15th ICCRTS

"The Evolution of C2: Where Have We Been? Where Are We Going?"

Title of Paper: **Connections between communications and social networks using ELICIT**

Topic(s):
Topic 5: Experimentation and Analysis
Topic 6: Modeling and Simulation
Topic 8: C2 Assessment Metrics and Tools

Name of Author(s)

Kevin S. Chan
Natalie Ivanic

Point of Contact: Kevin S. Chan

Name of Organization: US Army Research Laboratory

Complete Address:
RDRL-CIN-T
2800 Powder Mill Road
Adelphi, MD 20783

Telephone: 301-394-5640

E-mail Address: kevin.s.chan@arl.army.mil

Report Documentation Page		*Form Approved* *OMB No. 0704-0188*
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.		
1. REPORT DATE **JUN 2010**	2. REPORT TYPE	3. DATES COVERED **00-00-2010 to 00-00-2010**
4. TITLE AND SUBTITLE **Connections between communications and social networks using ELICIT**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Army Research Laboratory,RDRL-CIN-T,2800 Powder Mill Road,Adelphi,MD,20783**		8. PERFORMING ORGANIZATION REPORT NUMBER
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 **Proceedings of the 15th International Command and Control Research and Technology Symposium (ICCRTS ’10), Santa Monica, CA, June 22-24, 2010**		
14. ABSTRACT **Our goal is to find relationships between social/cognitive networks and communications networks to devise strategies to maximize various performance metrics within these networks. We consider the case of a group of users that are performing a particular decision-making objective by passing information through a social network that uses a communication network with errors and delays in the transmission of information. The quality of service of the communication network will adversely affect overall user performance and trust relationships within the users by changing the dynamics of information-sharing within the network. However, if the affected users are able to adapt to these network errors, they may be able to maintain the same level of performance when compared to their performance in an optimally performing network. We are interested in characterizing the effects of these errors and determining if these dynamics can be compared to properties of traditional communication networks. We are currently exploring the use of ELICIT to examine the effect of communications errors and delays on user performance. We use existing capabilities within ELICIT by altering the sense-making agent parameters to mimic communication errors (failure to share factoids) and delays (delay in sharing factoids). Further, we are interested in the effect of connectivity within the organization structure for the ELICIT experiments. This is a study using ELICIT from a perspective that concentrates on the relationship of the communication network with the social network.**		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**21**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Abstract

Our goal is to find relationships between social/cognitive networks and communications networks to devise strategies to maximize various performance metrics within these networks. We consider the case of a group of users that are performing a particular decision-making objective by passing information through a social network that uses a communication network with errors and delays in the transmission of information. The quality of service of the communication network will adversely affect overall user performance and trust relationships within the users by changing the dynamics of information-sharing within the network. However, if the affected users are able to adapt to these network errors, they may be able to maintain the same level of performance when compared to their performance in an optimally performing network. We are interested in characterizing the effects of these errors and determining if these dynamics can be compared to properties of traditional communication networks. We are currently exploring the use of ELICIT to examine the effect of communications errors and delays on user performance. We use existing capabilities within ELICIT by altering the sense-making agent parameters to mimic communication errors (failure to share factoids) and delays (delay in sharing factoids). Further, we are interested in the effect of connectivity within the organization structure for the ELICIT experiments. This is a study using ELICIT from a perspective that concentrates on the relationship of the communication network with the social network.

1. Introduction[1]

Within social networks, the underlying communication network connecting the users of the network may dictate the performance of a group in executing certain tasks. The connectivity and quality of service of these networks results in a varying degree of mission performance among the users of the network. Conversely, dynamics within social networks may affect the performance of a group despite a communication network with near-perfect quality of service. Issues with trust between individuals or lack of experience or teamwork will hamper mission performance and completion. This paper considers the relationship between the social networks and communication networks and how these interactions affect individual and group performance.

We have used the Experimental Laboratory for Investigating Collaboration, Information-sharing, and Trust (ELICIT) to conduct command and control (C2) experiments of humans and human-agent models. ELICIT is a configurable software platform designed to measure the behavior of social networks in a command and control information-sharing scenario. Participants in ELICIT experiments are periodically provided with "factoids" or snippets of information. These factoids are sent and received among the participants, or the participants can retrieve information from a set of simulated websites or databases. This information is used to deduce information of a fictional terrorist threat ("identify"ing the `WHO/WHAT/WHERE/WHEN` of the threat). ELICIT is designed to study the organization of social networks and the interactions within these networks.

In this paper, we study the performance of social networks by using ELICIT in an approach outside of the typical set of research using ELICIT. ELICIT aims to demonstrate though experimentation the effectiveness of variations in organizations, as suggested by Alberts [Alberts 2003], where it is hypothesized that edge (or flat topologies) organizations will outperform hierarchical organizations in command and control scenarios with uncertainty, complexity and requirements for agility. ELICIT allows for human-in-the-loop or agent-based experimentation with various organizations (including edge and hierarchical organizations). The underlying communications infrastructure is assumed, but not explicitly investigated. In this paper, we have manipulated the existing capability of ELICIT to simulate the effects of communication networks within these experiments. This paper investigates the effect of communication networks on the task completion objective within ELICIT.

1.1 Connections with Network Science

In this paper, we consider the effects of communication networks on social/cognitive networks. The motivation of this work is rooted in emergence of the field of network science as an area of multidisciplinary research [NRC 2005]. In high-level terms, the goal of this research is to understand networks, in particular, the communication, information and social/cognitive networks, which are referred to by the network science stack.

[1] The authors would like to acknowledge Mary Ruddy (Parity Communications, Inc. and Meristic, Inc.) for providing ELICIT configuration files and for her countless discussions to develop this work.

Broadly speaking, communication networks refer to the electronic devices, infrastructure, protocols and algorithms, and the transmitted of signals throughout the network. Within the field of telecommunications, the communications network refers to the physical, data link and network layers of the open systems interconnection (OSI) network stack [Zimmermann 1980]. In terms of ELICIT, the communication network is assumed to be the infrastructure allowing factoids to be shared and posted/pulled to the website. Currently, ELICIT employs a perfect and instant communications infrastructure. The social and cognitive network includes the interactions between humans and the cognitive processing of individuals. In terms of interactions between humans, ELICIT considers the organization of the group and the ability of the individual to determine the terrorist plot from the (sub)set of factoids. Social/cognitive networks include how information is presented and processed by individuals and groups. We consider the information network as the network layer in the network stack that translates the information sent in the communication network to the knowledge processed by the social/cognitive network. It spans information transmission techniques (*i.e.* error-correction coding, compression techniques) and also includes information sharing strategies within the organization. The information network within ELICIT includes the way in which the factoids are distributed, and the ability of users to share factoids directly with other users or post them to websites.

