01 Jan 2005

Network-Centric First Responder Architecture with Swarming Robots Entity

Lakshmanan Meyyappan

Cihan H. Dagli

Missouri University of Science and Technology, dagli@mst.edu

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LAKSHMANAN MEYYAPPAN *
PH.D. Student, Smart Engr Systems Lab
Engineering Mgmt and Systems Engr
University of Missouri Rolla
Rolla, MO 65409
E-mail: laksh@umr.edu

CIHAN H. DAGLI
Associate Chair, Systems Engineering
Engineering Mgmt and Systems Engr
University of Missouri Rolla
Rolla, MO 65409
E-mail: dagli@umr.edu

Abstract

This paper proposes a new network centric architecture that can be used by first responders to effectively respond to crisis situations. The powerful network-centric concept originally developed for and mainly used in the military environment, can be effectively used for civilian security and emergency response missions. This paper also proposes the use of a swarm of intelligent robots as a part of the network-centric architecture to aid the first responders. The swarm of robots works in tandem with the first responders and provides them with the necessary information on a real time basis. The proposed network centric architecture with a swarming robot entity is explained in detail using C4ISR framework. The proposed architecture if implemented successfully will result in solving crisis situations, may it be natural calamity or terrorist attacks, more efficiently and effectively.

Introduction

Network-centric operations (NCOs) are operations that exploit top-of-the-line information and networking technology to integrate widely dispersed human decision makers, and targeting sensors and response capabilities into a highly adaptive, comprehensive system to maximize mission effectiveness (Arquilla 1994). Use of network-centric operations improves information sharing and collaboration, which enhances the quality and assurance of shared information and situational awareness. This will result in enhanced collaboration, enables self-synchronization, improves sustainability and increases the speed of command or coordination (Alberts et al. 1995). The ultimate result is dramatically increased mission effectiveness and optimal resource utilization.

The powerful network-centric operations concept originally developed for the warfare environment, could be similarly effective for security and emergency response missions. The potential for network-centric operations to enhance civilian missions has gone largely unrealized, due in part to divergent funding sources, widely varying technical capabilities, uncoordinated and inconsistent requirements, and absence of a consolidated national operational framework.

A swarm is defined as a set of (mobile) agents which can communicate directly or indirectly (by acting on their local environment) with each other, and which collectively carry out a distributed problem solving (Beni et al. 1989). Swarm intelligence

* *To whom all correspondence should be addressed.*

is the property of systems of non intelligent robots exhibiting intelligent behavior through some kind of cooperation. The main motivation behind swarm intelligence is that small creatures exhibit complex behavior and the ability of animals exhibiting swarm intelligence to adapt to the changing environment easily (Baldassarre et al. 2003). Best example is an ant colony. Ants are behaviorally unsophisticated simple creatures but exhibit complex behavior as a team. Some of the main characteristics of swarm intelligence are:

- It is distributed, no central control
- It has no data sources
- It doesn't have an explicit model of the environment
- Ability to adapt to the environment

In this paper a new network-centric architecture with a swarming robot entity that can be used by first responders is proposed. The next section presents the associated disadvantages with the current first responder scenario and need for a new architecture. The advantages of using a swarming robot entity as a part of this architecture and pointers to research done at the Smart Engineering Systems Laboratory (SESL) at the University of Missouri Rolla (UMR) is presented in section 3. Section 4 describes the proposed network-centric architecture. Advantages and disadvantages of the proposed architecture is presented in the final section of this paper.

Motivation

First responders are the men and women who are "first on the scene" as a natural or man-made disaster unfolds. They are also the last to leave the scene. First responders are policemen, firemen, emergency medical technicians and the likes. Public Safety in its most elegant and critical implementation is the act of deploying emergency personnel and equipment to the right place at the right time with the ability to understand what has happened and how to effectively and efficiently deal with the situation. There are two absolute keys to success in first responder operations – communications and training.

