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Topology based Infrastructure for Medical Emergency Coordination

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***Abstract*— Recent terrorist attacks and natural disasters have forced humanity to respond to crisis situations as effectively as possible. In these situations, especially the first hours, the number of injured people exceeds the capability of a treatment facility and rescue workers cannot always rely on the existing communication infrastructure. This paper presents a coordination strategy for scheduling doctors to casualties in a crisis area, which uses an algorithm inspired by behaviour of ants in nature. Taking care of the distribution of victims in the field and their priority corresponding to the severity of the injuries, the proposed strategy optimizes the maximum number of lives saved. The necessary data is collected using electronic triage tags wireless connected in a Mobile Ad-Hoc Network (MANET). In order to facilitate the necessary functionalities the nodes are organized in a special topology and the communication between them takes place via a distributed blackboard structure.**

***Index Terms*— Mobile ad-hoc networks, distributed blackboards, situation awareness, emergency situations, coordination strategy, ant colony optimization.**

1. Introduction

MASS casualty incidents present a significant challenge to first responders. Rescuers, field medical personnel, and regional emergency departments and hospitals must often provide care to large numbers of casualties in a setting of limited resources, inadequate communication, misinformation, damaged infrastructure, and great personal risk. Emergency care providers and incident managers attempt to procure and coordinate resources and personnel, often with inaccurate data regarding the true nature of the incident, needs, and ongoing response. In this chaotic environment, new technologies in communications, computer miniaturization, and advanced smart devices have the potential to vastly improve the emergency medical response to such mass-casualty incident disasters [10].

The great challenge for disaster response is communication and information management. Effective response requires a moment-to-moment situational analysis and real-time information to assess needs and available resources that can change suddenly and unexpectedly. Accurate, real-time data acquisition regarding patient needs, rescue personnel, and resources available is critical to overall coordination.

Many approaches refer to crisis situations as the standard example of the use of MANETs (Mobile Ad-Hoc NETworks) [22]. In [16] presented this year at the ISCRAM conference, we introduced our approach which attempts to realize this idea, by giving a design of a system, to support solutions in the form of future applications / services for rescue workers. It uses embedded devices that efficiently monitor the physiological characteristics of the patients and track them through a fault tolerant communication infrastructure. The communication between the nodes takes place via a distributed blackboard systems. 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.

In a mass casualty incident, the number of injured people usually exceeds the capability of a treatment facility. Especially the first hours after a disaster can be of vital interest to the victims and an efficient coordination and well thought out approach can greatly reduce the number of victims [27]. Rescue workers entering the field are faced with the problem to provide help in an optimal way. They don't want to waste time helping less injured victims while other victims are dying because of deprivation of medical help. It is critical that patients are correctly diagnosed, monitored, and located to ensure the preservation of the maximum number of patients. For a triage system to be effective, it distributes limited medical resources in a manner that optimizes the maximum number of lives saved.

In this paper we extend the system presented in [16] with a rescue service meant to provide an optimal allocation of the medics to the victims in the crisis area. It uses a bio-inspired coordination mechanism which imitates the pheromone trail-laying behavior of ants when they are searching for food [11]. It takes care of the distribution of victims in the field and their priority corresponding to the severity of the injuries. We improved the Ant Based Control (ABC) algorithm for coordination described in [26] and included the possibility that one medic can quit an already assigned task and move to another casualty. We created more realistic testing scenarios by using the 'Manhattan geometry' (where medics are confined to make only the movement north-south and east-west) instead of the Euclidian geometry. The performance of the stochastic ABC algorithm was tested and compared with a deterministic Branch and Bound method.

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The paper has the following structure: in the section ”Related work” similar projects are presented. Then we give an overview of the topology of the proposed infrastructure. A stigmergy-based strategy for coordination, inspired by coordination mechanisms found in communities of social insects, is presented in ”The Rescue Services” section. The section ”Experiments and results” describes the experiments that were carried out in both real and simulation environment. The final section contains the conclusions of our work.

2. RELATED WORK

Immediately after the onset of a disaster there are calls for medical help. A common procedure is that emergency persons enter the field to localize the victims. They use a simple method, called triage, of quickly identifying victims who have immediately life-threatening injuries and who have the best chance of surviving. There are several triage algorithms applied in different parts of the world. A comparison between such algorithms can be found in [13].