One aspect of network science is to better understand the cross-network relationships. For example, how are social networks affected by changes in communication networks? Additionally, is there a measurable set of parameters that can be used to model and predict these effects? Certainly there are a set of parameters that determine these effects, but perhaps there is a dominating set of such parameters. The idea of modeling the performance of communication networks is well studied, but analytical models within social/cognitive networks are less common. Even more uncommon is the coupled modeling of the communication and social/cognitive networks. The network quality of service can be modeled, but the interaction with humans is multi-dimensional and also varies with each user. Within social/cognitive networks, the challenge is dealing with the complexity of human cognition. The reactions, experience and dynamics of each user are unique in each case. This paper is an initial investigation of the effects of communication networks on the performance of social/cognitive networks.

We present a result of a series of experiments using ELICIT and several aspects of its agent-based version (abELICIT). The organization of this paper is as follows. First, we consider how communication networks can be expressed in ELICIT. We use several of the sensemaking agent parameters to represent communication network parameters. Second, we examine the scalability of abELICIT in terms of the size of the organization. Using this communication network model within abELICIT, we then consider the effect of loss and delay of transmitted messages. We also consider the variation of network topologies or organizational structure by examining the effect of communication radius on the performance of ELICIT. The final sections are a discussion of related work and conclusions.

2. ELICIT and Communication Networks

The focus of ELICIT [Ruddy 2007] is to provide a command and control software platform to run human-based experiments to examine the effect of organization on an information sharing scenario. Recently, sensemaking agents were developed to run ELICIT [Ruddy 2009], which enabled trials of ELICIT to be run without human participants. This version of ELICIT is called agent-based ELICIT (abELICIT), (for this paper, ELICIT will subsume both abELICIT and ELICIT). These sensemaking agents are governed by a set of parameters, which can be used characterize the way the agent processes and shares information with other participants in the experiment. For example Anderson [Anderson 2009] considers the effect of several parameters (propensity to seek, propensity to share, sharing modality) on the performance of ELICIT. Agents and humans are able to participate in the experiments together; however, we only consider experiments comprised solely of agents. It is assumed that the sensemaking agents are valid models of humans in these experiments. A validation of the ability of agents to model actual human behaviors was performed by Wynn [Wynn 2010].When considering communication networks within ELICIT, it is hypothesized that the sensemaking agent parameters can represent communication network parameters. We alter sensemaking agent parameters to simulate the effect of a parameter in the communication network.

2.1 Mutual Vocabulary

Studying social networks and communication networks invariably introduces two sets of vocabulary. Terms within the social/cognitive and organizational behavior field and in the communication networks space are used to represent the parameters with regard to the network. Here, the relationship between the vocabulary used in ELICIT and communication networks is clarified in Table 1. These terms are be used interchangeably throughout this paper.

ELICIT	Communication Network	Parameter Description
Team Member, User, Player Participant, Sensemaking agent	Nodes	Individual in the trial with certain interconnections.
Organization	Topology	Graph representation of nodes and links between nodes.
Edge Organization	Random graph	Flat network where any node can communicate with any node.
Factoid	Packet	Snippet of information being shared between nodes.
Identify	-NA-	Measure of situational awareness.

Table 1: List of ELICIT and Communication Network parameters

To measure the performance of ELICIT, we evaluate the correctness of the group in being able to “identify” the details of the terrorist threat. The correctness measure represents a measure of situational awareness within this scenario. The ELICIT terrorist threat scenario used is “The Violet group plans to attack a financial institution in Psiland on April 5 at 11:00 AM”. Correctness is measured by the accuracy of the *WHO (Violet group), WHAT (financial institution), WHERE (Psiland),* and *WHEN (April, 5, 11:00, AM)* in each of the identifies. *WHO, WHAT, 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, a value between 0 and 1 is:

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

2.2 Factoid Set

An unexpected factor of the performance of the ELICIT experiments emerged while analyzing the results. When conducting runs of network sizes with variable size, new factoid sets are created from the original factoid set. The original factoid set [Anderson 2009] consists of 68 unique factoids, distributed with information on the WHO, WHAT, WHERE, WHEN. There are also “noise” factoids, information that provides no useful information. Additionally, factoids are randomly seeded into the nodes within the organization in three waves (occurring at 0, 5 and 10 min).

When the factoid sets were constructed to create trials for more than 34 nodes, multiples of the original factoids were made. For example, the 17-node factoid set assigns the 68 factoids to a particular node and wave number. The factoid set for an organization that is a multiple of 17 is constructed by copying the original factoid set, and duplicating the set of factoids and node numbers (node numbers 1-17 are replaced by 18-34, etc…) as necessary. This introduces duplicates of the each factoid and also the “noise” factoids. Using this approach to generate factoid sets, we observe inconsistencies in the results of average correctness when trying to characterize the effect of network scalability and also when trying to determine the impact of packet loss rates. As the size of the network grows, the time to gain average correctness increases significantly. The reason attributed to this unexpected result is the increased congestion and processing time as a result of the increased number of noisy factoids. Secondly, as packet loss increases, the network is able to maintain a level of average correctness. This is attributed to the duplication of the factoids throughout the network.

We consider this to be an interesting result, as this demonstrates the effect of the information network on the performance of the social/cognitive network despite varying QoS of communication network. However, this result does not contribute to the direction of this paper, but is of future consideration. For our experiments, we implement a factoid set that seeds a total of 68 unique factoids, regardless of the network size. Additionally, each of the factoids is seeded at time 0. This prevents intentional duplication of factoids and controls the amount of noise inserted into the network.

