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16th ICCRTS

"Collective C2 in Multinational Civil-Military Operations"

Title of Paper

Research on Information Sharing Method for Future C2 in Network Centric Environment

Topics

Topic 4: Information and Knowledge Exploitation (The primary topic)

Topic 2: Approaches and Organizations

Topic 8: Architectures, Technologies, and Tools

Name of Authors

Heng Wang

Lixin Zhu

Shaojie Mao

Boquan Xu

Point of Contact

Heng Wang

Name of Organization

Science and Technology on Information Systems Engineering Laboratory

Address

#1406-69, NO.1, MUXUYUAN EAST STREET, Nanjing, Jiangsu Province, 210007, P.R. China

Telephone

(86)0139-1298-1215

Email

puchengew@yahoo.com.cn

nriee.wangh@gmail.com

Research on Information Sharing Method for Future C2 in Network Centric Environment

Heng Wang Lixin Zhu Shaojie Mao Boquan Xu

Abstract — Information in network centric environment has characteristics of massiveness, heterogeneousness, dynamic, and uncertainty. As a result, how to share information on demand for command and control (C2) missions so as to support generation of high-quality battlefield situation in networked condition has become one of desiderative problems to be solved in future C2. In mode of platform-centric, the method for information sharing is static and predesigned according to tree-pattern echelon of command, which led that rich information resources could not be adequately exploited and generated to complete and consistent operational situation. Therefore, it needs to be explored new method of information sharing for future C2 in network centric environment. Information sharing issues for future C2 are wide, and we focus on the aspects concerned with theoretical analysis, information sharing/dissemination method and measurement. In this paper, our work include: 1) the complexity analysis for information sharing are given from operational requirement and systematology view respectively; 2) an information sharing method is proposed from systematology by using the idea of importing negative entropy; 3) from a technical point of view, an information sharing method based on Publish/Subscribe is put forward, and simulation results demonstrate that this method performs better information sharing performance than the existing method; 4) a four-dimensional measurement framework is proposed to measure information sharing capacity for future C2.

Keywords **-** information sharing; future C2; network centric environment; information value chain; information negative entropy.

1. Introduction

Network Centric Warfare (NCW) provides the theory of warfare in the Information Age [1], and also presents a kind of operation pattern in future. NCW provides a new conceptual framework with which to examine military missions, operations, and organizations. The Chief of Naval Operations, Admiral Jay Johnson, has called it “a fundamental shift from platform-centric warfare.” [2]. NCW is based on adopting a new way of thinking—network-centric thinking—and applying it to military operations. NCW focuses on the combat power that can be generated from the effective linking or networking of the warfighting enterprise. It is characterized by the ability of geographically dispersed forces (consisting of entities) to create a high level of shared battlespace awareness that can be exploited via self-synchronization and other network-centric operations to achieve commanders’ intent [3].

NCW is defined as “the concept of linking all aspects of warfighting into shared situation awareness and understanding of command intent so as to achieve a unity and synchronicity of effects that multiplies the combat power of military forces.” [4] From this point of view, apparently command and control (C2) is the key and soul of NCW. Consequently, future C2, i.e., C2 in network centric environment has become one of the research hotspots, for example, Joint Command and Control (JC2) and its successor, Net-Enabled Command Capability (NECC). Further, information sharing is one of the important issues of future C2. The reason is the fact that information sharing is foundation and core of realizing shared situation awareness and generating Common Operating Picture (COP), and further supports decision-making effectively.

