Topology based Infrastructure for Crisis Situations

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ABSTRACT

Recent terrorist attacks and natural disasters have forced humanity to respond to crisis situations effectively as possible. In these situations especially the first hours rescue workers cannot always rely on existing communication infrastructure. Knowledge about the situation is to be gathered to obtain an aggregate world model of the situation. Decisions can be taken based on this world model. The solution we propose consists of using a Mobile Ad-Hoc Network (MANET), in which the nodes are organized in a topology in order to facilitate the necessary functionalities. Communication between the nodes takes place via a distributed blackboard structure. This architecture supports services developed with the purpose of assisting rescue workers. The agents (humans/sensors) in the network provide data as input to the network. Our approach takes care of processing of this input data to provide users with appropriate information and to obtain a shared world model. As a proof of concept we implemented a prototype of our approach on a number of mobile devices and tested the idea in real life.

Keywords

Mobile ad-hoc networks, communication, crisis situations, dynamic role assignment, fittest node, context awareness, situation awareness.

INTRODUCTION

Recent terrorist attacks and natural disasters have forced humanity to respond to crisis situations effectively as possible. After the event of a crisis, rescue workers have to be able to do their work in a dynamic and dangerous environment, with all means available. In these situations it has turned out that the communication between rescue workers on a local and global level is problematic. This has become even clearer with the recent release of communication messages that were exchanged between the rescue workers at the attacks on the Twin Towers on September 11th 2001.

Especially the first hours after a disaster can be of vital interest to the victims and an efficient and well thought out approach can greatly reduce the number of victims. Beside the actual rescue worker has the task of helping victims and reporting about the situation, another challenge is to collect all the knowledge that is available, to get an overview of the situation. This knowledge is distributed in the network and to get control over the situation, this knowledge is to be collected and aggregated in a shared world model.

In case of a crisis we can not always rely on the existing infrastructure. The existing communication infrastructure can be overloaded or can, in case of terrorism or large natural disasters, (deliberately) be destroyed. GSM networks can fail or the power can break down in a crisis area, which makes the wired infrastructure useless. A possible solution is to use ad-hoc networks of mobile devices, but these have such problems as limited antenna range, low bandwidth, limited battery power and less CPU power than “normal” computers. In ad-hoc networks the connection between nodes can be disabled or enabled in a dynamic way. Nodes have or have no access to other nodes and data resources. Many approaches refer to crisis situations as the standard example of the use of MANETs (Quarantelli 1999). Our approach will attempt to realize this idea, by giving a design of a system, to support solutions in the form of future applications / services for rescue workers. The overall problem can be defined as the lack of a reliable communication infrastructure and the fact that the knowledge and software systems to process data, is distributed in the crisis area. Part of this knowledge is to be stored somewhere in the network but also be available at different places in the network. To duplicate all the knowledge and data at every node is not an option due to limited bandwidth and storage capacity. The communication between the nodes takes place via distributed blackboard systems. Blackboards have been used for many years in the area of Artificial Intelligence. The challenge in ad-hoc networks is how to distribute the data with a minimum of message passing and duplication and redundancy of data and how to handle inconsistency of data between the nodes caused by the dynamic character of those networks.

We propose a MANET network, in which the nodes are organised in a topology in order to facilitate the necessary functionalities. In the stable part of the network data is stored and processed. The ad-hoc part of network takes care of data gathering. A certain amount of redundancy in the data gathering process guarantees that relevant information will not be lost by the dynamic, ad-hoc character of the network.

This paper is structured as follows: in the section “Related work” similar projects are presented. In the section “Model” the design of our approach is explained. The prototype that has been built is explained in the section “Implementation”. The section “Experiments & results” discusses the experiments that were carried out with the prototype. The final section contains the conclusions.