In this paper we base our assumptions on the START system [6]. The triage portion of START, relies on making a rapid assessment (taking less than a minute) of every patient, determining which of four categories patients should be in:

- Green: Minor delayed care / can delay up to three hours,
- Yellow: Delayed urgent care / can delay up to one hour,
- Red: immediate care / life-threatening,
- Black: victim is dead / no care required.

But critical changes in the health of a patient might go undetected after this is initially triaged. Computer miniaturization and wireless technologies, have allowed the development of mobile wireless data acquisition and monitoring capabilities, to individually identify and track victims of disasters [10]. The Automated Remote Triage and Emergency Management Information System (ARTEMIS) equips responders and casualties on the field with wearable embedded sensor tags that process, store, and analyze physiological data collected from the subject [9]. By continual monitoring of responders and casualties the ARTEMIS project seeks to provide situational awareness to all level of commands in order to increase patient survival rate during emergencies.

Similar to ARTEMIS is the Wireless Internet Information System for Medical Response in Disasters (WIISARD) project [5]. It is also focused on designing and testing end-to-end solutions for the care of victims at disaster sites that use mobile applications and wireless data networks to manage assessment of impact and triage of patients. A critical aspect of WIISARD is the development of scalable and robust network infrastructure capable of supporting data communications. It combines the use of IEEE 802.11b standard for communications between end users devices and access points, use of a wireless distribution system for communications between access points in the network, with the use of cellular wide area networking for Internet connectivity and to prevent nodes from being disconnected with severe network disruptions.

Part of our research activities are realized within the framework of the COMBINED (Chaotic Open world Multi-agent Based Intelligently NEtworked Decision support) Systems project of the DECIS Lab [1], [8], [25]. 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 [23] we presented the PIRA model approach, which assumes that there is some form of a fixed/wired infrastructure available at a crisis. Our new approach drops this requirement and can therefore be seen as the next step in efficient disaster recovery.

In the COMBINED system Cougaar [3] has been used as software architecture. Cougaar provides a distributed agent system and a distributed blackboard system [4]. Blackboards have been used for many years in the area of Artificial Intelligence. The authors of [7] 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 blackboard system we used in the current project provides even more flexibility in distribution of data and processing systems with emergent structures. This represents one of the main difference between our approach and the one used in the projects mentioned above. More work concerning blackboards can be found in [21].

As mentioned in the introduction for the coordination mechanism we chose for an Ant Colony Optimization (ACO) algorithm. This type of algorithms has been successfully applied to solve many combinatorial optimization problems like the Traveling Salesman Problem (TSP) [11]. Our coordination problem can be perceived as a special class of the vehicle routing problem, the Dynamic Vehicle Routing Problem with Time Windows (DVRPTW). Each medical doctor acts as a vehicle, trying to serve as many customers (casualties) as possible. In [12] is shown that for the static VRPTW, an ACO algorithm performs uniformly better than the other metaheuristics (Simulated Annealing, Tabu Search, and Genetic Algorithm [24]) with the exception of the clustered data sets. In [20] ACO is applied to a DVRTW problem where new orders are received as time progresses and must be dynamically incorporated into an evolving schedule. In this case the ACO algorithm outperforms a Multi-Start Local Search algorithm.

Still the dynamic aspects in our problem makes it different than the DVRPTW presented in [20]. The number of doctors (vehicles) is a constraint that changes in time. The number of casualties (customers) is also not fixed and is changing continuously when new ones are discovered. From this aspect our problem is similar to the Dynamic Traveling Salesman Problem (DTSP) with insertion and deletion of the cities [15], [14]. More, in our problem the exact time windows (the time which a casualty will survive) are not precisely known (just approximated). Also the time necessary to serve a casualty depends on the time when the help is provided.