However, information in network centric environment has characteristics of massiveness, heterogeneousness and dynamic. Therefore, information sharing in such comprehensive environment also presents many uncertainties, such as the existence of the information that warfighters or commanders need is uncertain, where to find the information is uncertain, whether the received information content is complete or consistent is uncertain, and so on. Such uncertainties have brought great challenges to information sharing in network centric environment, i.e., how to organize and share information on demand for C2 missions to support the generating of high-quality battlefield situation in networked condition has become one of difficult problems to be solved in future C2. Future C2 systems requires the following capabilities: “picking up” right information dynamically from distributed information source nodes according to different battle missions, filtering and mining usable information related with missions in a complicated and huge “information pool”, further integrating quickly these usable information to complete, consistent, and accurate high-quality information, and at last rapidly, availably and efficiently disseminating and delivering information to right warfighter. In this paper, we discuss some of issues concerning information sharing for future C2, put forward to information sharing methods from systematology and technical view respectively, and give the measurement framework of information sharing.

The rest of the paper is organized as follows. Section 2 describes some of the existing work that is related to this paper. Section 3 gives complexity analysis for information sharing from operational requirement view and systematology view respectively. Main research work is introduced in Section 4, and it concludes detail information sharing methods and simulation experiment. Section 5 concludes the paper.

2. Related work

In recent years, much theoretical research has been devoted to the development of information sharing in network centric environment or Internet environment. Dr. David S. Alberts and CCRP (The Command and Control Research Program) [5-7] has devoted the theoretic research concerning NCW, information superiority, and future C2. Also, DSTO (Defense Science & Technology Organization) has published a serial research reports [8-9] about NCW and information age warfare C2 issues. These reports focused on how to solve the issues such as C2 efficiency, warfare superiority and battlefield uncertainness. The above works discussed information sharing problem from information domain of NCW and capstone level.

Ref. [10] and [11] studied information sharing issue based on net-centric information management, respectively. Ref. [10] considered that there were technical challenges that must be addressed besides non-technical challenges (such as information management discipline). The author proposed enterprise-level infrastructure objectives and technical challenges for their vision of an information management environment whose services adapt to the operational needs of joint and coalition enterprises for universal real-time access to tailorable, actionable information. Dr. Scott Renner [11] believed that information sharing was a key tenet of NCW, and described the essential architecture of a net-centric information management process.

As for measurement of information sharing, Alberts [12] presented three following major dimensions or vectors to describe key attributes of the information domain: richness, reach/distribution, and quality of interaction, and provided framework guidance. RAND Corporation developed a framework for metric of information superiority in 2004 [13], and also studied the definition, characteristic and metric principle in terms of three domains: the physical domain, the information domain and the cognitive domain.

From practicality of information sharing, U.S. DoD (Department of Defense) has devoted to the implements and technologies of information resources sharing for many years. For example, a National Defense Report named “network centric data strategy” was issued by DoD in April 2003 [14], and the data management strategy in network centric warfare environment was described in this report. Also, U.S. DoD in July 2003 released “The Department of Defense Discovery Metadata Standard (DDMS)”[15], and this draft defined discovery metadata elements for resources posted to community and organizational shared spaces. The purpose is to ensure that the information published to a shared space is visible, understandable and available. In addition, to integrate all kinds of resources in GIG (Global Information Grid) and realize information sharing among dynamically changing organizations, U.S. DoD began to develop Net-Centric Enterprise Services (NCES) program [16] in 2002. NCES is a transformational program that delivers a set of shared services as part of the DoD’s common infrastructure to enable networked joint force capabilities, improved interoperability, and increased information sharing across mission area services.

From the viewpoint of complex network system, there were some theories and methodologies, such as kinetic theory of information dissemination, information self-organization theory [17], theory of dissipative structure [18], etc. For the Internet environment, some methods could be used to address “information sharing” issue, such as information filtering, personalized information services, information clustering, intelligent agents. These methods were used for reference, but are not suit for C2 requirements and information sharing environmental characteristics, such as C2 has more complex network environment, and C2 network not only includes broadband cable networks, as well as satellite communication networks, mobile communication networks and so on. And, timeliness of C2 information, security, and flow pattern of information during the command process, are quite different with the one in Internet. Therefore, these models and methods can’t be directly applied to information sharing of C2 in network-centric environment, only to have some reference.