First Responders generally have a very high level of training that allows them to observe and assess any emergency situation, to react properly to those assessments, and to be prepared for the unexpected. However it is the communication area that needs to be tuned a little bit more. Different first responders use different frequencies to get additional help. For example the local police generally use 800 MHz non-P25 frequency, state police use 800 MHz P25 frequency, Local firemen use VHF, US military uses UHF and state national guards use some other frequency. The use of difference communication channel causes a lot of delay in the operations of first responders especially if the situation in hand is big. A typical response force assembled in the aftermath of a major disaster in the U.S. will include local police, county sheriffs, regional firefighters, ambulance services, the United States Coast Guard, in both its military and civilian components, and, perhaps state or regional National Guard troops.

These emergency responders might typically be communicating on several different radio frequencies. All of these frequencies need to be known to the responders involved and can be transmitted over various mobile information technologies. The responders must be aware of the specific frequencies to be used during the emergency, those to avoid, and the protocol for communication within and among the groups. Taking a network-centric operations approach can keep the responders from stumbling over one another and instead maximize their potential benefit to citizens who are caught up in the ongoing crisis.

In addition to the above mentioned communication problems, in a number of cases the first responders are rendered help less as they cannot get into certain locations like small voids. Also these rescue missions endangers the lives of first responders. In the following sections we will see how swarming robots can help first responders in crisis situations and how using a network centric approach will make this operation more effective.

Swarming Robots to Aid First Responders

In case of a natural disaster like earthquake or a terrorist attack, the first responders have to search the entire sight as soon as possible to rescue possible survivors. If it is going to take more than 48 hours, the likelihood of anyone surviving is really less. Also, searching such places involves a lot of personal risk for the first responders as the place can further collapse or may be hostile and can result in the death of first responders. Finally and perhaps best addressed by the proposed work, both people and dogs are frequently too big to enter voids, limiting the search to no more than a few feet from the perimeter. In all the above situations swarm of small robots can be used effectively. The idea is not to replace all the first responders with robots, but to make the robots aid the first responders perform their duty more easily and effectively. These robots will be used to collect information from places where the first responders cannot go and provide it to the central database. The central database will access these data and pass the necessary information to the first responders. The major goals of the proposed swarming robots entity are:

- To explore GPS unfriendly locations autonomously
- To build maps of unknown locations
- Identify “item of interest”
- Detect Intruders

This system relies on a novel navigation system and autonomous routing algorithms currently being developed at the Smart Engineering Systems Laboratory (SESL) at University of Missouri Rolla. The work leverages previous research conducted at SESL in robotics, image processing and routing technologies. Some of the related projects successfully completed and implemented at SESL are summarized below:

- An intelligent path planning and scheduling algorithm for automated guided vehicles using evolutionary algorithms as documented in (Meyyappan et al. 2004)
- Cooperative cleaning of an area using distributed autonomous robots using fuzzy cognitive maps as documented in (Subramanian et al. 2003)
- Solving the predator-evader problem using evolving neural networks as documented in (Ersoy et al. 2000, Vishvanathan et al. 1999)
- Collaborative work by a group of autonomous Khepera robots in searching for a light in an unknown environment as documented in (Aedula et al. 2002)

The main activities to be conducted currently are to leverage previous research conducted at SESL, link them together and to develop swarm control software, to design distributed control and navigation algorithm and to implement them in small autonomous real world robots. The proposed swarm of robots will work in tandem with the first responders and provide them with the necessary information on a real time basis. This will greatly reduce the personal risk associated with the first responder jobs. The robots can also gather information easily from places where the first responders cannot reach.

Proposed Network-Centric Architecture with Swarming Robots Entity

The network-centric architecture proposed is a communications capability that ties together key decision makers and responders so that critical information can be shared. The proposed architecture will overcome most of the short comings discussed in the earlier sections associated with the current style of operation of first responders. It will also increase flexibility and make data collection faster with the use of swarming robots. This capability should be able to meet critical and time-sensitive bandwidth and other media demands in crises involving multi-agency and multi-site events. A simple block diagram of the various activities in the proposed architecture will look as shown in the figure 1.