2.3 Geometric Graphs and Organization

With ad-hoc wireless communication networks, it is inevitable that each node will not be able to directly communicate with every other node in the network. Communications must be sent through multi-hop paths (sent through intermediate nodes). These topologies can be represented by a geometric graph $G(n,r)$. With a graph of n nodes, there is a link between two nodes x_i and x_j if the distance between the two nodes is less than communication range, r. A graph is *connected* if there is a multi-hop path between every pair of nodes. Connectivity within random graphs has been shown to exhibit a threshold effect, where $G(n,r)$ is connected with high probability for $r > r_T$ and not connected with high probability for $r < r_T$.

Figure 1 shows this threshold effect for $n = 51$. A set of 100 network topologies of $G(n,r)$ have been created and the network connectivity is determined. This figure indicates that the minimum communication radius to have a random graph of n nodes with high probability is $r \approx 0.27$. Figure 2 is a plot of the minimum such r required for a network of n nodes to be connected with high probability.

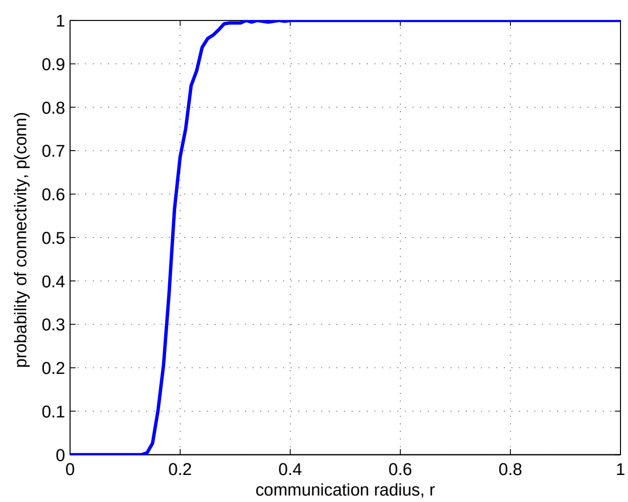

Figure 1. Probability of connectivity vs. communication radius *r* for *n = 51*.

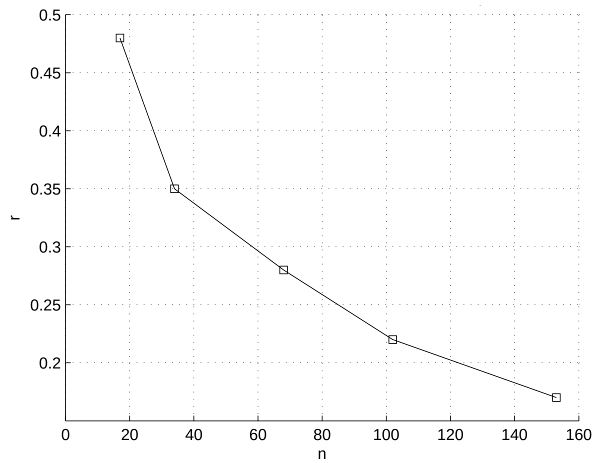

Figure 2. Communication radius *r* required for connectivity versus network size *n*.

Subsequently, Figure 2 is used to formulate the organization files in our ELICIT experiments. The most commonly studied organization structures in ELICIT experiments are hierarchical and edge organizations. Our experiments consider edge organizations. The organization is created by randomly choosing positions of *n* nodes and creating edges with nodes within communication radius *r*. For each network size, we use communication radii that are sufficient to have connectivity with high probability. We generate a set of organizations for each network size that represent unique representations of random graphs *G(n,r)*. These organizations represent reasonable communication structure in distributed networking environments supporting command and control scenarios.

Additionally, the baseline ELICIT experiment allows for users to post and pull factoids to a set of simulated websites. These websites serve as centralized locations where multiple users can access factoids (broadcast) as opposed to just sharing through peer-to-peer communications. In our ELICIT experiments, we chose not to use the websites. All sharing of factoids is peer-to-peer.

2.4 Network Quality of Service

In addition to the organization, we are interested in simulating communications with variable network quality of service (Qos). Packet completion ratio and packet latency within networks are two parameters by which network QoS of communication networks are measured. By varying the network quality of service, we are interested in determining the effect on the performance of the social network in ELICIT. These network QoS parameters were simulated in ELICIT trials with two sensemaking parameters: `ShareWithFactor` and `SharingPostingMessageDelay`. Table 2 is a list of the parameters that are altered within ELICIT for our experiments.

Communication Network	Sensemaking Agent
Probability of a successfully transmitted packet	`ShareWithFactor`
Packet latency	`SharingPostingMessageDelay`
Network topology	Organization

Table 2: List of Sensemaking agent parameters and Communication Network parameters

Packet transmission ratio represents the probability that a message that is transmitted is successfully received by the intended recipient. This is represented within ELICIT by the `ShareWithFactor` parameter. The interpretation of this parameter within the agent model is that for every share an agent wants to make, it actually shares it with probability `ShareWithFactor`. This is a parallel to the communication network with the packet transmission ratio.

Packet latency is the time it takes a packet to travel from its source to intended destination. The time may include transmission and processing delays through multiple hops. In ELICIT the sensemaking agent `SharingPostingMessageDelay` is used to simulate packet latency. For each potential share or post, the agent simply delays the share or post by `SharingPostingMessageDelay` milliseconds.

The remaining sensemaking agent parameters are held constant throughout the duration of these experiments. However, several parameters are changed with respect to the original sensemaking agent setup. To minimize processing delays and to let the communication delays dictate the performance of these networks, several of the network parameters are set to value = 100 (Appendix A is the baseline sensemaking agent configuration file with its associated parameters.):

- `screeningSelectedMessageDelay`
- `informationProcessingDelay`
- `socialProcessingDelay`
- `sharingPostingMessageDelayk`
- `awarenessProcessingDelay`
- `determiningKnowledgeNeedsDelay`

3. ELICIT Experiments

In this section, we investigate the influence of communication networks on ELICIT described in Section 2 with several experiments in ELICIT using the sensemaking agents. First, we consider the scalability of the task completion process for a variable set of network sizes. Then, we investigate the effects of packet loss and delay within ELICIT. Last, we study the effect of connectivity with the organization and encounter an unexpected behavior.

