] as an environment to test algorithms and applications for mobile ad hoc networks. Emulation provides a more realistic environment than simulation while avoiding most of the difficulties of full-scale experimentation. In a typical Mobile Ad-hoc Network (MANET) emulation, the communication medium is abstracted while the systems themselves are implemented using real hardware and software. Emulation environments are advantageous because they enable a higher fidelity environment in which there will be actual algorithms and hardware variables (CPU, bus, driver speeds) not present in simulation. Furthermore they are typically viewed as the intermediary grounds between simulation and field experimentation because these elements will be more accurate in emulation and may not exist in simulation.

The WEL makes use of the emulation environment Extendable Mobile Ad-hoc Network Emulator (EMANE) [31]. In this environment, components of the tactical environment can be configured or simulated/emulated for a network of up to 1000 nodes. The general architecture and modules that the WEL can configure are shown in Figure 4. These modules can be configured to represent specific tactical networking scenarios. For instance, given terrain data obtained from geographic information system (GIS) sources such as Google Earth, *Terrain Integrated Rough Earth Model (TIREM)* has the ability to predict radio frequency (RF) propagation patterns based on the terrain models. Software called Topodef [32] has been developed to specify topology and mobility dynamics. There are also capabilities allowing for the generation of simulated network traffic to determine how well communication networks handle congestion. The EMANE environment also allows for configurable network protocols such as the routing protocol, Medium Access Control (MAC) schemes and other security services. WEL robustly models communication network performance, and doesn’t model any intelligence at network endpoints so it is a perfect complement to a system that models intelligent information processing at network endpoints.

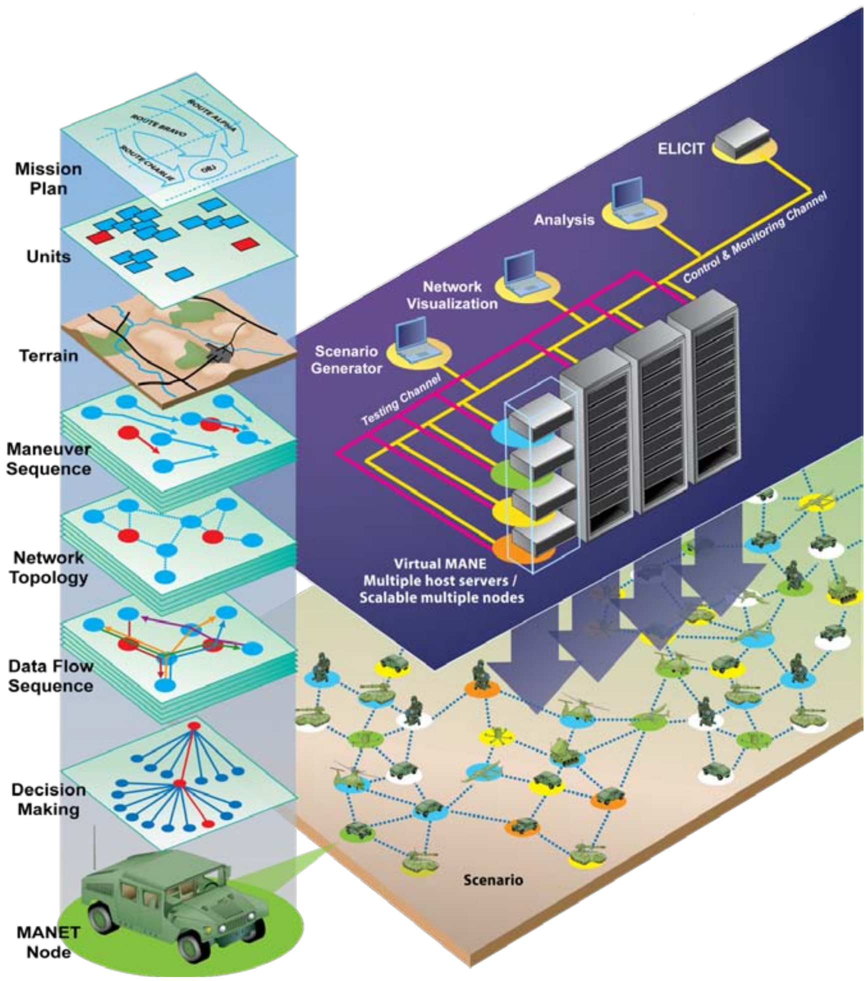

Figure 4. Overview of architecture and modules of the Wireless Emulation Laboratory (WEL)