RELATED WORK

More research on crisis situations is done in the RESCUE project (Mehrotra, Butts, Kalashnikov, Venkatasubramanian, Rao, Chockalingam, Eguchi, Adams and Huyck 2004), which also focuses on responding to crisis situations. The RESCUE project puts more emphasis on transforming “*the ability of responding organizations to gather, manage, use, and disseminate information within emergency response networks and to the general public*”. The test bed within this project is called CAMAS (Mehrotra, Butts, Kalashnikov, Venkatasubramanian, Altintas, Hariharan, Lee, Ma, Myers, Wickramasuriya, Eguchi and Huyck 2004). A difference between this approach and our approach is that the reporting in our system is based on icons, which is language independent. In CAMAS natural language processing is used.

Part of our research activities are realised within the framework of the COMBINED project of the DECIS Lab (http://combined.decis.nl/; Tatomir and Rothkrantz 2005). This project has a focus on assisting rescue workers by coming up “*...with new concepts and systems that will be used by the crisis response organization of the future*”. In the COMBINED system Cougaar (http://www.cougaar.org/) has been used as software architecture. Cougaar provides a distributed agent system and a distributed blackboard system. Agents communicate with each other via an asynchronous, built-in message passing system. The blackboard system we used in the current project provides even more flexibility in distribution of data and processing systems with emergent structures.

More work is also being done in other projects around the world, as can be concluded from the recent ISCRAM conference 2005 (International Community on information systems for crisis response and crisis management). On this conference work was discussed on knowledge engineering and management aspects in crisis situations. This aspect, although on a somewhat lower and practical level, will return in our approach. Another conference about crisis situations was recently held in Las Vegas, the 11th International conference on Human Computer interaction (2005). One of the approaches discussed there is the PIRA model (Rothkrantz, Datcu, Fitrianie and Tatomir 2005). This approach assumes that there is some form of a fixed/wired infrastructure available at a crisis. Our approach drops this requirement and can therefore be seen as the next step in efficient disaster recovery.

Furthermore E.L. Quarantelli, from the University of Delaware, presented an overview of 50 years of research in the crisis domain in (Quarantelli 1999). In this work four important phases are discussed: the mitigation, preparedness, response and recovery. Our approach mainly concerns the third phase, i.e. the response phase. More work concerning blackboards can be found in (Picco, Murphy and Roman 1999). Another approach that uses the idea of blackboards for communication can be found in (Brown, MacColl, Bell, Chalmers and Greenhalgh 2005). The authors point out that the discussion of these kinds of systems often remains limited to the design of effective communication and the concept of blackboards is not seen in the broader context of an infrastructure. The latter observation will be discussed in our approach. The idea of the approach in (Brown et al. 2005) is to support multiple users collaborating around certain places and exchanging information. The purpose is to share information related to a specific place. For this reason location information is used based on GPS or user input, we drop this requirement.

THE RESCUE SERVICES

To handle the communication problem and the problem of distributed knowledge in crisis situations, we propose offering services to the rescue workers integrated into one system using an architecture based on an ad-hoc network of mobile devices. Besides the services and the architecture, we also incorporate intelligent processing of data. This is necessary to prevent an information overflow at the local crisis centres that are part of the standard procedure of rescue workers (Rothkrantz, Tatomir and Porzio 2003). Furthermore, this is necessary to provide the right people with the appropriate information to execute their tasks. The services we have developed are to be offered to rescue workers on their handheld devices. The main functionalities that are necessary in crisis situations are reporting about the situation.

ISME

For reporting about the situation, we have developed two applications based on icon-communication. This natural interaction style is based on a graphical user interface. This style of interaction is language independent, which makes it suitable for crisis situations. One of the developed applications, the Icon-based System for Managing Emergencies (ISME), provides the user with icons that can be put on the map of the environment, for example, if an observer observes a building that is on fire (Figure 1). This application is based on the idea that some people describe their observations by sketching ideas on a piece of paper (Rothkrantz et al. 2005). To provide extra information, an icon has some attributes. The icon for a "fire", for example, has the attributes status, size and intensity (e.g. under control, big, high). We defined scenarios for different types of disasters such as building on fire, traffic accident, bomb and gas explosion. For every scenario we defined a world model with characteristic objects (represented by icons) and relations between objects. An observer selects a scenario and is able to report about the crisis using the pre-defined set of icons. In this way we reduce the ambiguity of reports using natural language, where users are allowed to use their own language and their own concepts. The information from this reporting tool is collected and based on expert system rules an overview of the situation is provided. In case a user reports only about fire the system will ask the user if there was no smoke. The system will check the reports for correctness, completeness and consistency.