3.1 Scalability

The original ELICIT experiments consisted of a group of 17 individuals participating in trials. Since then, trials involving 34 individuals have been made possible. The limiting factor for human-in-the-loop experiments of larger sizes is acquiring adequate testing populations. The development of agents in ELICIT allows for trials of larger organizations (or a mixture of agents and humans). The use of larger networks of agents may enable more reasonable scenarios involving decision-making and command and control. Larger networks may also be able to simulate information dissemination among larger non-homogeneous populations. To assess the scalability of ELICIT, we are interested in determining the maximum size agent organization that the hardware and software can handle and the maximum organization that produces maximum correctness (C = 1, *i.e.* full situational awareness) within a specified amount of time. The current instantiation of ELICIT runs the agents on the same system running the ELICIT administrative processes. Therefore, if too many agents are used, it is possible that the agents or the administrative processes may not receive adequate resources.

For our experiments, we run ELICIT on a Dell Server 1950 (Quad-Duo Core, 32 GB RAM, 200 GB HDD). In terms of available processing capability, RAM, and I/O, none of these resources were a limitation in the experiments. We consider networks of $n = \{17, 34, 68, 100, 150\}$ nodes. In terms of the generated log files, agent logging is turned off, which may reduce the strain on the I/O. Agent auditing is turned off by including the line "`agentauditing|false`" at the end of an agent batch file. These agent-based ELICIT trials are run for variable amounts of time (from one hour to 16 hours). The resources of the system are not affected by the duration of the trials.

The experiments are run with organizations of the stated network sizes to study the scalability of ELICIT. In terms of the configuration of the trials, the connectivity of the agents was created using communication radii according to Figure 2, which determines the organization. Each subsequent trial uses another random instance of $G(n,r)$. The same sensemaking agent is used for each node in the network. We employ sensemaking agent parameters to create a packet latency of 8 seconds, and no packet loss. The trials were run for 10 hours and the average correctness was determined after one and two hours. Figure 3 shows the diminished average correctness versus time as n increases. Note that the discontinuity of correctness at t = 15 min is due to the system allowing an identify to occur only after 15 minutes have elapsed in the trial. Also, Figure 4 shows a plot of correctness after one $C(1)$ and two hours $C(2)$ as a function of n. A threshold effect is present in $C(1)$, $C(2)$ as a function of n around 80 nodes. We also consider the time required to achieve full correctness in the network. In Figure 5, we plot the time required to achieve average correctness, *t* when $C(t) = 0.99$. Additionally, we show the time required for the node with the maximum correctness value to achieve full correctness. One standard deviation is also shown for each data point. These two plots are show as a function of n. One standard deviation is shown in the error bars of this figure.

Given the feasibility of running scenarios with large network sizes, the challenge is to determine if the network performance can attain a certain level of performance within a given time period. The implication of scalability in command and control scenarios is that decision-making tasks must be completed within a certain time period. Decision-making capability and situational awareness must be attained to adequate levels of performance in command and control scenarios. We have also shown the performance of the highest achieving node and its degradation as the network size increases. In this scenario, the time required increases by 30 minutes, whereas the time required for the average performance of the network triples. In some situations, this is the metric that is of interest. However, in these experiments, the node with the maximum performance is not specified and also may change.

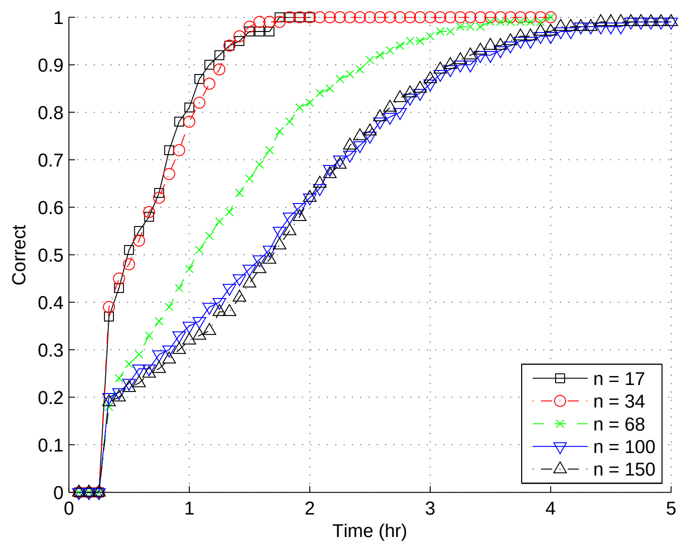

Figure 3. Correctness vs. time (min) for n = { 17, 34, 68, 100, 150 }.

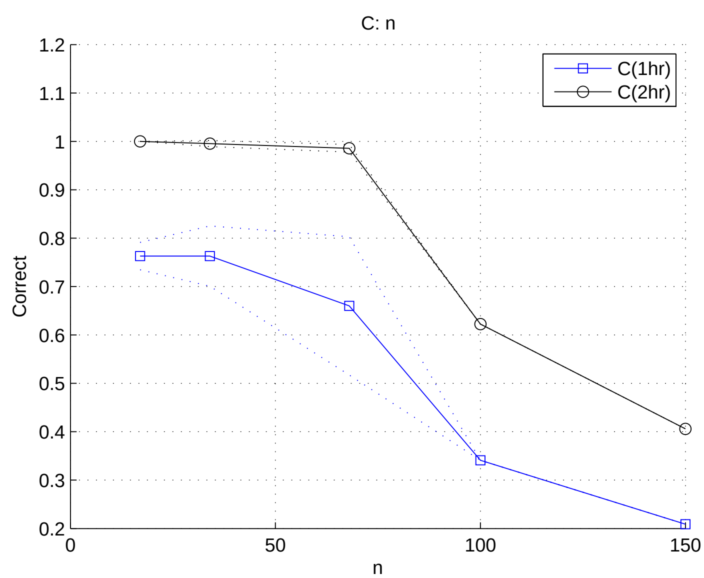

Figure 4. Correctness after one and two hours vs. network size.