Thus, using the WEL environment with ELICIT may provide a higher fidelity representation of the communications typically implemented in tactical networks. The integration of ELICIT into the WEL will provide a means to run experiments with higher fidelity communication models by using elements of EMANE such as the routing and MAC protocols. As seen in [26] the impact of network effects on the task performance of the group can be quantified by using the ELICIT agent parameters to simulate link qualities in terms of loss and delay. By using EMANE, it will be possible to implement link quality of service by using emulated communications. This section describes the steps taken to integrate the ELICIT and WEL environments.

Integrated Communication and Social Network Model

In order to create a platform that models both communication networks and social networks, ELICIT and WEL are integrated. The integrated environment represents communication networks with increased fidelity. The integration approach places a configurable ELICIT agent on each WEL node. The figure below depicts an ELICIT-WEL integration for a two node system.

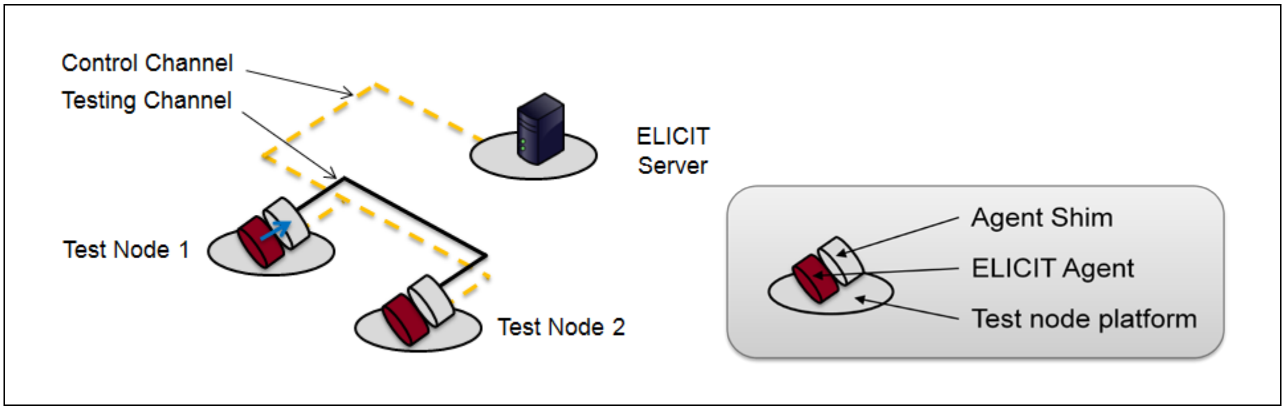

Figure 5. Integration of ELICIT and WEL process showing communications between two nodes and the ELICIT server

This diagram shows the communication required for the ELICIT agent on EMANE node 1 to share a factoid with the ELICIT agent on EMANE node 2. Each EMANE node has the capacity to be both a sending and a receiving node. Using EMANE's capabilities for autoconfiguring EMANE nodes, this two node configuration is instantiated on hundreds of nodes.

In ELICIT version 2.4, when ELICIT agent 1 shares a factoid with ELICIT agent 2, all communications take place in the ELICIT server process and take place immediately. EMANE has a sophisticated configurable process for modeling communications delays. So to leverage this capability, EMANE is used to model network delays between ELICIT agents. The fundamental approach is that when ELICIT agent 1 shares a factoid with ELICIT agent 2, instead of the factoid being communicated to agent 2 immediately, it is put in a queue on the ELICIT server and a message is sent via a shim to the EMANE node on which agent 1 is running. Then EMANE node 1 communicates with EMANE node 2. The time required to do this can be varied by the EMANE system to model various types of communications delays and outages, etc. Once the shim message from EMANE node 1 is communicated to EMANE node two, EMANE node 2 sends a message to the ELICIT server and ELICT releases the factoid to agent 2.