Observers are supposed to be remote in time and location and have a subjective view of the world. The incoming data from multiple ISME clients is collected and this data is fused. Furthermore, based on the fused data, possible scenarios are determined, again based on expert system rules. The most probable scenario is selected by the system and again the system will verify the reports for correctness, completeness and consistency. In case the data is ambiguous or incomplete, the system will ask the user for additional information. This application enables the use of different profiles for different rescue workers, e.g. to provide e.g. firemen with detailed icons for their tasks.

Figure 1. The ISME application on a PDA

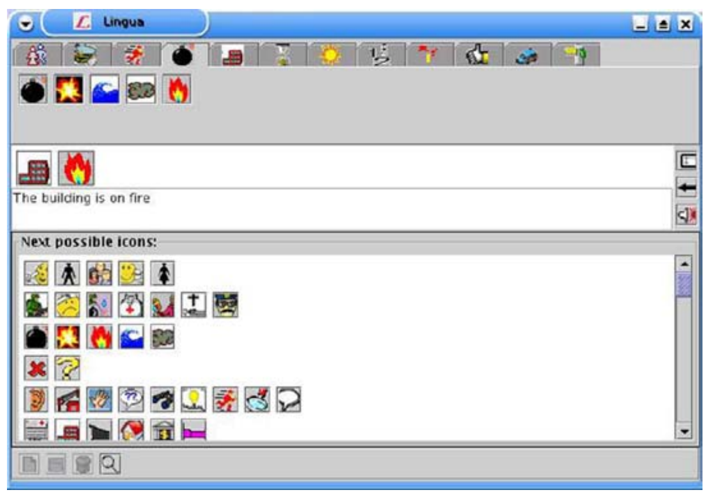

Figure 2. The GUI of Lingua

Lingua

Another icon based application that was developed, Lingua, allows the user to form sentences with icons (Figure 2) (Fitrianie and Rothkrantz 2005). The application includes a grammar that is used to make sentences from the icons that are given as input by the user. Our prototype currently only provides translation to English text messages, but any language is possible. The translation is based on some grammar rules structured as a Backus-Naur-Form and English grammar. The input is checked using the grammars and if correct, seven slots are created, prefix (for question words), subject, infix (for an infinite passive, an auxiliary and a negation), verb, object, preposition, and suffix slot (for e.g. question mark). The sentences are then completed using extra rules, for converting the iconic sentence into natural language based on the semantic context. Based on the history of added icons and based on Bayes rule the probability of an icon string is estimated (Rothkrantz et al. 2005):

$$P(s) = P(w_1, w_2, ..., w_{i-1}) = \prod_{i=1}^{\infty} P(w_i \mid w_1, \ ... \ , w_{i-1}) = \prod_{i=1}^{n} P(w_i \mid h_i)$$

in which h_i is the history of icons, when predicting icon w_i. This is a n-gram word prediction model. Predictions of icons enable the user to interact faster with the system. In this way this application allows for fast language independent input that is suitable for communication. Messages can then be sent to other nodes in the ad-hoc network, where the information is processed. On request sentences can be transformed to synthesised speech.

MODEL

The architecture that supports the communication between the different nodes in the network consists of a Mobile Ad-hoc Network (MANET) that uses communication via the blackboard paradigm. We introduce a structure in the topology of a Mobile Ad-hoc Network (MANET) that is most applicable to a crisis situation, consisting of three layers, which will be explained below.

The reason for choosing a MANET is that this approach does not rely on any form of an underlying infrastructure that might be partially or completely destroyed at a crisis. The assumption is that the communication infrastructure is down and that the rescue workers only have their PDAs to communicate. Furthermore, an approach that is completely centralized is not desirable, since a central point in the network is also a central point of failure. Besides in a central system, we cannot guarantee optimal communication due to the fact that the nodes in the system are sometimes/usually not connected to the rest of the network. We use a hybrid approach consisting of a network that is partially centralized and partially distributed.