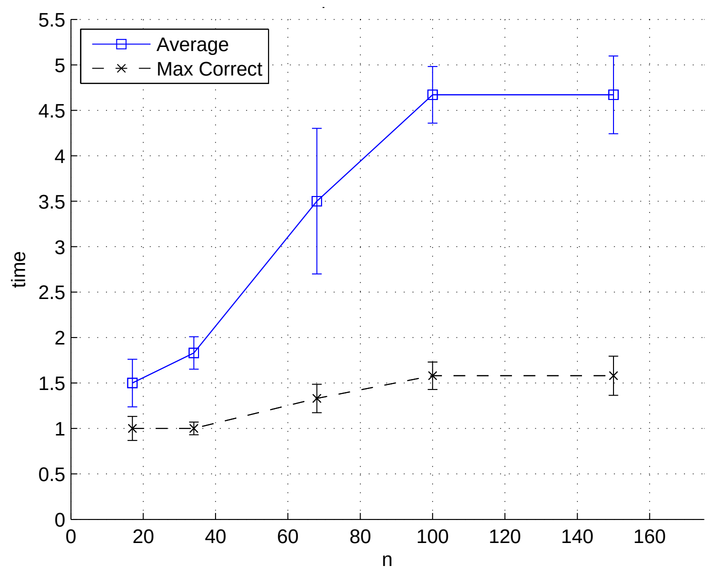

Figure 5. Time required for *C = 0.99* vs. *n* for network average and for maximum node.

3.2 Packet Loss and Delay

We now present results on the ELICIT simulations regarding packet loss and delay. These results are capable of being used in the design of communication networks that are supporting social networks in C2 environments. The network design process can take these parameters into account to optimize the mission completion measure in situations where loss and delay are controllable in the network. For these two network QoS parameters, a high packet completion ratio will likely result in higher packet latency, and a lower packet completion ratio will yield lower packet latency. In this way, the optimal achievable combination of the two can be designed to yield the maximum social network performance. This is also an example of the cross-network analysis of communication networks and social/cognitive networks.

Our set of experiments consists of implementing packet delays and packet loss ratios. The trials consist of organizations of 68 nodes, and the organization is constructed using communication radius according to Table 2. These trials are run for 2 hours, and the correctness after one *C(1)* and two hours *C(1)* was measured. We have shown that the baseline (8 second packet latency, 0% packet loss) achieves full average correctness after approximately 2 hours. By incorporating packet delay and loss in the communications, the average correctness is degraded. This set of experiments, listed in Table 3, illustrates the impact that packet delay and packet loss has on average correctness. First, we show the effect of packet latency on the correctness of the ELICIT decision-making task. Then, we show the effect of packet loss on the performance of ELICIT. Last, we show the combined effect of loss and delay on the performance. This set of experiments provides insight into which parameter has more influence on the correctness measure.

Network Parameter	Values
Packet latency	8s, 15s, 30s, 1min., 2 min., and 5 min.
Packet loss	{0, 20, 40, 60, 80, 90}%

Table 3: Packet loss and latency values used in ELICIT experiments

To illustrate the effect of packet delay on correctness within ELICIT trials, we vary the packet latency from 8 seconds to 5 minutes. In each trial, one packet delay is used for every share transmitted throughout the network. Figure 6 shows the average correctness versus time, for the set of packet latencies. In these trials, there is no packet loss. This figure shows the impact of packet delay on the average correctness. Figure 7 shows the average *C(1)* and *C(2)* vs. packet delay. This set of experiments demonstrates that there is a threshold effect for this particular scenario at around a packet latency of 30 seconds as seen in Figures 6 and 7.

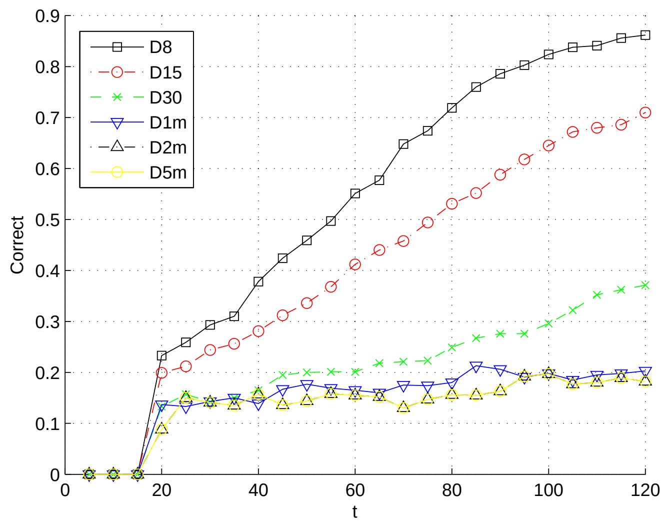

Figure 6. Correctness vs. Time for packet latency = 8s, packet loss = 0%.

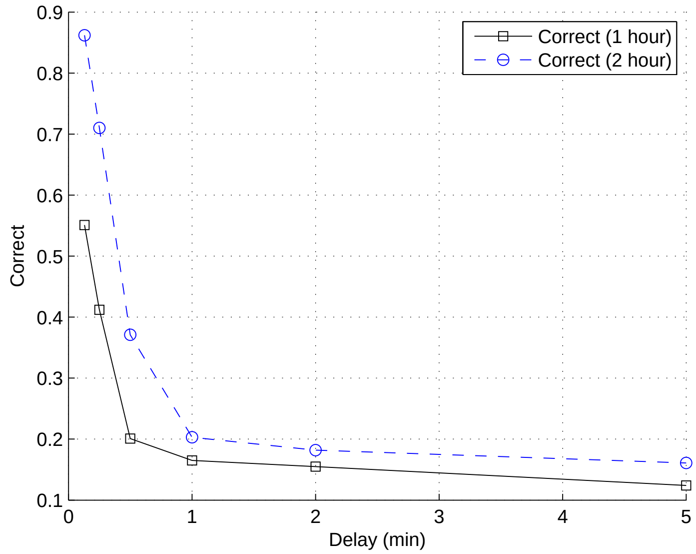

Figure 7. Correctness vs. delay, packet loss = 0%.

To illustrate the effect of packet loss on correctness within ELICIT trials, we consider packet loss rates of 0%, 20%, 40%, 60%, 80%, and 90%. In each trial, every share is successfully transmitted with probability according to the packet loss rate. Figure 8 is a plot of correctness vs. time for each of the trials for the set of packet losses. This shows the degradation in performance as packet loss increases. Figure 9 shows average *C(1)* and *C(2)* versus time for a set of trials, where each plot line represents a run for a particular packet loss. In these trials, the packet delay is 8 seconds. This figure shows the impact of packet delay on the average correctness. There is a threshold effect for this particular scenario at around a packet loss rate of 50% as seen in Figures 8 and 9.