3. SYSTEM ARCHITECTURE

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

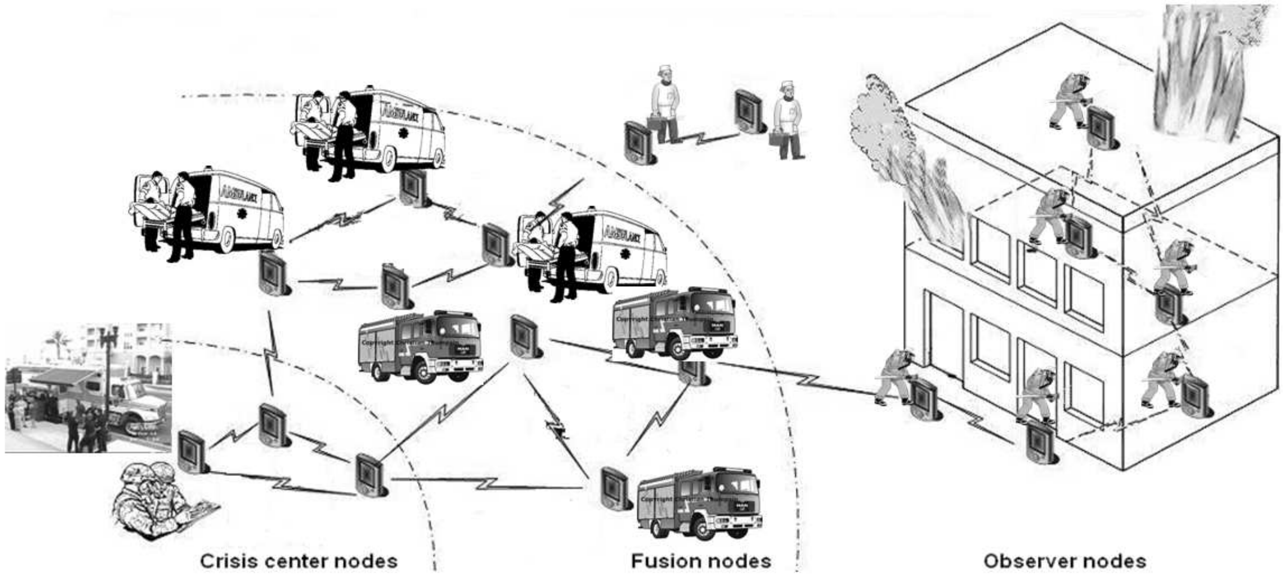

Fig. 1. The layered model topology

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 during 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.

3.1. A layered 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 1.

The three layers consist of:

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

The layer of observer nodes concerns the outer part of the network. These are the paramedics which are doing the actual rescue work and the electronic triage tags deployed to the victims. These devices are equipped with sensors that once attached to the patients will continuously monitor their clinical evolution. Several medical sensors have been proposed and tested for on-scene providers and for victims at a disaster site. Devices such as the wristband personal status monitor and pulse oximeters, which monitors vital signs, have undergone pilot trials [28], [18], [17]). Beyond transmitting clinical status, one important aspect of such devices would be the ability to provide real-time information on location. This can be done by combining the monitoring and positioning devices that relay personnel location with a global positioning system (GPS) [9].

This enormous amount of data, including the vital signs of the patients, the location of the patients, and the location of the first responders must be gathered and monitored efficiently. Is the function of the middle layer to pre-process the data that comes in from the observer nodes. This layer involves the part of the network that is somewhat stable, although nodes are also assumed to disappear but less often as in the case of the outer ring of the network that is assumed to be highly dynamic. It can be represented by the mobile devices present in the intervention vehicles used by the rescuers. They have increased battery power and a better connection range and ensures the connectivity between the other two layers.

Eventually, the filtered 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 crisis. 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 middle part of the network, which can then be used to update the global world model.

3.2. 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 [19].