Introducing a topology

Our approach for providing a communication infrastructure consists of introducing mobile crisis centres as a stable part in the MANET. This approach has become a standard procedure for rescue workers. Around these mobile crisis centres rings of nodes take care of the processing of data from the outer ring that consists of sensor nodes. The layered model is shown in Figure 3.

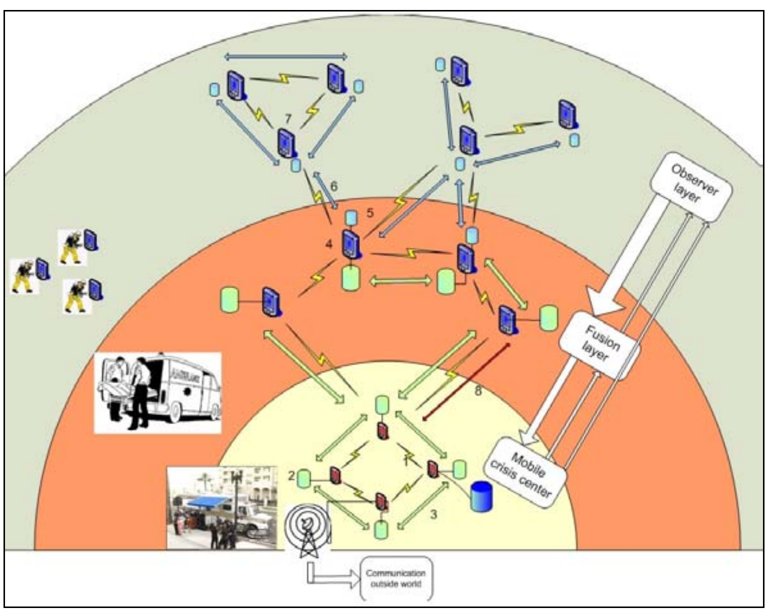

Figure 3. The layered model

The three layers consist of:

- Observer nodes
- Pre-processing nodes
- Mobile crisis centre nodes

The upper layer of sensor nodes of the network concerns the outer part of the network. These are the field workers that are doing the actual rescue work in buildings, tunnels etc. They are the observers that should report about the crisis situation. This layer of the network contains human observers and sensors (e.g. for gas and smoke detection). Another way to report about the situation is by using a camera for giving detailed information about the situation.

Eventually, all sensor information is to be sent to the mobile crisis centre. In this stable part of the network, people locally in charge can get an overview of the situation and manage the situation. From the overview information the people in this local crisis centre should be able to define more/new actions for the rescue workers that can be sent into the network again to be delivered to the rescue workers. The nodes in this part of the network take care of the storage of the (important) data in the network and process the information that comes in from the sensor part of the network, which can then be used to update the global world model.

The third layer, the middle layer, that we discern, involves the part of the network that is somewhat stable, although nodes are assumed to disappear more often than the nodes in the mobile crisis centre, but less often as in the case of the outer ring of the network that is assumed to be highly dynamic. The function of this layer is to pre-process the data that comes in from the observer nodes. This data can come from multiple sources and can be pre-processed as indicated in the previous section. Furthermore, the nodes in the middle ring also take care of the "messaging" task. Since wireless connections only have limited range, the distances between the nodes may not be too large. The middle ring also provides for the necessary connectivity.

The knowledge flow

Now that the global idea is explained, the knowledge flow in the network can be illustrated in more detail, based on the three layers as indicated in Figure 4.

The outer layer, layer A, consisting of the sensor nodes provides the world models of these nodes. These world models have to be translated by using concepts and relations. These should be limited, since computers cannot reason with as many and as complex concepts as humans can. Therefore, the world model has to be translated with a number of concepts and relations, which is done by the applications (Lingua and ISME).