3. Complexity analysis for information sharing

3.1 Analysis from operational requirement view

(1) Information sharing needn’t be enslaved to the organization of the force. In future C2, the various forces are usually being orchestrated or combined temporarily according to operational mission. The operational mission organization will be agile and diversified, and there is no fixed pattern. Necessary

sensors, weapons and communication resources can be dynamically adjusted according to operational missions, no longer must be monopolized by commander post. Functions of command have not to be bound tightly with information and data, so as to increase degree of information sharing.

(2) Cross-missions, cross-services and cross-organizations horizontal information flow. Besides traditional tree-pattern information flow, NCW will require that all Services can communicate and collaborate with each other, which determines that the flow of information must be able to rapidly and horizontally flow and share cross all services, or departments, or functional domains (i.e., intelligence, surveillance, reconnaissance, C2, and weapon).

(3) Dynamically organizing information according to operational mission. NCW will make battle rhythm quicken and process shorten, and operational mission may vary with changing battlefield environment. As a result, information organizing will dynamically change according to different operational missions, and statuses of information flow among operational units have to be changed. Moreover, information organizing and exchanging pattern will continuously evolve as battlefield environment during battle process.

(4) Requirement for counter-information increasing during procedure of information sharing. In NCW, the opposing sides of the commanders are trying to destroy each other as possible while protect them, and C2 activities will proceed in serious confrontation environment. The two sides will try every means to exploit or deny an adversary's ability to collect, process, and disseminate information, which results in increasing for counter-information. So, it needs to use any measure to obtain information rapidly, effectively, and accurately while deny an adversary's ability to do the same.

3.2 Analysis from systematology view

- Nonlinearity

Network topologies in future network centric environment will be taken as nonlinear complex network, and the flow of information among the various nodes running on the network also composes nonlinear complex network. These nonlinear correlations include information processing, information pushing, information pulling, and information flow changing as command organization adjusting, and so on. Take the case of Internet, research indicated that the dynamics behavior of complex network composed of Internet is mainly influenced by users' information requirement. The information correlation and flow of Internet websites presents power distribution phenomenon, and its power law is distributed between 1.7 and 1.8, which shows scale-free property [19]. Therefore, information sharing in future C2 is nonlinear and complex scientific issue.

- Emergence

In future battlefield environment, the correlation and effect among combat systems' elements are enormous and comprehensive, and emergence of information system shows more pervasive and sharper. Because essence of emergence is wholeness of system, and is taken as a transform of wholeness during system evolving, the emergence results often involve unexpected phenomena. Therefore, complexity of information sharing in future C2 may lead to serious "process capability overload" issue in C2 nodes at the situation information awareness level. At that time, it will happen breakdown of C2 systems or hierarchy, even if the adversary's behaviors, such as disturb, strike or destroy, do not exist.

- Uncertainty

Obviously, future C2 is a complex system. During the status evolution of such complex system, it will happen to come forth many unexpected and uncontrolled cases due to nonlinearity and emergence. Therefore, the status of system shows powerful randomicity, which is also certain situation in complex system. As for information sharing, some uncertainties may occur in such network centric environment as follows. Does the information that warfighters or commanders need exist? Where right information can be found? Is received information complete or consistent? Such uncertainties bring great challenge to information sharing in future C2.

4. INFORMATION SHARING METHODS FOR FUTURE C2

4.1 Basic ideas

In network centric environment, the whole process (sensor data→intelligence→situation→situation awareness) forms information value chain for C2, which also could be considered as the process from data, information, and knowledge to cognition (the evolution of information value). The characteristics of information in such an environment result in the raise of information uncertainty and the decrease of information exploitability in each link in the whole information value chain and ultimately affect the generation and understanding of high-quality situation. Therefore, our final goal is to improve the information value during its evolving through information sharing, shown in Fig.1.