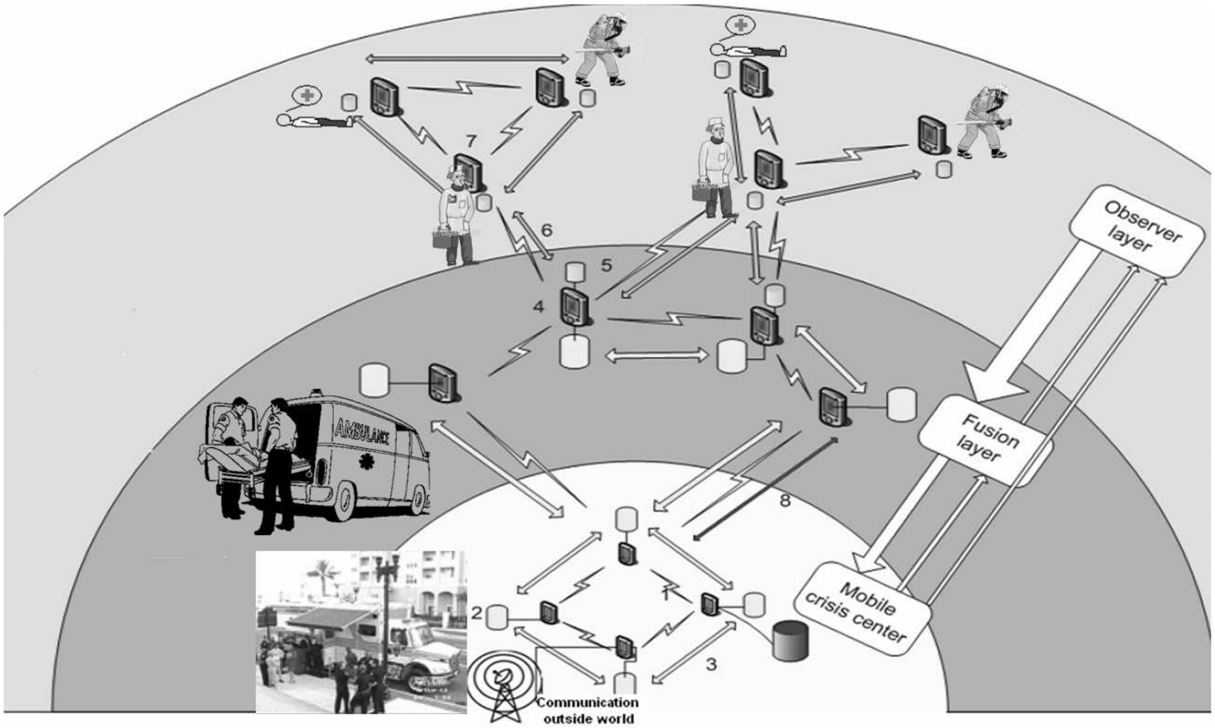

Fig. 2. Overview of the communication flow

The blackboard is organized in a hierarchy, since this approach fits the structure that is brought into the topology (Figure 3). In our approach, the nodes in the outer layer have the task of putting their messages on the local blackboards. 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 / fusion the data on the blackboard that is specifically meant for the inner layer. This hierarchy is expected to prevent overloading of the distributed blackboard structure.

In Figure 2 an overview of the communication in the designed system is given. This picture is divided in the same three layers as in the previous subsection. The lower part of the picture indicates the nodes in the mobile crisis center (e.g. 2). The connections between these nodes is assumed to be reasonably stable (e.g. number 1 in the picture). The bottom lines in the figure (e.g. 3) represent the blackboard communication between these nodes. There are also nodes connected with the outside world.

The nodes in the crisis center are (parts of the time) connected with the nodes in the fusion layer. These nodes (e.g. 4) are also looking at the main blackboard (if reachable). Since they are closer to the nodes in the observer layer (e.g. 7) they are (part of the time) connected also with these nodes (e.g. 5). At this level the communication is done via local blackboards (e.g. 6). Besides the communication via the blackboard, there is also a possibility to contact nodes directly (if desired) as indicated by arrow 8.

The communication flow in the system can then be visualized as in the right part of the figure. The flow from the observer layer is drawn with a thick arrow to indicate that a lot of data messages are flowing from this layer to the fusion layer. After preprocessing the amount of data has decreased. Therefore the arrow from the fusion layer to the mobile crisis center is drawn less thick. The arrows back into the network are even thinner, since part of the data is stored in the crisis center and is not relevant to the observers. Besides part of the relevant information, the coordination decisions taken in the crisis center are to be sent to the nodes in the fusion layer and the observer layer. This is captured by the arrows from

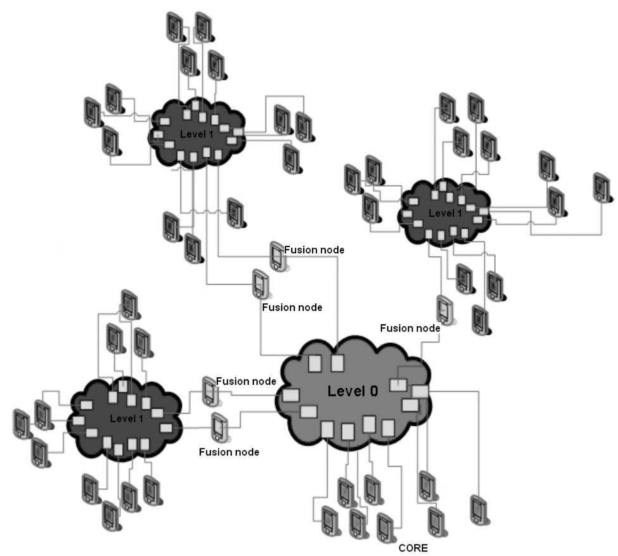

Fig. 3. An ad-hoc network of PDAs using a hierarchy of blackboards

the crisis center to the fusion nodes and the observer nodes.