In the network-centric approach proposed, there will be a central location where any of the first responder can reach and convey the situation. All first responders will be able to reach this central location using common frequency and equipment. Once a responder calls this central location, the personnel working at the central location will authenticate the first responder and then get more information using satellite features and approve the situation and pass on the information to all other first responders via broadcasting techniques. The central organization will also keep a close watch at the situation and take any additional measures required like getting help from a neighboring state and so on. Finally all information will be archived and audited. This information will be used for analysis later and in making the system more efficient in the future. Future predictions and emerging behaviors can be achieved using these data.

A high level operational concept graphical diagram of the proposed architecture is shown in figure 2. The proposed architecture is also expressed using various (not all) C4ISR views (operational and systems views) to provide a better understanding of the architecture and its functionalities in the figures below. The acronym C4ISR stands for Command, Control, Computers, Communications, Intelligence, Surveillance, and Reconnaissance (C4ISR). The C4ISR Architecture Framework Version 2.0 is a framework giving comprehensive architectural guidance for all of these related Defense and DoD domains, in order to ensure interoperable and cost effective systems. Figure 2 also serves as the operational view 1. Operational view 5 (activity model) is depicted in figure 3. Three different systems views are presented in figure 4, 5 and 6 respectively. These depict the interface and communication among the various nodes in the system.

As can be seen from these figures, as soon as any first responder reaches the crisis area, he/she can call the central organization and pass the information. The central organization will use satellite communication and photographs to authenticate and to get a better picture of the situation and based on the information it will broadcast the information and commands to either all the first responders within the city or the state or the country. Data analysis experts help in auditing the crisis and use the info for bringing about emerging behavior the next time. Swarming robots will be used only if the situation in hand is big. Hence the swarming robots are used only if the statewide or nationwide first responders are involved in the process.

Advantages and Disadvantages

The proposed architecture has a number of advantages over the currently used system. The proposed architecture if implemented successfully will result in solving crisis situations, may it be natural calamity or terrorist attacks, more efficiently. The proposed architecture is also flexible. The use of a network centric approach will result in faster resolving of crisis situations by making