In the next layer, layer B, the pre-processing or fusion of data takes place. This layer has nodes that try to solve conflicts in the different input that is received from different agents in the outer layer as described above, to come to the most probable (local) world model. This should be done somewhat close to the outer layer, since these nodes have information about the local situation. The nodes in the crisis centre usually do not have a good idea what is happening in the outer part of the network, since it can be too far away.

In the crisis centre (layer C) data is received and further processed to come to an aggregated world model. This world model should be the "best estimate" of the world, i.e. the (whole) crisis situation. Furthermore, this layer is to store the data that comes in from the outer part of the network. The data that is to be collected in the crisis centre, is stored distributed over the nodes. Each node has its own part of the blackboard and data can be stored there. The nodes also have background knowledge to process data and provide additional information to nodes from the other layers. The information is stored for later re-use (e.g. information about a dynamic floor plan can be used for escape routing). Furthermore, the mobile crisis centre should answer requests from the observer layer (e.g. provide information about the world model).

Besides gathering information, the mobile crisis centre also has the task of communicating with the outside world, e.g. to inform overall leaders and the media.

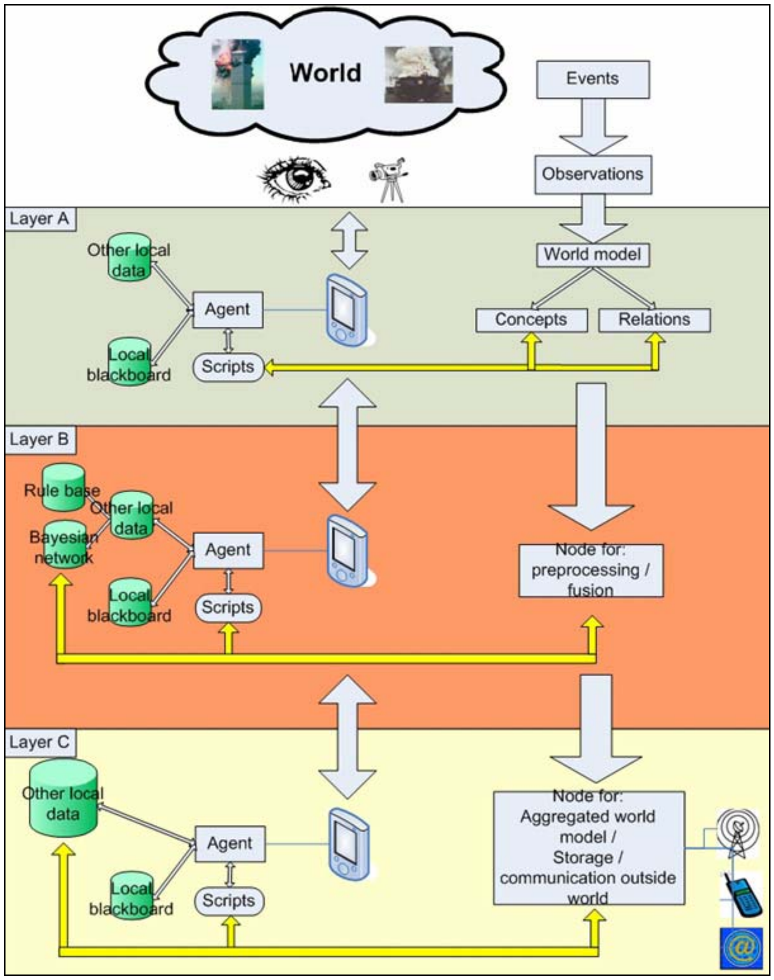

Figure 4. The knowledge flow in the system

Besides providing a communication infrastructure for crisis networks, our architecture will also concern the assignment of tasks within the network. Some tasks are specifically requested by the user, and should thus be executed on the node under consideration. However, some tasks, including some tasks for keeping the services in the network "up", can be executed at different places. This assignment of tasks to nodes will therefore also be taken into account in the system. This will be done with the model discussed above in mind. Eventually the idea is that the data that is generated by the users (via the services) will be safely get to the location where it is requested.

Communication

For the communication in the network, the choice was made for a distributed blackboard approach, since it facilitates the sending, reading and processing of messages independent of time and place. Furthermore, this data-driven approach is considered to be effective when there is no strong coupling between the producers of information and the consumers of this information in a network (Miletic 2005).