4. THE RESCUE SERVICES

Integrated into one system, using the architecture described in the previous sections, we propose supporting services to the rescue workers on their handheld devices. Furthermore it is necessary to provide the right people with the appropriate information to execute their tasks.

In the next pages of the paper we will discuss a newly developed service which not only collects and filters the information, but also takes decisions and assigns the medical units to the appropriate victims to whom they have to go and provide the first aid in the field.

As mentioned in the previous sections, after the victims are discovered they are classified in one of the four categories of the triage algorithm. This information is permanently monitored with smart devices (e.g. pulse oximeter) which are wireless connected. The information is collected and propagated by our wireless architecture to the Crisis center. Here, for each doctors in the field, an optimal plan to follow is computed. The goal is of course to help as much victims as possible, taking care of the priority of the casualties. There are several aspects we have to take care:

- how to route the doctors along the victims,
- how to deal with the priority of the victims and the time limitations (some victims need help in the shortest time),
- how to handle the dynamic aspects (new victims are localized in the course of the time; different medical doctors are entering or leaving the area). So the routes have to be adapted continuously.

We need an algorithm which is able to keep track of all the occurring modifications and continually optimize in order to be able to to present a valid, good solution at all times.

4.1. *Ant colony system model*

In our Ant Based Control approach model for emergency coordination the following concepts are going to be used:

- Casualties $V = \{1, 2, ..., n\}$. Every casualty has a fixed location, a triage level and, depending on this level, an expected time of death Td_i.
- Triage level. This is a representation of the diagnosis of a casualty, i.e. red, yellow, green. Every level corresponds to a treatment time Tt_i (e.g. red takes 30 minutes). At specific times (different for every patient) the triage goes to the next level (e.g. if yellow untreated for about 40 minutes - switch to red) and as a consequence the time necessary for the treatment of the patient also grows.
- Medics $M = \{1, 2, ..., m\}$. They need to give the first aid to the casualties. Their main objective is to minimize the number of deaths. A second objective is to reduce the total effort time of the medics: the time travelled between patients plus the time spent on their treatment.
- Ants. Software agents ants are generated by the medics and travel between the nodes in the graph of casualties. These mobile agents imitate the trail-laying behavior of the real ants and try to optimize the path followed by the doctors to help the casualties. They are searching for the longest cycle which contains each medic and the maximum number of casualties. Each agent constructs a partial solution where each casualty is visited at most once. As a quality of their generated solution, they leave pheromone trails. The pheromone values are stored at each node in the form of a routing tables.

We represent the environment as a graph G where the set of vertices consists of the subsets V and M (the initial position of the medics) (Figure 4). A travel time T_{ij} is associated with each arc in G. T_{ij} is the time necessary for a medic to move from the casualty i to the casualty j.

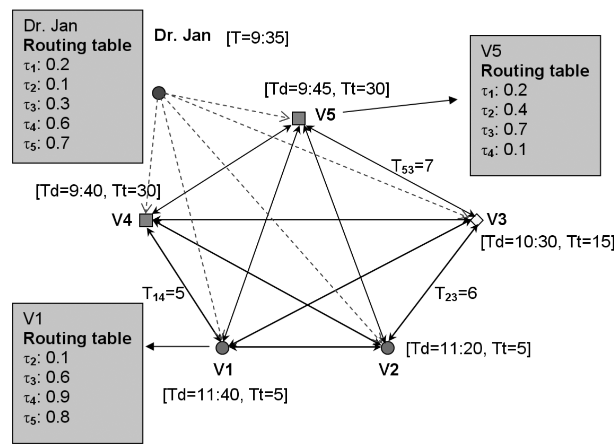

Fig. 4. Graph representation of the problem

G is a fully connected graph. At each medic and casualty node a routing table is maintained. These routing tables are updated by the ants on the basis of pheromone trails τ. The higher the level of pheromone the more attractive the link is, for example see $V1$ and $V5$. Maintaining a pheromone table also at each medic node as well, offers the possibility of exchanging tasks between doctors and lead to better solutions. The pheromone value τ_{in} is not allowed to go below $\frac{1}{T_{in}}$ because we want to keep a small exploration probability on the correspondent link.