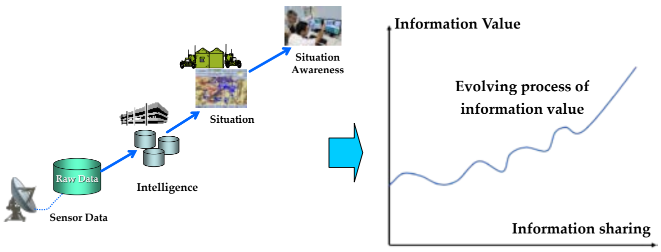

Fig.1 Information value chain and information sharing

As stated above, information sharing is a critical factor to implement reliable information service capabilities, reduce information uncertainty and increase information exploitability and information value in network centric environment. The basic ideas are as follows: starting from each link of C2 value chain, and considering the user's information needs in the network centric information sharing space, locate and search the vast amounts of information. Then filter out the information users' requirements from heterogeneous information resources, and to establish the most optimal and most reasonable information dissemination manner to deliver the information to the user quickly and efficiently. Finally, set up metric (such as richness, reach, exploitability and countermeasure) framework of C2 information sharing, so as to support the generation of high-quality shared situation in the battlefield from the perspective of methodology, and thus support the implementation of information superiority, decision-making superiority and NCW. The framework of basic idea for information sharing is shown in Fig.2:

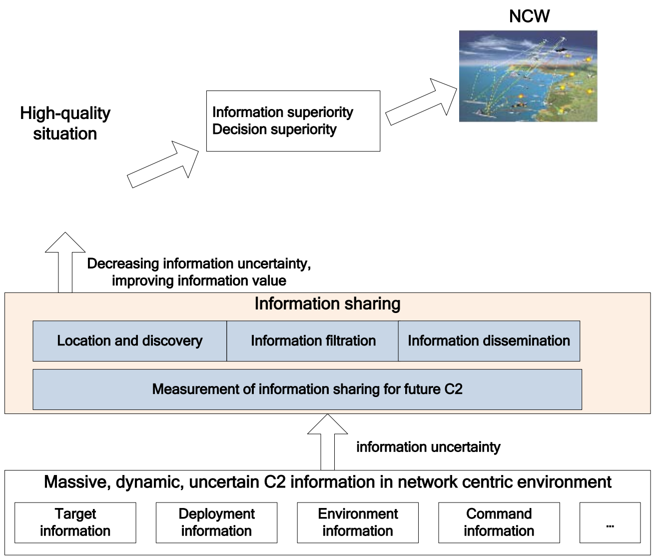

Fig.2 The basic framework for information sharing

4.2 Information sharing method from systematology

In this section, we give information sharing method to deal with the issues about information uncertainty and information value from systematology.

According to Shannon's information entropy theory,

$$H = -\sum_{i=1}^{n} P_i \log P_i \tag{1}$$

where, H denotes information entropy, n is the number of event contained in sources, and P_i is the i^{th} event probability. It can be seen, the information entropy is used to describe the amount of information of all kinds of sources, and the number of information uncertainty can be used as a measure of the amount of information. The value of information depends on the amount of information uncertainty to reduce. Therefore, from the perspective of the Shannon information theory, information entropy can be used as a factor to measure the level of information value. According to formula (1), higher degree of information has lower entropy, and lower degree of information has higher entropy. In the absence of negative entropy to be introduced, the more widely spread, the longer spread, the more valuable the information with higher degree of cited (i.e., information appears in the high probability).

If the information sharing process in future C2 is regarded as a complex system, clearly it is an open system. According to theory of dissipative structures [18], an open system far from equilibrium, through constantly exchanging the energy and material with the external world, may arise from self-organization phenomena under a certain conditions to form the new, stable ordered structure, so as to achieve the transformation from disorder to order, from the lower order to higher order. Therefore,

$$dS = dS_i + dS_e \tag{2}$$

dS is the total entropy of system, dS_i denotes the internal entropy of system (or entropy of the system itself), dS_e is negative entropy input from the external environment.

Obviously, $dS_i > 0$, $dS_e > 0$ or $dS_e < 0$. If $dS_e < 0$ and $|dS_e| > dS_i$, then $dS = dS_i + dS_e < 0$.