Several communication network parameters in EMANE are controlled with the RF Pipe PHY model parameters [33]. Along with Topodef, the RF pipe physical model determines the connectivity of the network throughout the experiments. The EMANE experiment scenario is generated using the Topodef mobility data, which calculates path loss values for each pair of nodes for every time step. The presence of a link for each pair of nodes is determined by the following expression from [33]:

RxPower (dBm) = Tx Power (dBm) + Tx Antenna Gain (dBi) + Rx Antenna Gain (dBi) – Pathloss (dB).

The RF pipe model specifies the TX Power, Tx Antenna Gain and Rx Antenna Gain. In this work, we only vary TX Power and leave both antenna gains to be 0 dBi. Additionally, static topologies are used. For unsuccessful transmissions within EMANE, the transmitting node retransmits 10 times before giving up. This behavior was adopted in the shim design described in the Integration Phase 3. This integration approach allows us to leverage the full modeling configurability of both ELICIT and WEL. It required enhancements to the ELICIT platform and extension of WEL via ELICIT-WEL shims. This integration is achieved using a phased approach which is summarized below

Integration Phase 1

- Enabling ELICIT to support modeling of network delays and links outside of ELICIT. ELICIT is modified so that it can be configured to put shared factoids in a queue and only release them when the release is specifically requested (after a modeled delay.) This functionality is tested using a static black box in Phase 1.

Integration Phase 2 (which itself consists of three parts)

- Enabling ELICIT to run agents on separate machines so that ELICIT can be used in conjunction with WEL. Previously ELICIT agents could only run on the same machine as the ELICIT server process. We leverage the ability of humans to participate in an ELICIT trial via a browser and wrap an HTTP-client around the agent software so that an agent can run on any machine connected to an internet/ intranet and communicate with the ELICIT server.

- Enabling ELICIT to send a shim message to the EMANE node on which it is running. ELICIT is modified so that after an agent shares a factoid (and the factoid is put in a queue to wait for the modeled delay) the agent also makes a POST http request with the following parameters: shareDate, senderId, recipientId and factoid key number. Note that shareDate is a String representation of the Date in format: MMddyyyNNmmssSSS, where
    - y Year
    - M Month in year
    - d Day in month
    - H Hour in day (0-23)
    - m Minute in hour
    - s Second in minute
    - S Millisecond

  This shim message provides all the information needed to fully describe the sharing of a particular factoid between two agents and communicate that to EMANE.

- Enabling ELICIT to release the shared factoid once it receives the appropriate shim message from EMANE. The mechanism created in phase one is modified so that a particular factoid is released to the receiving agent once a message to release that particular factoid to that agent is received by the ELICIT server from EMANE. A utility called update-share-delay.do is created to trigger this message release. The following message format is an example of how this utility is used to tell the ELICIT server to release factoid 17 that was shared by participant 2 to participant 1: (http://util.azigo.net:8086/ccrp2.5_b7/update-share-delay.do?senderId=2&recipientId=1&factoidKey=17). Thus we can precisely control when a receiving participant will get a delayed message.

As with all ELICIT enhancements, this capability is configurable and can be turned off. This new delay behavior is only operational if a Network Connectivity Scenarios option is selected for an ELICIT trial. This Network Connectivity Scenario file (NCS Configuration file) in turn references a NCS file which specifies a matrix of delays. Shared factoids are only held in a queue if the value specified in the NCS file is greater than zero.

Integration Phase 3 (which itself consists of three parts)

WEL is extended with a software shim that is used to provide communications links between ELICIT and EMANE (same EMANE test node). There are three aspects to this shim:

- Creating an EMANE shim capability that can accept a POST http request from the ELICIT agent on a EMANE node that is a notification that an Agent has initiated a share

- Creating an EMANE to EMANE shim capability to pass this request to the receiving EMANE node via EMANE so that EMANE can be leveraged to model delays

- Creating an EMANE shim capability to update the ELICIT server to indicate that a specific factoid had been communicated via EMANE. Thus a shared factoid is only released to the receiving participant after EMANE has directly modeled the communications delay between the sending and receiving nodes.