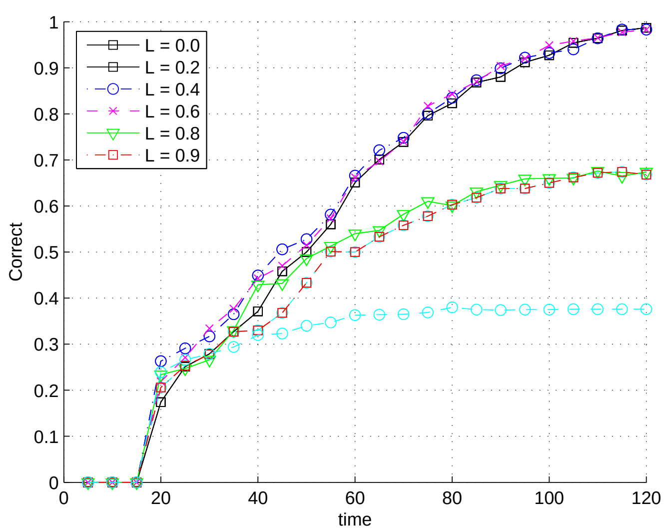

Figure 8. Correctness vs. time, packet delay = 8 s.

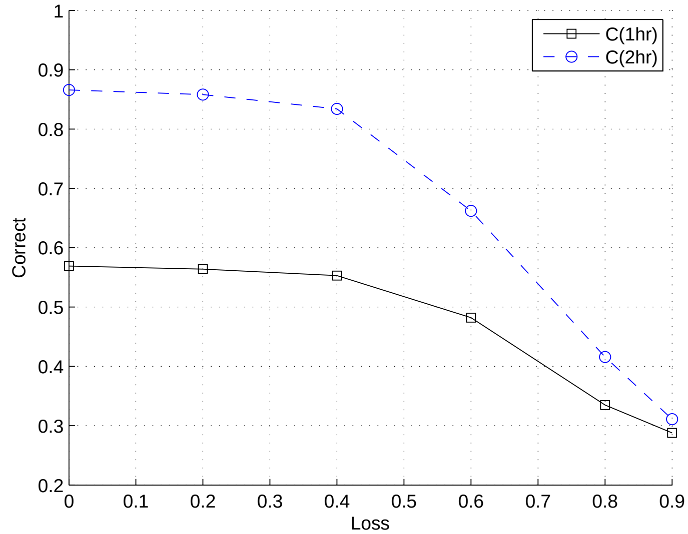

Figure 9. Correctness vs. loss for Packet latency = 8s.

With these results, both packet loss and packet delay can be considered together. To illustrate the effect of these two network parameters on correctness within ELICIT trials, we consider each pair of packet loss rates (0%, 20%, 40%, 60%, 80%, and 90%) and packet delays (8 s., 15 s., 30 s., 1 min., 2 min., and 5 min.). The same approach to the organization and use of factoids as the last set of trials was implemented. Figure 10 shows *C(2)* as a function of both packet loss and packet delay. ELICIT demonstrates a tolerance of packet loss in low packet latency situations. Once the packet latency is greater than around 30 seconds (as shown in Figure 7), the performance of ELICIT drastically decreases, regardless of the packet loss rate.

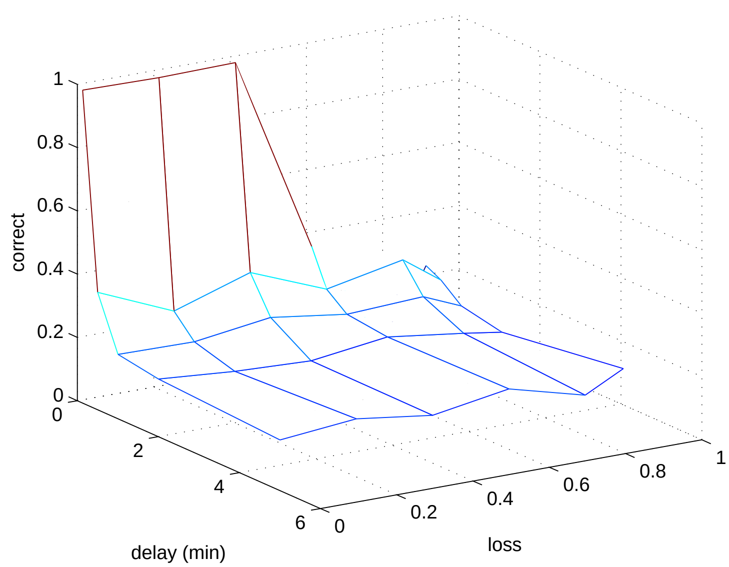

Figure 10. Surface plot of Correctness after 2 hours for packet delay and loss.

This is an unexpected result, as one would believe that an organization would be able to tolerate packet delay as opposed to losses in the transmission of packets. In the ELICIT experimental setup, neither the transmitter (sender) nor the receiver are aware of a failed transmission. The transmitter is aware that it did not send the factoid, per the `shareWithFactor` parameter. However, its behavior is not affected by the knowledge of the failed packet transmission (*i.e.* the node will not attempt to resend failed transmissions). Agent behavior does dictate ELICIT performance. An explanation for the indifference of the correctness with respect to the packet loss rate is that the agent model indicates that the nodes will continue to attempt to share factoids (via the `propensityToSeek` parameter). With respect to packet latency, the performance of the trial is affected for each shared factoid. The nodes in the trials are unable to compensate for the effect of the latency, but due to the redundancy of the sharing of factoids, the agents are able to eventually recover from failed factoid shares.

3.3 Connectivity

In this section, we show the effect that connectivity of the organization has on the correctness measure within ELICIT. To vary the connectivity within the organization, the communication radius r is varied when creating $G(n,r)$. In terms of the communication network, the cost of increased connectivity is increased energy consumption. Figure 11 shows the performance of the organization versus the communication radius of the organization.