The above result shows that the total entropy of system decreases, and the system evolves to the direction of reducing entropy, i.e., by reducing the entropy of the system to reach a new equilibrium orderly.

Therefore, from the perspective of systematology, our method is that: considering information sharing as a complex system, some important factors influenced C2 information value chain are analyzed, and negative entropy is imported to decrease information entropy, further to decrease information uncertainty, and to increase information value at last.

4.3 Information sharing method based on Pub/Sub

From a technical point of view, an information sharing method based on Publish/Subscribe (Pub/Sub)[1] is proposed in this paper as follows:

The whole framework follows the Pub/Sub model, namely, the information providers publish their summary (or profile) of the information content by means of metadata, and the information users (or customers) launch subscription (or search) request. Then, some of the information service nodes for future C2 deal with these users' requests, locate, federated search the required information, further process information, and finally disseminate the correct information to right users. The framework of information sharing based on Pub/Sub is shown in Fig.3.

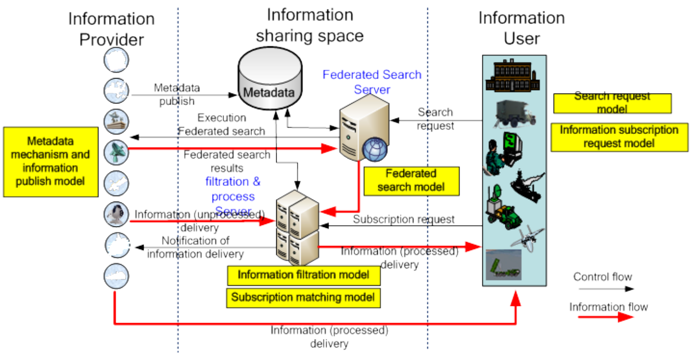

Fig.3 Information sharing based on Pub/Sub

In detail, the federated search server is responsible for resolving the search requests sending out from the users, and executing the federated search. The information filtering and processing server can parse the users' subscription requests, and pass to these requests to the appropriate information providers according to the metadata base. If the information providers possess information processing capability, then the right information will be directly delivered to users; if not, then the information filtration & process server may integrate and process these information, and final delivers to the users.

Here, there exist theoretical or methodological issues (the yellow text in Fig.3) that impact on efficiency of information sharing in every part of above procedure, which are the difficult problems to be resolved. For example, feasible metadata mechanism and information publishing model (such as the U.S. DoD's DDMS) need to be established at the information provider end, information search request model and subscription request model at the user end, high-performance federal search model (such as the

[1] Publish/Subscribe is a messaging paradigm where senders (publishers) of messages are not programmed to send their messages to specific receivers (subscribers). Rather, published messages are characterized into classes, without knowledge of what (if any) subscribers there may be. Subscribers express interest in one or more classes, and only receive messages that are of interest, without knowledge of what (if any) publishers there are. This decoupling of publishers and subscribers can allow for greater scalability and a more dynamic network topology.

Google, JBI QED[2] [20]) in federated search server, information filtering model, or information subscription matching algorithm (such as users subscribe the target information at two different regions existing intersection) in information filtering & processing server, etc.

4.4 Simulation experiments

In this section, we will evaluate part of our proposed information sharing method based on Pub/Sub through simulation experiment. We have implemented information dissemination function by using C++ language in Microsoft Windows XP. The simulation experiments are run in network environments, and bandwidth of link can be adjusted as 100Mbps or 2Mbps by using a “bandwidth controller” equipment. Information provider (or information source) is act as a Radar simulator that simulates the generation of real-time Radar target information. Three groups of experiments are carried out so as to demonstrate adequately performance of proposed information dissemination method.