Every second an iteration of the algorithm is executed. At every medical node an ant is generated and sent to find an optimal solution. The ants are processed one by one and not in parallel.

Each ant starts to build its chain with the patients that can be treated by medic which created it. When no casualty can be added to the solution, it switches to a new medic which was not visited yet and starts to build its corresponding chain of patients. Every ant maintains a stack where it memorizes its previous steps.

When an ant A travelling between nodes in G, moves from a victim V_i to a new victim V_n it computes the time necessary to for a medic M_j to reach it.

$$T_{V_n} = T_{V_i} + Tt_i(T_{V_i}) + T_{V_iV_n} \quad (1)$$

$Tt_i(T_{V_i}) = Tt_i$ represent the treatment time spent by doctor M_j to treat victim V_i at time T_{V_i}. Once this time stamp is computed the ant pushes it on the stack together with the indexes V_n of the node and M_j of the doctor.

Each step the ant selects the next node n to go using the following formula:

$$n = \begin{cases} \max \tau_{il}\eta_{il}, q \leq q_0 \\ N, q \geq q_0 \end{cases} \quad (2)$$

$$P_{ij} = \frac{\tau_{iN}\eta_{iN}}{\sum_{l \in N} \tau_{il}\eta_{il}} \quad (3)$$

where:

- N represents the set of unvisited nodes,
- η is the 'urgency' function,
- τ is the pheromone value,
- $q_0 = 0.5$ and balance the choice between the max value and the probability distribution.

$$\eta_{in} = \frac{Tt_n}{Tt_n + T_{in}} \quad (4)$$

In the formula above we did not make use of the time T_d when the patient will die. This is because although the triage is known, the exact time the patient will die can't be known in advance.

Each time an ant makes a step, it removes some quantity of pheromone lay down along the link:

$$\tau_{in} = (1 - \rho)\tau_{in} \quad (5)$$

In this way the selected path becomes less attractive for the other ants helping the exploration search for new and better solutions.

After no more casualties can be inserted in the partial solution, this is compared with the best solution found so far. We tried to maximize the number of total rescued victims A (the length of the cycle). If the stack of the new ant has more elements than the global ant, the new solution is better and it replaces the global solution. If their size is equal they are compared using the second criteria which refers to the effort time spent by the medics.

At the end of each iteration a local search is applied to see if the solution can be improved. For example in case that we have V_i in yellow stage waiting for doctor M_k and V_j in red faze waiting for doctor M_l. If $T^k_{V_j} < T^l_{V_j}$ then the medics exchange their list of patients in the global solution. The one in red phase has more chances to be rescued.

Finally with the global solution an update is done for all the links on the paths:

$$\tau_{in} = \tau_{in} + \rho\frac{|A|}{|C_a|} \quad (6)$$

- C_a represents the total number of alive casualties which haven't received the first aid yet,
- $|A|$ is the size of the ant and represents the estimate number of victims that can still be rescued,
- $\rho = 0.1$.

When a medic has to move to another patient, the selection is made following the path stored in the global solution.

4.2. Reacting to a change

An important issue in our algorithm is how to deal with the insertion of a new doctor or casualty. When a new element is introduced in the graph, his pheromone table is initialized with values proportional with the time necessary to go to the other nodes. In case of a casualty i, new values corresponding to the new node are also introduced in the pheromone table of each of the entities already existent in the graph G (medics and casualties). In this case the pheromone value set on this field is an average between the initial quantity and the maximum value existent in the routing table of x.

$$\tau_{xn} = \frac{max(\tau_{xk}) + \frac{1}{T_{xn}}}{2} \quad (7)$$

This is because we want that new solutions containing the new element to be generated fast. When a casualty dies or its treatment is completed, the links corresponding to this node are removed from the graph. In the next section we describe the pseudocode of the ABC algorithm for one iteration step.