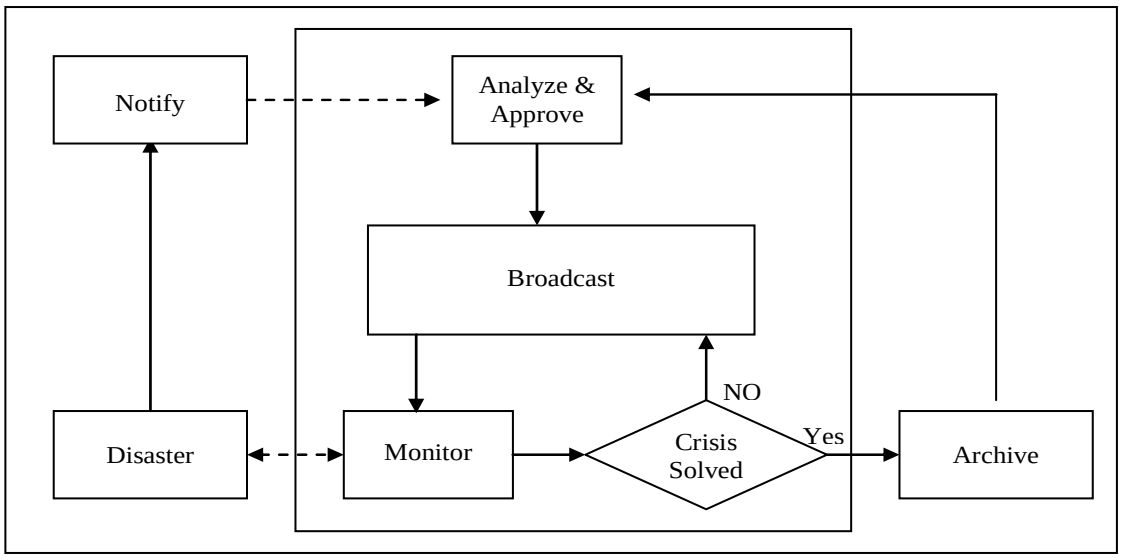

Figure 1. Block Diagram

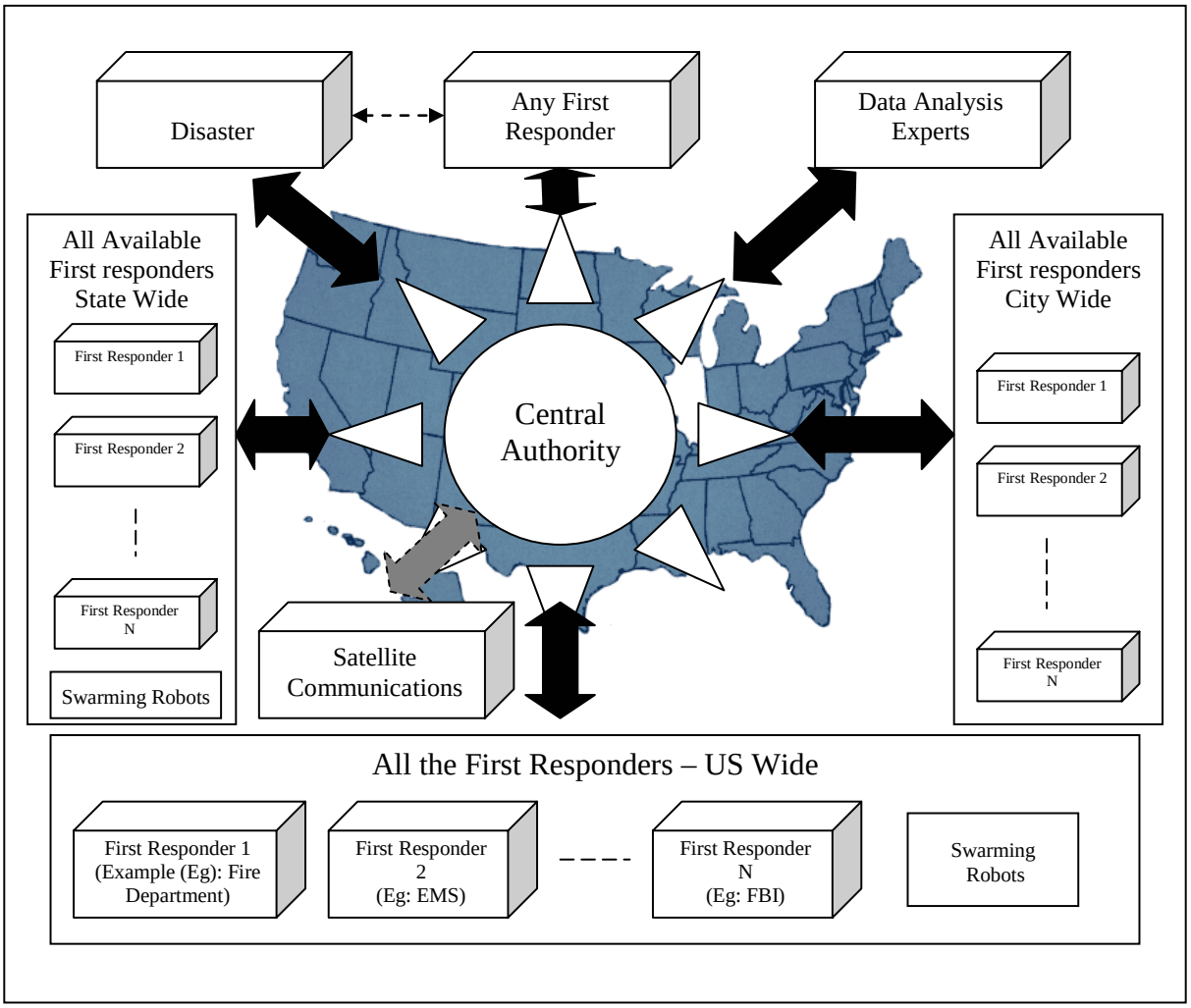

Figure 2. OV1 Architecture – High Level Operational Concept Graphical Diagram

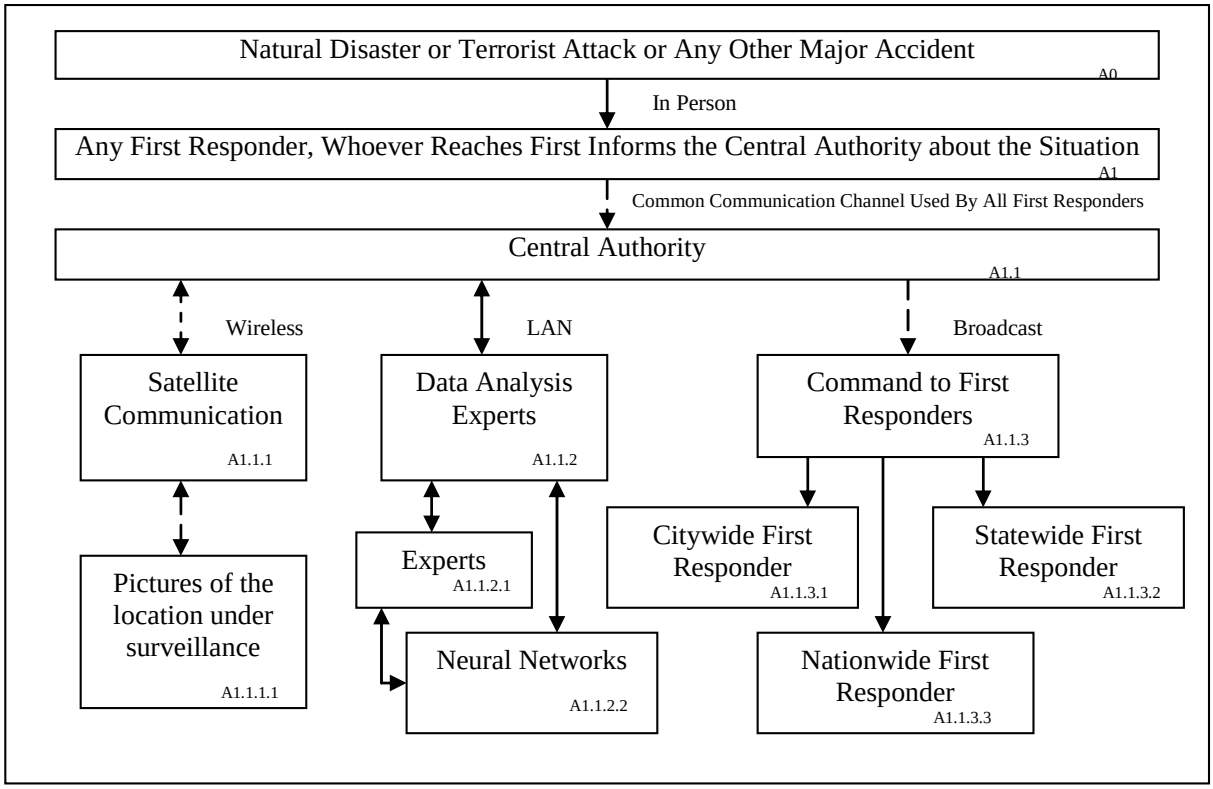

Figure 3. OV5 Architecture – Activity Model

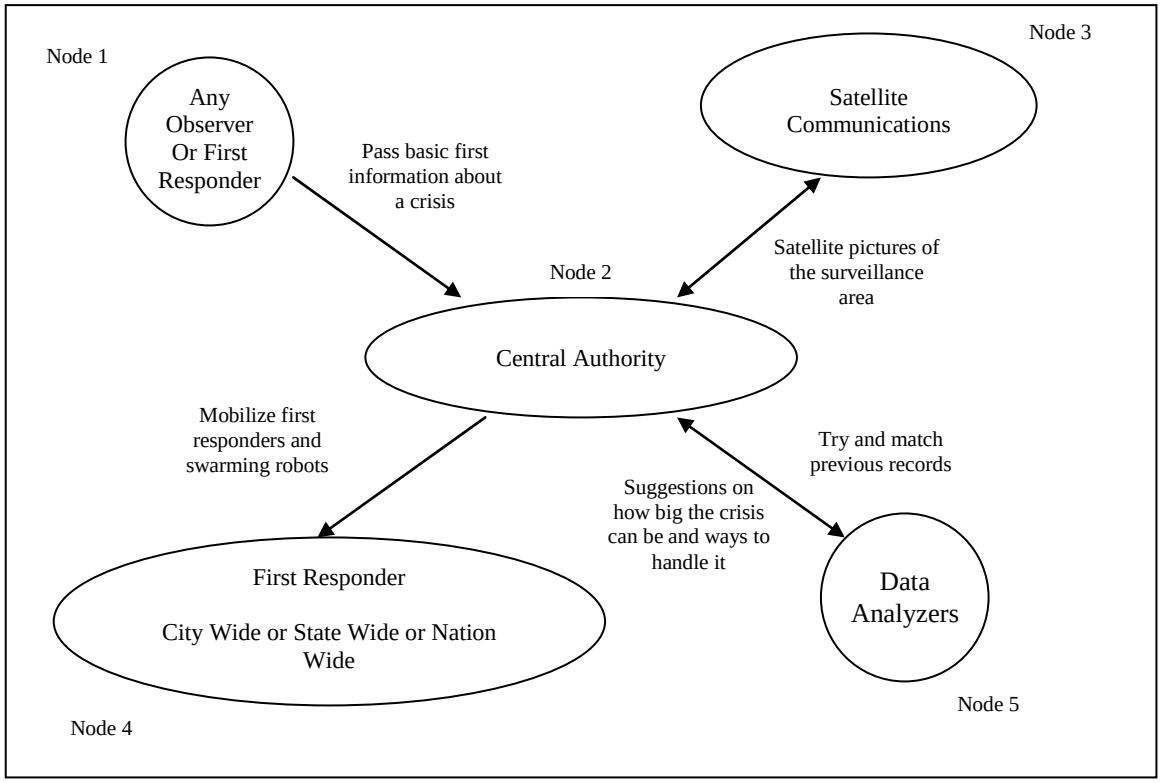