The capabilities developed in the above phases are integrated, tested and refined on an intranet at ARL. Once the new ELICIT capabilities and EMANE shim extensions are developed, they are deployed into the WEL. Scripts are developed to automatically launch an emulation scenario for the EMANE test nodes. The scripts also launch the ELICIT agents and the EMANE shims, logging the agents on to the ELICIT application and preparing the shims to accept communications within EMANE. These scripts are highly configurable to accept any topology or organizational structure as well as different ELICIT agent software and configurations (different agent personalities for each agent instantiation).

To further automate research processes, the ability to configure agent-based ELICIT experiments to run in batch mode, is extended to include runs using distributed agents installed on EMANE nodes.

Integrated Platform Experiments

For the first time, we now have a configurable operational research platform that models the communication, information and social/cognitive aspects of complex networks. This complex network research platform leverages proven network research platforms: WEL and ELICIT. We are now in a position to perform highly automated research trials that much more fully model the behavior, efficiency and effectiveness of human network operations.

In previous work, we used the ELICIT agent parameters to represent communication network effects to determine the impact on task performance [26]. Prior to this work, the communications models within ELICIT were idealized with respect to the communication network. The network did not incur any delays or drops of factoid shares or interaction with websites. By implementing losses and delays in the communications, we were able to identify the impact of these network parameters on the task performance of the group. The result of these experiments was the determination that information delay had a severe threshold effect on the performance of the ELICIT experiments. Given moderate information loss, the organization was able to overcome these losses due to redundancy of information within the organizations. Additionally, performance was studied as a function of network size as well as connectivity. With regard to connectivity the agents experienced a level of information overload in situations with increasing network connectivity. The results were simulation-based, and the open question remained whether or not organizations would actually reflect this behavior given communications models with higher fidelity.

The integration of the ELICIT and WEL platform allows for a comparative validation of the parameter-based simulations of the communication networks within the ELICIT experiments in [26]. Based on the previously run experiment, we conduct a similar set of experiments to determine the appropriate modeling of the ELICIT experiments when using the agent parameters to represent the communication models. In this section, we will present results of the ELICIT experiments examining three different network parameters: scalability, information loss and delay, and connectivity. If differences in the impact of these network parameters are observed, then it may be possible to determine possible shortcomings of the model and will allow for adjustments in the simulation models to be made. Observed differences may highlight the benefit of the increased fidelity of the communication models that are otherwise difficult to represent easily within the simulated model.

Scalability

Understanding the impact of organization or network size is crucial to the modeling of complex networks. We ran ELICIT experiments with networks of $n = \{17, 34, 68, 100\}$ nodes. Our initial objective of this set of experiments was to determine the ability of the ELICIT platform to support larger organizations or networks. The expectation is that the time to perform the task will increase as a function of the network size. In [26], it was shown that the ELICIT platform could be run on networks of up to 150 nodes. The scalability of the communication network with respect to the ELICIT platform can be determined with the integrated platform. With this set of experiments, the reduction in average correctness is shown as a function of time. This is shown in Figure 6. The general behavior of the average correctness in these experiments is similar to those found in [26].

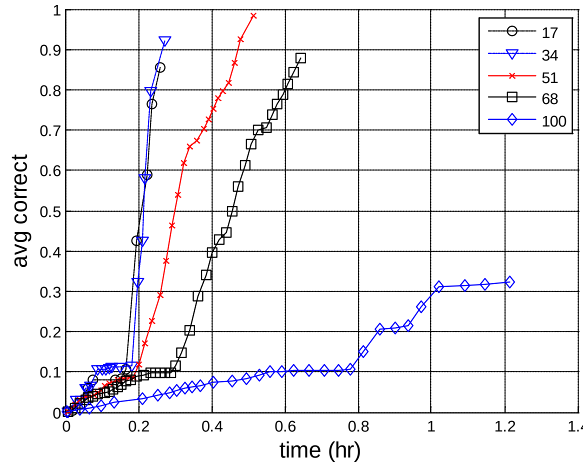

Figure 6. Average correctness vs. time (hr) for network sizes.