4.3. The Ant Based algorithm

```
{MdList - list of doctors}
{GlobalAnt - the best ant found so far}
{V_i - the current victim}
{V_n - the next victim to go}
{M_j - the original medic}
{M_n - the next medic in the solution}
for all medics M_j in the MdList do
  if M_j has patient then
    { create ant at M_j at current Time}
    CreateAnt(A_{M_j})
    M_n ← M_j
    while M_n ≠ nil do
      V_n ← GetNextPatient(A_{M_j})
      if V_n ≠ nil then
        {T_{M_n V_n} - time necessary for M_n to move to V_n}
        T_{V_n} ← Time+T_{M_n V_n} {add the new information
        on the stack}
        A_{M_j} ← (T_{V_n}, M_n, V_n)
        move A_{M_j} to V_n
        {Evaporate pheromone between M_n and V_n}
        Evaporate(τ_{M_n V_n})
        V_i ← V_n
        V_n ← GetNextPatient(A_{M_j})
        while V_n ≠ nil do
          T_{V_n} ← T_{V_i}+Treatment(V_i, T_{V_i})+T_{V_i V_n} {add
          the new information on the stack}
          A_{M_j} ← (T_{V_n}, M_n, V_n)
          move A_{M_j} to V_n
          {Evaporate pheromone between V_i and V_n}
          Evaporate(τ_{V_i V_n})
          V_i ← V_n
          V_n ← GetNextPatient(A_{M_j})
        end while
        M_n ← GetNextMD(A_{M_j}) {select a new medic}
      else
        M_n ← GetNextMD(A_{M_j}) {select a new medic}
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```
      end if
    end while
    { evaluate the new found solution}
    if A_{M_j} < GlobalAnt then
      GlobalAnt ← A_{M_j}
    else
      destroy A_{M_j}
    end if
  end if
end for
OptimizePlan(GlobalAnt)
UpdatePheromone(GlobalAnt)
```

5. Experimental environment

A prototype of the basic infrastructure has been developed for a real MANET. For testing we used 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. For the underlying distributed blackboard structure, a pre-release of a new version of Lime is used ([21], [2]). This software was, together with the rescue service applications, ported to Java 1.3.1.

Experiments were carried out 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. The result of bringing a structure into the network was positive.

5.1. Hello world scenario

Using 4 PDAs and one laptop, we tested the coordination mechanism in a real ”Hello world scenario”. The laptop played the role of the crisis center and was placed at the entry of the EWI faculty building on ”Mekelweg” street (Figure 5). Two of the PDAs were simulating two casualties and were positioned in the neigbourhood at the intersections with ”Stieltweg” and ”C. Drebelweg” (about 50 m away from the crisis center). The other two PDAs received the role of medics and were placed in between the crisis center and the casualties.

The first one who entered the scene was doctor Leo. He detected the two casualties with the triage level set to yellow and forwarded the information at the mobile crisis center. He received the task to help the closest victim V1. After 1 minute doctor Jan enters the scene and is suggested to help the second victim V2. Because the short distance between the actors, we chose to keep them in the same place and just watch the messages passed in the wireless network. We were more interested to test the coordination mechanism. For this we changed the triage level of the second victim V2 to red. Doctor Leo, who was closer to this casualty than doctor Jan, is reassigned to help V2. The first casualty V1, who was still on yellow level, had to wait for help from doctor Jan.

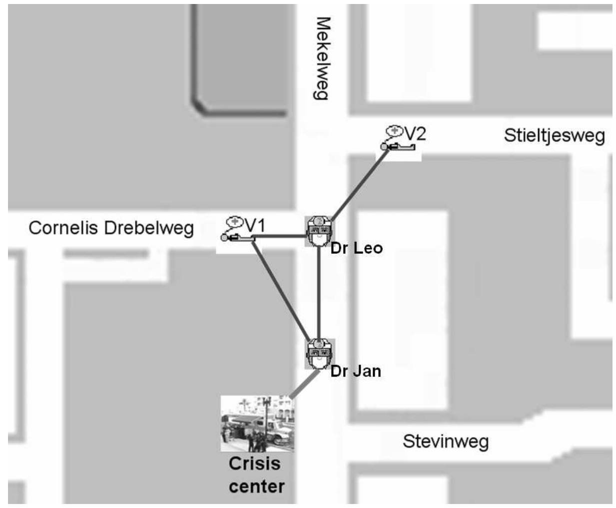

Fig. 5. Map of the test area

6. Simulation tests

Because of lack of a huge number of mobile devices, we developed a simulation environment where we tested our coordination strategy in much more serious scenarios, with hundreds of actors. We limited the disaster area to 1 km x 1 km (Figure 6). Every simulation started at T=0 and can run up to 6 simulated hours (T=360 minutes). In this area casualties appeared at random locations, at random intervals in a period of three hours. After three hours, there were no new casualties generated.