Figure 4. SV1 Architecture – System Interface Description

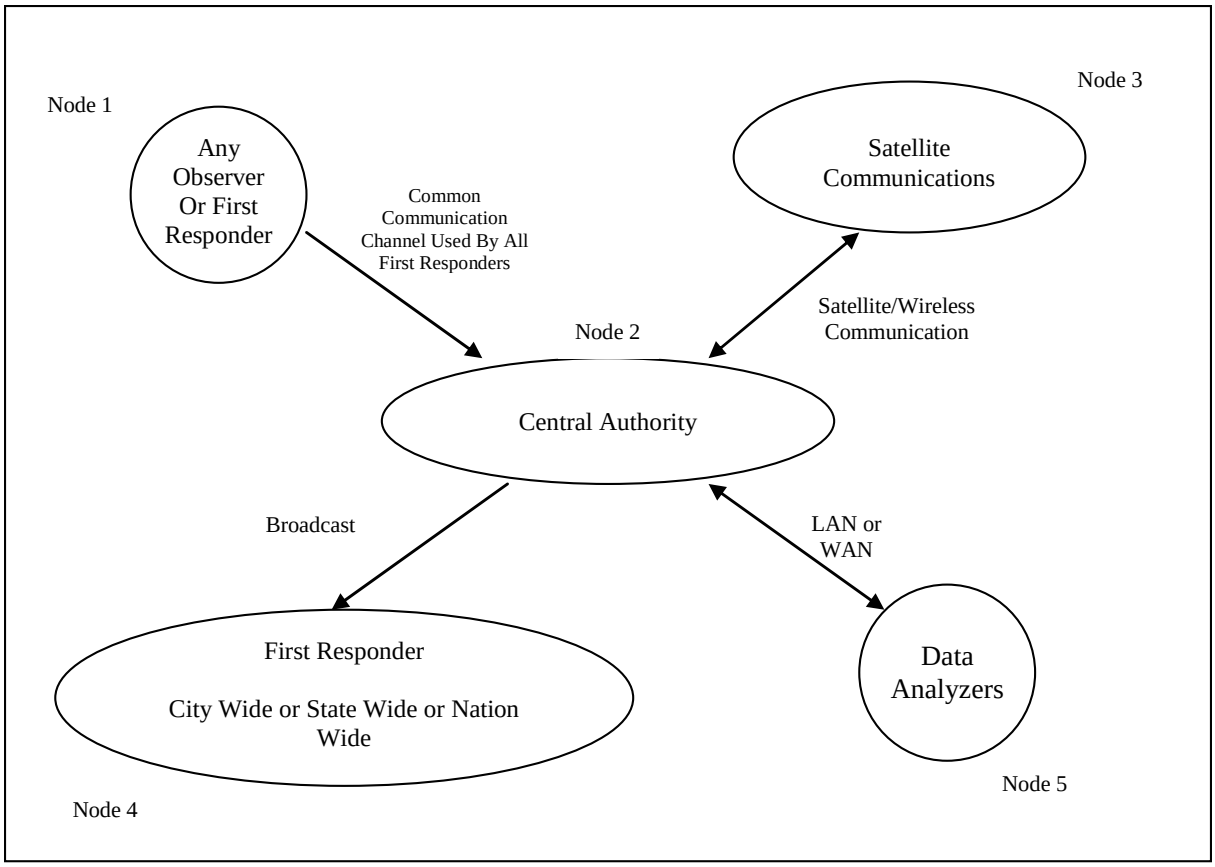

Figure 5. SV2 Architecture – Systems Communications Description

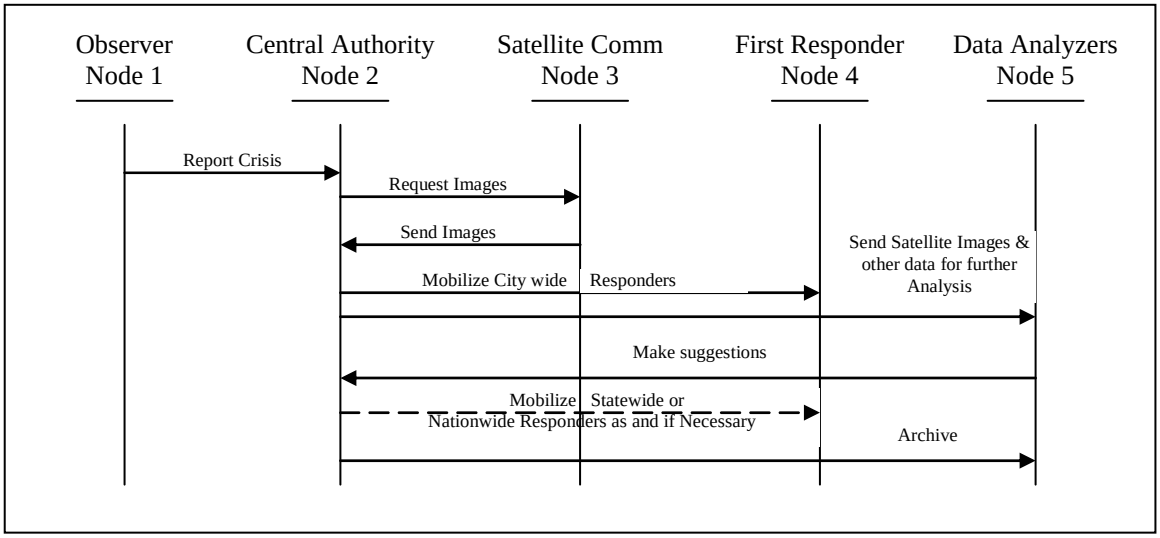

Figure 6. SV10C Architecture – System Event/Trace Description (Sequence Diagrams)

a good use of available data. This will result in enhanced collaboration, enables self-synchronization, improves sustainability and increases the speed of command or coordination. The ultimate result is dramatically increased mission effectiveness and optimal resource utilization. The swarming robots can aid the first responders in many ways. This can greatly reduce the personal risk associated with the first responder jobs. The robots can also gather information easily from places where the first responders cannot reach. The cost associated with the use of swarm of robots is also comparatively cheaper. Also using a swarm of robots gives more flexibility and robustness, and is highly scalable.