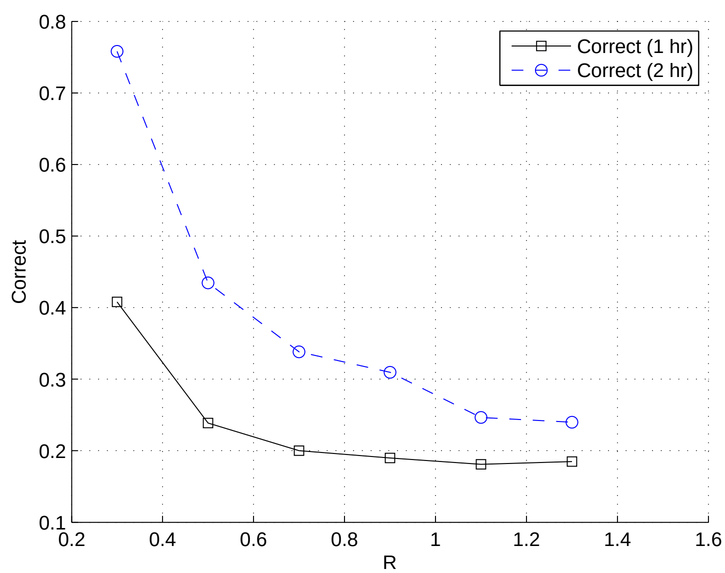

Figure 11. Correctness vs. Communication Radius

The result of this set of ELICIT experiments contradicts the expected outcome. We found that with increased connectivity, the average performance of the organization decreases.

One would expect that with greater connectivity in the network the performance of the network would improve. By allowing for the nodes to share factoids with nodes farther away, this requires less multi-hop communications so factoids will be disseminated more rapidly.

The immediate explanation is that the agents are suffering from "information overload". Due to the increasing number of neighboring agents in the organization, the nodes are receiving more factoids than the agent is able to process. This is shown in Figure 12. The total shares received in each 5 minute interval over the two hour trial length are plotted for each of the communication radii used to create the topology of the organization. In the regions where $r > 1.0$, the average total number of shares received is saturated, where the nodes in the network are receiving an average of 4000 shares in the course of the two hour trial. When examining the performance of the network in Figure 11 and considering the share behavior in Figure 12, this indicates that the nodes are receiving and average of 58 factoids in a 5 minute interval, but their performance does not correspond to the number of received factoids. This indicates that the nodes are flooded with factoids and cannot process all of the factoids. The phenomenon of overwhelmed agents explains the observed behavior.

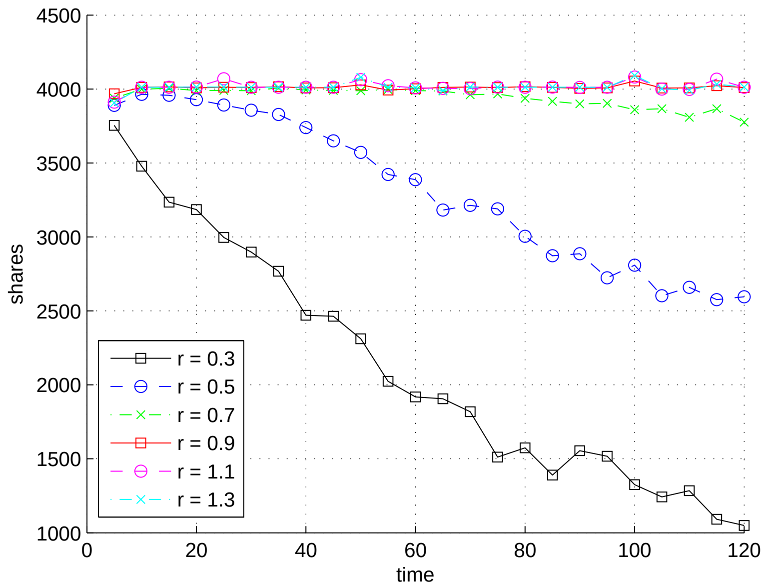

Figure 12. Total shares received in each 5-minute interval for *r* = {0.3, 0.5, 0.7, 0.9, 1.1, 1.3}.

4. Discussion of Related Work

Existing social network studies use social network analysis concepts such as the centrality, betweenness and closeness of networks. In these cases, the communications structure is abstracted. Houghton [Houghton 2006] considers the effect of structure of organizations in various emergency operations from a social networking analysis point of view. Dekker [Dekker 2002] uses an experimental platform called SCUDHunt to study the effect of organizations, information quality and coordination in networks. Based on the tempo of the information flows, quality of sensors, they determine optimal organization and coordination for specific scenarios. Delays in communication between nodes within the command and control network, but the delays considered here are the result of information understanding. Brehmer [Brehmer 2009] considers self-synchronization within C2 environments. An experimental platform called D3FIRE was used to verify these ideas on self-synchronization.

The existing studies with regard to ELICIT consider social networking concepts and test them with regard to different organizations. Leweling [Leweling 2007] studies the effect of mental models and learning effects within edge and hierarchical organizations. Powley [Powley 2008, 2009] considers the effect of trust relationships on the performance of ELICIT in edge and hierarchical organizations. Rosinha [Rosinha 2009] studies the effect of emergent leadership in various organizations within ELICIT. In general, the majority of ELICIT experiments have considered organizational behavior and shared information concepts without considering the underlying communication network.

5. Conclusion

This work has used ELICIT to consider the effects of the communication network on the social/cognitive network. We have performed this work in ELICIT using a significantly different approach than past studies. The set of ELICIT experiments that have been presented show the effect of packet loss and packet latency on the correctness measure of a set of sensemaking agents. It is shown that packet latency has a more significant effect on the performance of the network than packet loss. Further, we have considered scalability of the network size and also the effect of the connectivity of the organization on the ELICIT trials. We have performed agent-based ELICIT trials with organizations larger than done before. The contributions of this work are an investigation into network science research in using an existing social networking experimental platform and implementing quality of service aspects of a communication network. Further, we have contributed to the ELICIT research community a novel set of agent-based experiments that consider the effect of several sensemaking agent parameters.