The blackboard is organized in a hierarchy, since this approach fits the structure that is brought into the topology. In our approach, the nodes in the outer layer have the task of putting their messages on the local blackboards. These are indicated in blue in Figure 5. The task of the middle layer is to get messages from these blackboards in the outer layer. These messages can then be pre-processed / fused. This is done using a time frame. Messages can then be discarded or kept for later use in case reasoning in time is to be supported. The nodes in the middle layer can then put the result of pre-processing / fusing the data on the blackboard that is specifically meant for the inner layer (indicated in red). This hierarchy is expected to prevent overloading of the distributed blackboard structure.

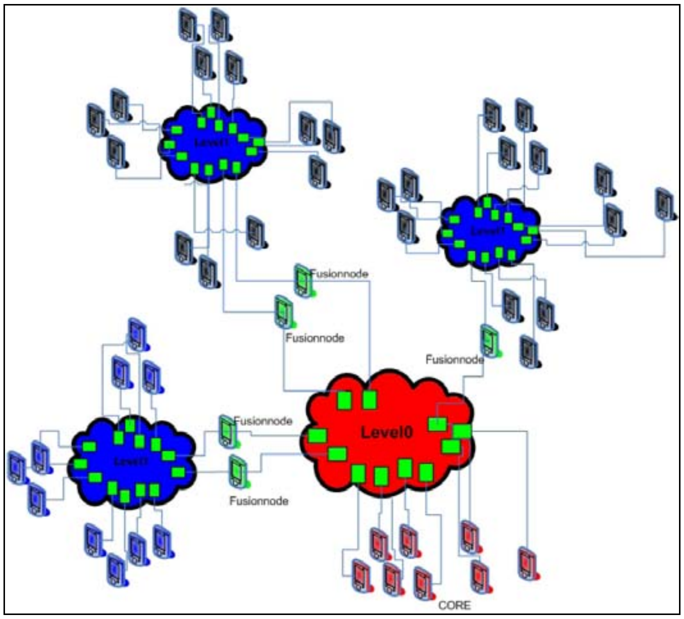

Figure 5. An ad-hoc network of PDAs using a hierarchy of blackboards

IMPLEMENTATION

A prototype of the basic infrastructure has been developed for a real MANET, i.e. not for a simulation. The MANET consists of a number of Sharp Zaurus PDAs, the types SL-C760 and SL-C680. These PDAs communicate using Wifi cards (Linksys WCF 12 IEEE 802.11b cards). The operating system running on the PDAs is Linux with kernel 2.4.18. These PDAs are running Java version 1.3.1, which is used for the implementation. No higher version of Java was available for the ARM-architecture at development time. For the underlying distributed blackboard structure, a pre-release of a new version of Lime is used (Picco 1999; http://lime.sourceforge.net/). This software was, together with the rescue service applications, ported to Java 1.3.1. For this system to run, the routing algorithm has to support both unicast and multicast. The latter was a restriction for finding a suitable multihop routing algorithm.

Concerning the performance measurements on the nodes, some platform specific commands were necessary. Using the Java Native Interface, it was possible to get information about individual processes and to get an overview of the total memory usage, storage usage, CPU power usage and battery power.

The functionalities in the system were developed as separate as possible, so that it was possible to test the individual roles and applications in the network. All testing during the development was not only done locally, but also using a number of Zaurus devices. The used test programs consisted of the icon applications, ISME and Lingua. The former is, as already indicated equipped with a reasoning engine that uses expert system rules. This expert system consists of a Jess rule base (http://herzberg.ca.sandia.gov/jess/), for which the rules are read from XML files. This structure allows for defining profiles for different types of rescue workers. The profiles that can be stored in XML files can be dynamically provided to the application.

The reasoning engine is the part of the application that is monitored and for which a history of fused information is kept. The reasoning engine that is responsible for the aggregate world model is considered a crisis center task. Pre-processing of the information (primarily filtering of duplicate messages) is done in the middle ring.