The system also has a few disadvantages associated with it. The cost of implementing such a network-centric system will be slightly high in the initial years. This will also result in difference of opinion among a number of people from different organizations like the fire fighting teams, health service teams, and local police and so on. The bandwidth required for transmitting and broadcasting data to all first responders through a common channel may be very high and can be very expensive. The security of the entire system is bleak right now and has to be shaped carefully. The data analyzers, especially the neural networks or other artificial intelligence tools need to be trained properly for some time before they make any proper suggestions. Memory and power limitations will curtail the extensive use of robots to a great extent. At least to begin with the first responders may not like the idea of searching along with a group or robots.

Conclusion

In this paper a new network-centric architecture that can be used by first responders during crisis situations is proposed. The paper also proposes a swarming robot entity as a part of the network-centric architecture. Pointers to various researches conducted at SESL in the field of swarming robots, collaborative work, path planning algorithms, and image processing and navigation techniques are also provided. Network-centric operations rely on information-centric strategy in which the clients are separated from the information and both are posted in a central location. This provides the needed flexibility for the systems-of-systems approach to see, understand and act on the situation. The proposed architecture has a lot of advantages and some potential disadvantages. In spite of the potential disadvantages, such a system is very essential in the near future if various crisis need to be solved quickly and effectively.

References

Aedula, V. and Dagli, C.H., “Collective Behavior in Robots Using Evolutionary Algorithms.” In the Proceedings of 2nd International Symposium on AMIRE, 2003

Alberts, D.S. and Haynes, R. E. "The Realm of Information Dominance: Beyond Information War." First International Symposium on Command and Control Research and Technology, 1995

Arquilla, J. "The Strategic Implications of Information Dominance." Strategic Review, 1994

Baldassarre, G., Nolfi, S. and Parisi, D., “Evolving Mobile Robots Able to Display Collective Behavior.” Artificial Life, 2003.

Beni, G. and Wang, J., “Swarm intelligence.” In the Proceedings of the Seventh Annual Meeting of the Robotics Society of Japan, 1989

Bonabeau, E., Dorigo, M., Theraulaz, G., *Swarm Intelligence: From Natural to Artificial Systems*. Oxford University Press, New York, 1999.

DoD Document C4ISR Architecture Framework Version 2.0

Ersoy, I. and Dagli, C.H., 'Evolving Subtasks in Predator-Evader Problem.' In the Proceedings of ANNIE, 2000

Kennedy, J., Eberhart, R., Shi, Y., *Swarm Intelligence*. Morgan Kaufmann, 2001.

Meyyappan, L., Buyurgan, N., Dagli, C.H, Saygin, C., "Intelligent Path Planning and Scheduling for Automated Guided Vehicles using Evolutionary Algorithms." In the Proceedings of ANNIE, 2004

Subramanian, H and Dagli, C.H., "Cooperative Cleaning for Distributed Autonomous Robot Systems Using Fuzzy Cognitive Maps." In the Proceedings of 22nd International Conference of the North American Fuzzy Information Processing Society, 2003

Viswanathan, S., Ersoy, I., Bunyak, F., Dagli, C.H., "Evolving Neural Networks Applied to Predator-Evader Problem", In the Proceedings of International Joint Conference on Neural Networks, 1999

Biography

Lakshmanan Meyyappan received the Master of Science degree in Computer Engineering from the University of Missouri Rolla (UMR) and is currently pursuing his PH. D in Engineering Management and Systems Engineering at the UMR. His research interests are in the field of evolutionary robotics, swarm intelligence and network-centric systems.

Cihan H. Dagli is a Professor of Engineering Management and Systems Engineering at UMR. He is the associate chair of Systems Engineering Department and director of the Smart Engineering Systems Lab (SESL) at the UMR. He received B.S. and M.S. degrees in Industrial Engineering from the Middle East Technical University and a Ph.D. from the School of Manufacturing and Mechanical Engineering at the University of Birmingham, United Kingdom. His research interests are in the areas of smart engineering systems design through the use of artificial neural networks, fuzzy logic, and evolutionary programming and network-centric systems.