Bibliography

1. *[Alberts 2003] D. Alberts, and R. Hayes, "Power to the Edge," CCRP, 2003.*

2. *[Anderson 2009] C. Anderson, D. Wynn, J. McEver, M. Ruddy, "Exploring the Effects of Individual Characteristics on Organizational Performance using the ELICIT Experimentation Platform," Proceedings of the 14th International Command and Control Research and Technology Symposium, Washington, DC, June 2009.*

3. *[Brehmer 2009] B. Brehmer, "Command without Commanders," Proceedings of the 14th International Command and Control Research and Technology Symposium, Washington, DC, June 2009.*

4. *[Dekker 2002] A. Dekker, "C4ISR architectures, social network analysis and the FINC methodology: an experiment in military organisational structure," Technical Report: DSTO-GD-0313, Jan. 2002.*

5. *[Houghton 2006] R. Houghton, C. Baber, R. McMaster, N. Stanton, P. Salmon, R. Stewart, G. Walker, "Command and control in emergency services operations: a social network analysis," Ergonomics, Vol 49, No. 12-13, Oct. 2006.*

6. *[Leweling 2007] T. Leweling, M. Nissen, "Hypothesis Testing of Edge Organizations: Laboratory Experimentation using the ELICIT Multiplayer Intelligence Game," Proceedings of the 12th International Command and Control Research and Technology Symposium, Newport RI, June 2007.*

7. *[NRC 2005] Network Science, Committee on Network Science for Future Army Applications, National Research Council. 2005. The National Academies Press (2005)ISBN 0-309-10026-7.*

8. *[Powley 2008] E. Powley, M. Nissen, "Trust-Mistrust as a Design Contingency: Laboratory Experimentation in a Counterterrorism Context," Proceedings International Command & Control Research & Technology Symposium, Seattle, WA, June 2008.*

9. *[Powley 2009] E. Powley, M. Nissen, "Trust as a Design Contingency: Laboratory Experimentation in a Counterterrorism Context," Proceedings International Command & Control Research & Technology Symposium, Washington, DC, June 2009.*

10. *[Rosinha 2009] A. Rosinha and J. Esteves, "Emergent Leadership on Edge Organizations: Building Trust and Cooperation in the context of ELICIT experiments," Proceedings of the 14th International Command and Control Research and Technology Symposium, Washington, DC, June 2009.*

11. *[Ruddy 2007] M. Ruddy, "ELICIT – The Experimental Laboratory for Investigating Collaboration, Information-sharing and Trust," Proceedings of the 12th International Command and Control Research and Technology Symposium, Newport RI, June 2007.*

12. *[Ruddy 2009] M. Ruddy, "Instantiation of a Sensemaking Agent for use with ELICIT Experimentation," Proceedings of the 14th International Command and Control Research and Technology Symposium, Washington, DC, June 2009.*

13. *[Wynn 2010] D, Wynn, M. Ruddy, M Nissen, "Tailoring Software Agents to Emulate Specific People", Proceedings of the 15th International Command and Control Research and Technology Symposium, Washington, DC, June 2010. (Draft)*

14. *[Zimmermann 1980] Hubert Zimmermann, "OSI Reference Model — The ISO Model of Architecture for Open Systems Interconnection," IEEE Transactions on Communications, vol. 28, no. 4, April 1980, pp. 425 - 432.*

Appendix A: Sensemaking Agent file

The sensemaking agent is controlled by a set of 48 parameters. The parameters that we considered in our study are in **bold**. This is the base sensemaking agent used in our experiments

SenseMaking_Agent_57_1
<begin agent configuration parameters>
SenseMaking_Agent_1.jar
net.parityinc.ccrp.web.agent.impl.SenseMaking_Agent_1
readyIntervalDelay|Time interval to click Ready button|10000
messageQueueCapacity|Capacity of queue (-1 means unlimited)|-1
messageQueueTimeRemainInQueue|Time a factoid can remain in queue (-1 means unlimited)|-1
messageQueueNewerBeforeOlder|If true then newer messages are selected before older|false
selectMessageFromQueueDelay|Select message from queue delay|1000
shareBeforeProcessing|If true then share message before Processing|false
postedTypes|PostedTypes|who,what,where,when
postFactor|PostFactor|1
postOutOfArea|PostOutOfArea|true
shareWithFactor|ShareWithFactor|1
sharedTypes|SharedTypes|who,what,where,when
shareRelevantAccordingToSiteAccess|ShareRelevantAccordingToSiteAccess|false
shareAccordingToSiteAccess|ShareAccordingToSiteAccess|false
isCompetitiveHoarder|IsCompetitiveHoarder|false
pullFactor|PullFactor|1
timeBeforeFirstIdentify|Time before the agent does its first identity (in minutes)|15
minSolutionAreas|The minimum number of ID tables with some data|1
hasSeenEnoughToIdentify|HasSeenEnoughToIdentify|5
isGuesser|IsGuesser|true
isFrequentGuesser|IsFrequentGuesser|false
idConfidencelevel|IdConfidencelevel|0.49
partialIdentify|Identify if there are no some answers|true
propensityToShare|PropensityToShare possible values (low, moderate, high, very high)|very high
shareModalChoice|ShareModalChoice possible values (both, post dominant, post only, peer to peer dominant, peer to peer only)|post dominant
screeningSelectedMessageDelay|Screening selected message (message processing) delay|100
informationProcessingDelay|Information Processing delay|100
socialProcessingDelay|Social Processing delay|100
sharingPostingMessageDelay|Sharing/Posting each Message delay|100
awarenessProcessingDelay|Awareness Processing delay|100
determiningKnowledgeNeedsDelay|Determining Knowledge Needs delay|100
idAttemptDelay|ID Attempt delay|20000
webRequestDelay|Web Request (Pull)|9000
shareWith|List of players with whom agent may share (-1 means share with all from organization configuration file)|-1
shareWithWebSites|List of websites with whom agent must share|what,when, who,where

```
propensityToSeek|PropensityToSeek possible values (low, moderate, high,
very high)|very high
minTimeBetweenPulls|If the time since the last pull is not >=
minTimeBetweenPulls, do not Pull (in milliseconds, -1 means ignoring
this parameter)|20000
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
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 opinon,8=no opinion,9=no
opinion,10=no opinon,11=no opinion,12=no opinion,13=no opinon,14=no
opinion,15=no opinion,16=no opinion,17=no opinion
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
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
primary|Primary areas of interest. Possible values: who, what, where,
when)|who,what,when,where
secondary|Secondary areas of interest. Possible values: who, what,
where, when)|
propensityToShareExternal|If message is not in area of interest, then
agent shares it according to sharing preferences with probability =
propensityToShareExternal|1
awarenessProcessingThreshold|If cumulative value of the perceived
message value is more or equal to this variable, then start awareness
processing.|2
pullBetweenSitesDelay|Pull between sites delay|1000
postBetweenSitesDelay|Post between sites delay|500
provideRelevance|Provide relevance for posted and shared messages|false
provideTrust|Provide trust for posted and shared messages|false
```