In the first set of experiments, our proposed method is compared with an existing information dissemination method for achieving information sharing between command posts. We compare the packet loss rate and the delay of disseminating information of given two methods in network environment with 100Mbps bandwidth. Firstly, we compare packet loss rate, i.e., the average packet loss due to information dissemination processing under the conditions of high information capacity, which partly reflects the performance of information sharing for C2. Fig.4 shows the packet loss rate of varying the number of information packets (from 1000 to 4500 packet/sec).

It is easy to see from Fig.4 that the average packet loss rate of two methods increases as the number of information packets increase. This is expected since, the more the number of packets; the more the number of the information needs to be processed by information dissemination module, which results in the increase of the packet loss rate. Our proposed method gives much higher performance than the existing method. We also note that in Fig.4, the average packet loss rate of our method is below 5% for all scenarios we tested. The average packet loss rate of the existing method has been over 10% when the number of packets exceeds 2500 packet/sec, which obviously could not satisfy the requirement of information sharing in network centric environment.

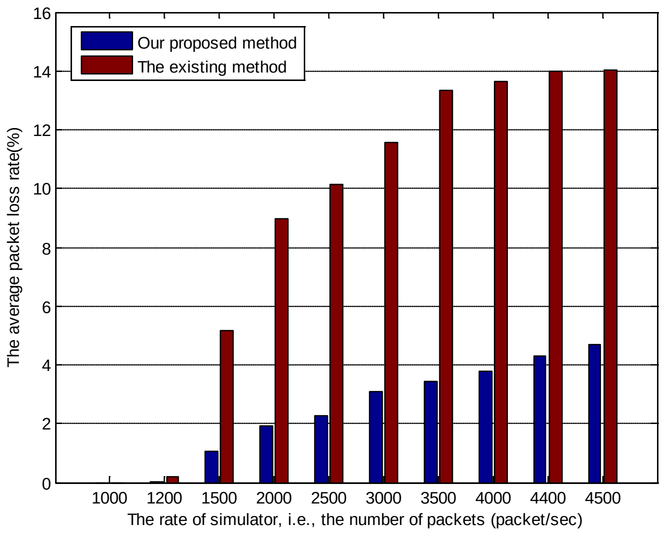

Fig. 4 The average packet loss rate of two methods

We next compare the delay caused by disseminating to different numbers of information users, which reflects the performance of information sharing for large numbers of concurrent C2 users in future network centric environment. Fig.5 shows the delay of dissemination of given two methods for different numbers of concurrent users (from 100 to 500 in steps of 50). Observe that the delay obtained by two methods increases as the number of users. This phenomenon is expected because as the number of concurrent information user increases, the quantity of the packets need to be disseminated gets larger, so the delay of dissemination increases. It can be seen that our proposed method gives lower delay than the existing method, and the delay for all scenarios we tested is below 70ms, which shows better performance.

[2] JBI QED: Joint Battlespace Infosphere Quality of Service Enabled Dissemination. The aim of QED information dissemination is to meet the various quality requirements of users and the missions they are undertaking in a manner that is reliable, real-time, and resilient to the changing, hostile conditions of tactical environments.