In addition to average correctness, it is of interest to study the time that it takes any node within the network to achieve full correctness. It may only be required for a single decision-maker to have the full correctness. We ran a set of experiments to understand how the time it takes for one node in the network to achieve full correctness as a function of the network size. Figure 7 shows that the time increases exponentially as a function of n.

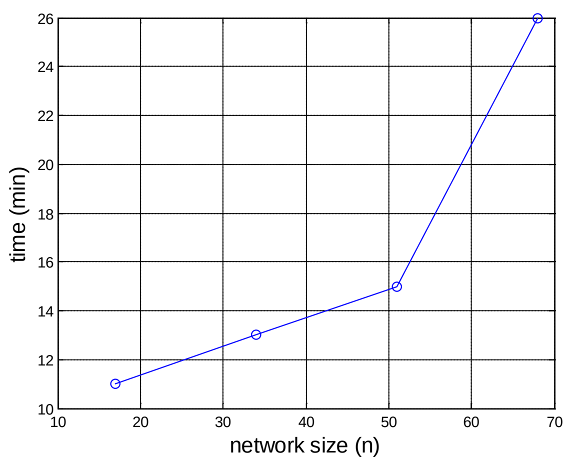

Figure 7. Time (min) required for first node to achieve full correctness vs. n.

Additionally, we can look to the number of successful shares executed in the experiments. When looking at this property with respect to network size, we expect an increase in shares per time interval as the number of nodes increases. In Figure 8, we show the total number of shares for the first 30 minutes of the experiment. We observe that there is a drop in the shares after the 68-node experiment. While one would expect that the number of shares to increase with time, the effect of the overhead of the communication protocols is potentially expressed. Once the network size is larger than 68 nodes, the network may be experiencing higher congestion and collisions. This is an item for future verification and investigation. Nonetheless, it appears that there is a performance and efficiency tradeoff with respect to the number of shares as the network size varies.

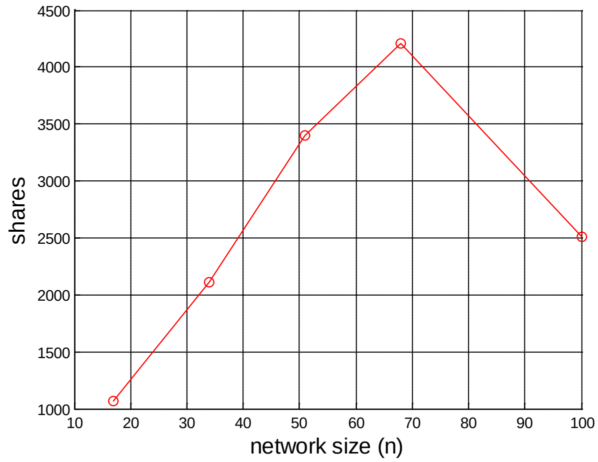

Figure 7. Total number of shares in a 30-minute period vs. network size n.

The main distinction between the simulated experiments and the integrated experiments is the underlying communication protocol in the emulation environment. The parameters in the simulated experiments implemented the loss and delay between two nodes. However, in communication networks, most communications occur over multiple hops, where the network quality of service may vary for each intermediate link. In [26] a G(n,r) network was applied to create the connectivity within the ELICIT organization. In the integrated experiments, we are able to allow each of the nodes to share with each of the other nodes, where the underlying communication network is inherently multi-hop. This is one example of the increased resolution of the integrated environment.

Connectivity

In this section, we show the effect that connectivity of the organization has on the correctness measure within ELICIT. In [26], the communication radius *r* is varied when creating G(n,r) to generate networks with various connectivity. In terms of the communication network, the cost of increased connectivity is increased energy consumption. In this set of experiments, we created networks of 34 nodes and varied the connectivity by adjusting the TX Power parameter in the RF pipe model. TX Power = 40 resulted in no links being formed, and TX Power = 60 generates a fully connected network. Figure 8 shows the average correctness after 30 minutes as a function of TX Power. A sharp threshold with regard to connectivity is exhibited. This behavior may be a result of the actual topology and path loss models being applied rather than the G(n,r) model, which may have created an over simplified topology representation.