EXPERIMENTS & RESULTS

Experiments were carried out indoors by walking around with the Sharp Zaurus PDAs. During the experiments different test scenarios were tested. The primary target was to test the communication between the Zaurus devices and to see whether it is possible to introduce a topology to let an optimal communication infrastructure emerge in the crisis network. Furthermore, the target was to test the blackboard communication in a multihop network. To come to good test results, it was also necessary to do experiments with the underlying multihop routing algorithm, the AODV algorithm (with multicast extension).

The performance of the communication was primarily tested indoors. Because of the problem of reflections and objects blocking the wireless signal, the performance of the routing was not as good as usually can be concluded from simulations. This was a verification of facts from literature. Furthermore, simulations are usually simplified models of the real world and therefore, the indoor performance is difficult to measure using simulations (Cavilla, Baron, Hart, Litty and de Lara 2004). Another verification of previous experiments was that the "HELLO" messages sometimes travel further than messages related to actual connections. For this reason, pinging a node did not always mean that a connection could be established.

The experiments showed that the communication was not always as reliable as desired. Especially the delays due to the on-demand character of the routing algorithm turned out to lead to problems when reading from the blackboard. For this reason (and because of limited processing capabilities of the Zaurus PDAs) some timing parameters needed to be adjusted to make the communication more reliable. This did degrade the speed of the overall system.

The result of bringing a structure into the network was positive. The fusion of input data from the rescue services, which took place in the middle layer, prevented overloading of the nodes in the mobile crisis centre, which consisted, in our experiments, from a number of PDAs with a fixed position. The other PDAs were carried around by humans that were sending messages using the ISME application. Messages were successfully pre-processed in the middle layer and an aggregate world model was stored in the crisis centre. Shutting down of random nodes was, as expected not always a problem, since the monitoring mechanism made the network more fault tolerant. Due to the combination of monitoring and replication, most of the knowledge in the network was safely stored and did not get lost. Simulations are necessary to determine the improvement of the fault tolerance in more detail.

With respect to the icon-based reporting tools, user experiments were performed, to see whether humans are capable of describing situations with strings of icons. It turned out that they were indeed capable of expressing the concepts and ideas in their mind. Furthermore, the experiments also addressed the usability of the user interface. Some users had problems finding the right icon for the concept in their mind. This was in some cases due to the fact that they did not recognize some of the icons on the user interface. In other cases there were difficulties in translating the concept in mind to an icon. The latter problem was due to the limited number of icons that was provided. This slowed down the interaction.

CONCLUSIONS

The primary conclusion that can be drawn is that the use of MANETs for crisis response can be considered as a serious future possibility. It is possible to build a wireless communication infrastructure for crisis situations based on blackboard communication. Despite some performance problems, our approach can be considered as a step towards a communication and coordination infrastructure that could be used in future systems for crisis situations. Already some tools are available that can assist rescue workers, such as our ISME application and the escape routing application. Hopefully this work motivates the development of new, sophisticated, task oriented services for the different rescue workers to come to a better response to crises.

Although the performance was depending on the underlying routing algorithm, the hierarchic blackboard structure in combination with the structure that was brought into the topology gave a reasonable performance in our experiments. The role assignment based on the topological information and the fittest node indeed brought the desired structure in the network. In combination with the monitoring and services for storing replicas, the whole infrastructure was reasonably reliable.

The user tests of the rescue services showed that users were indeed capable of reporting about situations. The experiments showed that user profiles are to be further developed to give different users the best possible list of icons to choose from. This can speed up the reporting and at the same time improve the quality of the reports. More experiments in real crisis situations and simulation are necessary to determine the performance of the total approach in real life.

We also concluded that more practical work is necessary to come to more stable routing algorithms for MANETs. Especially the problem of reflections can seriously hamper communication. The use of "HELLO" messages in the routing algorithm for neighbour detection also turned out to be working better in simulations than in practice. The need for these practical experiences is also clear from other initiatives concerning practical experiences with multihop routing (http://wiki.whatthehack.org/index.php/OLSR Experiences Notes).

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