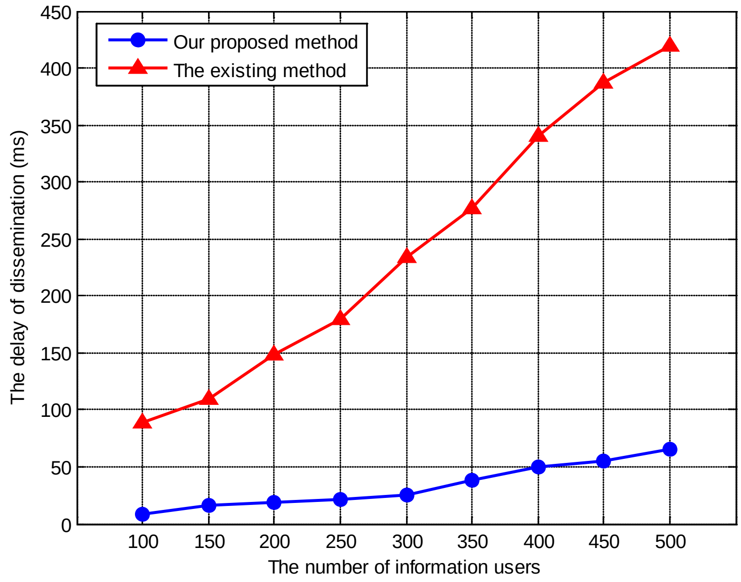

Fig.5 The delay of dissemination of two methods

Next, we track the CPU occupancy caused by “Transport service” and “Dissemination Service” in our proposed method, respectively. Fig. 6 shows the CPU occupancy of two services for different number of concurrent users (from 10 to 140 in steps of 10). It can be seen in Fig.6 that the CPU occupancy of two services increases as the user size increases, which shows that the running performance of the developed information sharing services (transport service and dissemination service) are stable.

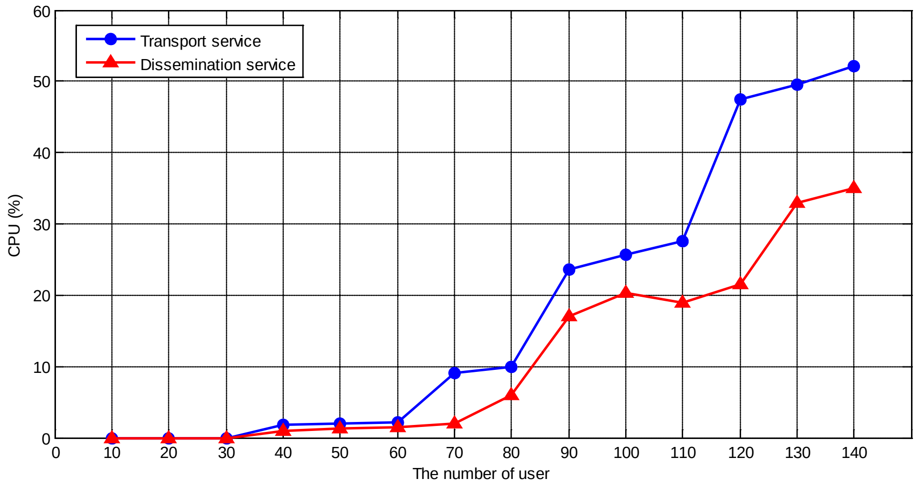

Fig.6 The CPU occupancy of two services

Finally, “bandwidth controller” equipment is used to control the bandwidth as 2Mbps and 100Mbps, respectively. Similar to the first set of experiments, we compare the packet loss rate of varying the number of information packets (from 100 to 700 packet/sec) in conditions of two types of bandwidth. Fig.7 shows that the packet loss rate is larger in lower bandwidth, and the gap of two curves sharply increases when the number of packets exceeds 400 packet/sec in particular.