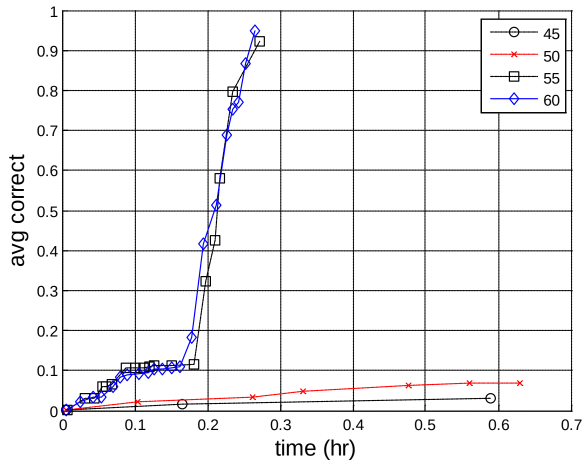

Figure 8. Average correctness vs. time for various connectivity with n = 34.

In [26], increased connectivity resulted in the agents becoming overwhelmed with the factoids, not allowing them to process the factoids necessary to achieve full correctness. This became more prominent as connectivity increased. In these experiments, we observe an increase in average performance as connectivity is increased. However, for larger networks (greater than 51), in situations with high connectivity, the routing protocol is overwhelmed and is unable to perform the ELICIT experiment. This is one example of communication network layer overload, which is similar in effect to social/cognitive information overload, but a distinct concept.

Conclusions & Discussion

We now have an operational research platform that can simultaneously model both the communications, and information and social/cognitive aspects of complex networks. This enables us to begin to explore the effects of communications on human task efficiency and effectiveness so that we can determine how best to optimize the use of available bandwidth to maximize operational effectiveness under varying communications conditions. Agility theory suggests that given certain network conditions (presence of network effects), parameters within the network can be adapted to maintain acceptable levels of performance. Building operational models to characterize and explore the interactions within complex networks enables the development of strategies to implement agility into tactical networks.

The use of communication networks yields an improved representation of actual communications protocols as compared to previous simulations and experiment setups. The result is a capability that can directly assess relationships between communication network and social/cognitive networks. The finer resolution of communication networks allows for visibility into the routing protocol, traffic congestion and transmission collisions. This approach also considers the effect of multi-hop communications. The ability to model these concepts will help in future experiments. This paper has shown preliminary evidence of the value of this improved modeling of the communication models within the larger experiment setup. We have compared previous simulation results with experiments conducted in the integrated ELICIT-EMANE platform. In the future, this setup will allow for experiments studying specific scenarios such as local network interruptions due to environmental effects or network attacks.

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Appendix 1 - Agent Parameters

Below is a sample Agent configuration file, with initial values that are representative of the values used in this effort. Note that time intervals are in milliseconds and this configuration is for the EBR (2.5) version of the Sensemaking Agent.

1. readyIntervalDelay|Time interval to click Ready button|10000
2. messageQueueCapacity|Capacity of queue (-1 means unlimited)|-1
3. messageQueueTimeRemainInQueue|Time a factoid can remain in queue (-1 means unlimited)|-1
4. messageQueueNewerBeforeOlder|If true then newer messages are selected before older|false
5. selectMessageFromQueueDelay|Select message from queue delay|1000
6. shareBeforeProcessing|If true then share message before Processing|false
7. postedTypes|PostedTypes|who,what,where,when
8. postFactor|PostFactor|1
9. postOutOfArea|PostOutOfArea|true
10. shareWithFactor|ShareWithFactor|1
11. sharedTypes|SharedTypes|who,what,where,when
12. shareRelevantAccordingToSiteAccess|ShareRelevantAccordingToSiteAccess|false
13. shareAccordingToSiteAccess|ShareAccordingToSiteAccess|false
14. isCompetitiveHoarder|IsCompetitiveHoarder|false
15. pullFactor|PullFactor|0
16. timeBeforeFirstIdentify|Time before the agent does its first identity (in minutes)|15
17. minSolutionAreas|The minimum number of ID tables with some data|1
18. hasSeenEnoughToIdentify|HasSeenEnoughToIdentify|5
19. isGuesser|IsGuesser|true
20. isFrequentGuesser|IsFrequentGuesser|false
21. idConfidencelevel|IdConfidencelevel|0.23
22. partialIdentify|Identify if there are no some answers|true
23. shareModalChoice|ShareModalChoice possible values (both, post dominant, post only, peer to peer dominant, peer to peer only)|peer to peer only
24. screeningSelectedMessageDelay|Screening selected message (message processing) delay|1000
25. informationProcessingDelay|Information Processing delay|3000
26. socialProcessingDelay|Social Processing delay|4000
27. sharingPostingMessageDelay|Sharing/Posting each Message delay|8000
28. awarenessProcessingDelay|Awareness Processing delay|3000
29. determiningKnowledgeNeedsDelay|Determining Knowledge Needs delay|3000
30. idAttemptDelay|ID Attempt delay|20000
31. webRequestDelay|Web Request (Pull)|9000
32. propensityToSeek|PropensityToSeek possible values (low, moderate, high, very high)|low
33. minTimeBetweenPulls|If the time since the last pull is not >= minTimeBetweenPulls, do not Pull (in milliseconds, -1 means ignoring this parameter)|20000

34. minTimeBetweenShares|If the time since the last Share is not >= minTimeBetweenShares, the agent should wait before it Shares (in milliseconds, -1 means ignoring this parameter)|5000
35. trustInIndividuals|TrustInIndividuals possible values (high, medium, distrust, no opinion)|1=no opinion,2=no opinion,3=no opinion,4=no opinion,5=no opinion,6=no opinion,7=no opinion,8=no opinion,9=no opinion,10=no opinion,11=no opinion,12=no opinion,13=no opinion,14=no opinion,15=no opinion,16=no opinion,17=no opinion
36. trustInWebSites|List of initial values of Trust for web sites. Possible values (high, medium, distrust, no opinion)|who=medium,where=medium,what=medium,when=medium
37. reciprocity|Reciprocity possible values (high, low, medium, na, none)|1=none,2=none,3=none,4=none,5=none,6=none,7=none,8=none, 9=none, 10=none,11=none,12=none,13=none,14=none,15=none,16=none
38. primary|Primary areas of interest. Possible values: who, what, where, when)|who,what,when,where
39. secondary|Secondary areas of interest. Possible values: who, what, where, when)|
40. propensityToShareExternal|If message is not in area of interest, then agent shares it according to sharing preferences with probability = propensityToShareExternal|1
41. awarenessProcessingThreshold|If cumulative value of the perceived message value is more or equal to this variable, then start awareness processing.|2
42. pullBetweenSitesDelay|Pull between sites delay|1000
43. postBetweenSitesDelay|Post between sites delay|500
44. provideRelevance|Provide relevance for posted and shared messages|false
45. provideTrust|Provide trust for posted and shared messages|false
46. sharingModality|peer to peer only, post only, both|peer to peer only
47. shareValueThreshold|Factoid value threshold for sharing and posting, integer value or high, medium, non-zero, none=any|none
48. shareTrustThreshold|Factoid trust threshold for sharing and posting, high, medium, no opinion, distrust=none=any|none
49. shareSourceThreshold|Factoid direct source threshold for sharing and posting, high, medium, no opinion, distrust=none=any|dist
50. postBeforeProcessing|Whether agent should post immediately before determining factoid value|false
51. shareBeforePost|Whether agent should do shares or posts first|true
52. noSharingIfPosted|In “post before share”, whether agent should take success/failure of posts into account for sharing, no, any or all|no
53. accessibleAgents|Agents that can be shared with, list of agents, or all or none|all
54. accessibleSites|Sites that can be posted to and pulled from, list of sites or all, none, primary|all