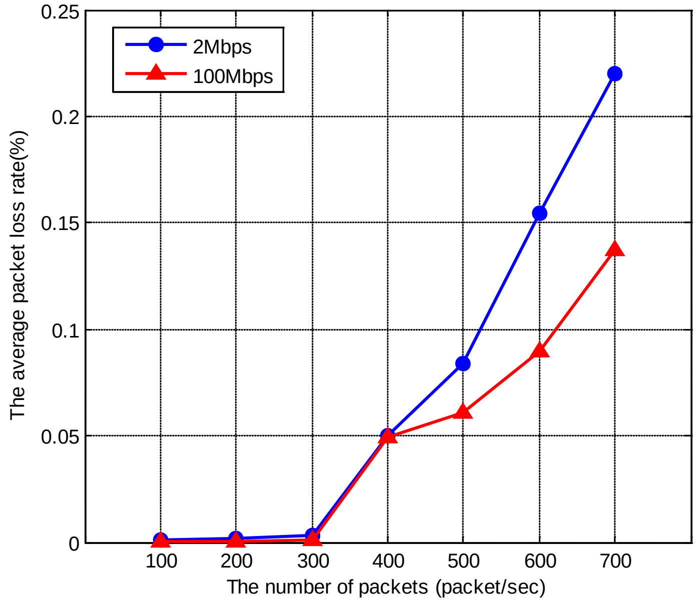

Fig.7 The average packet loss rate with different bandwidths

4.5 Measurement of information sharing

A measure of information sharing is an important aspect of theoretical methods of future C2, and is also the principal mean for measuring information capacity of future C2. On basis of three-vectors (richness, reach, and quality of interaction) of the information domain proposed by Albert [12], taking into account factor of counter-information in network-centric environments, a four-dimensional measure (richness, reach, exploitability and countermeasure) framework of information sharing is proposed in this paper, as shown in Fig.8:

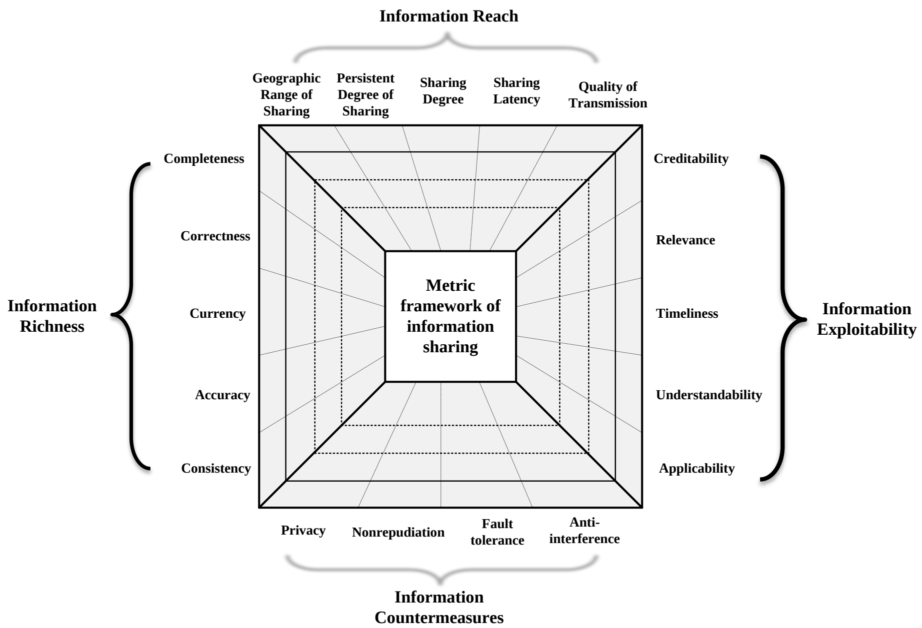

Fig. 8 The framework for measure of information sharing

This four-dimensional metric framework is evaluated information sharing in future C2 separately from the quality of information (i.e., information richness), the quality of information sharing (i.e., information reach), the degree of exploitability of information from information receiver (i.e., information exploitability), and the degree of counter-information (i.e., information countermeasure). In each dimension, just main metrics have been listed, of course, they can be extended. On basis of metric framework, it is important to be considered performance evaluation method [13] based on information entropy. Further, the relationship between all kinds of information evaluation elements can be modeled, so as to realize a comprehensive assessment of information effectiveness.

5. CONCLUSION

Command and control is evolving to the direction of network centric, and it is more important to share information on demand mission-oriented. From the theoretical and methodological aspects, the issues of information sharing for future C2 in network centric environment have been discussed in this paper. Combined with information value chain process, the basic idea is to reduce information uncertainty and increase information exploitability through information sharing. On the basis of analyzing the complexity of information sharing, two information sharing methods were presented from systematology and technical view, respectively. One was based on the ideas of importing negative information entropy, and the other was based on Pub/Sub paradigm. The simulation results demonstrate that this method performs better information sharing performance than the existing method. Finally, a measurement framework was proposed to measure information sharing capacity for future C2.

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