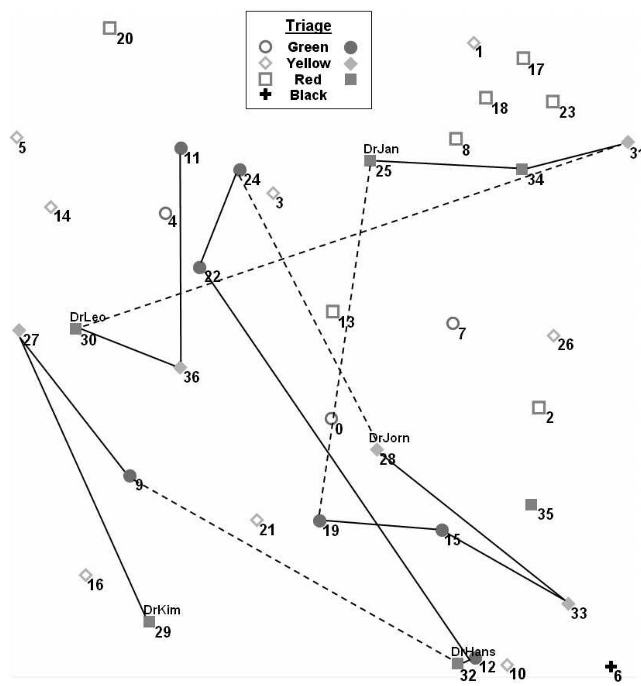

Fig. 6. Simulation view

Once a new casualty is discovered, his triage level is known and can either be green (minor), yellow (delayed) or red (immediate). New casualties do not have triage level black (morgue) and their position is fixed. Medics can enter the area from the up left corner and move around in the disaster area by foot following the 'Manhattan geometry'. It takes 15 minutes a medic to walk 1 kilometer (i.e. 4 km/h).

In Figure 6 the signs represent victims which are waiting for help or are under treatment. The empty figures represent patients that already have been treated. The death of patient 6 can be noticed by the cross sign "+". We used circle for green, diamond for yellow and square for red. The best available schedule is displayed. The solid lines draw the solution chains the medics should follow. The dotted lines are connecting the scheduling chains of different medics. The patient 35 is not part of the solution and eventually will be let to die. In our case the schedule plan is:

- for Dr Kim: 29, 27, 9,
- for Dr Hans: 32, 12, 22, 24,
- for Dr Jorn: 28, 33, 15, 19,
- for Dr Jan: 25, 34, 31,
- for Dr Leo: 30, 36, 11.

The condition of casualties will get worse in time if they are not treated. The average degeneration intervals are as follows:

- Triage level green to yellow after 120 minutes,
- Triage level yellow to red after 40 minutes,
- Triage level red to black after 20 minutes.

The time intervals for triage changing, were different from casualty to casualty. They follow a Poisson distribution with the means mentioned above.

As soon as a medic starts paying attention to a victim, the condition of that casualty will remain stable (i.e. the triage level will remain the same over time). Each medic will spend a certain amount of time to treat each casualty, depending on this triage level:

- Triage level green: treatment time = 5 minutes,
- Triage level yellow: treatment time = 15 minutes,
- Triage level red: treatment time = 30 minutes.

In order to compare our Ant Based Control algorithm (ABC) we implemented two greedy approaches. The first selects the next victim in the nearest neighbourhood (nearest neighbour NN). The second approach treats the victims based on the triage level (reeds first RF). We also wanted to see how far from the optimum the ABC solution is. For this we implemented a branch-and-bound algorithm (BB).

6.1. *Middle of the road scenario*

First we run a "middle of the road" scenario using our simulation environment. An area with 25 casualties was generated: 5 green, 10 yellow and 10 red. Two medics were sent into the field during the first test. The results in Figure 7 show that using the ABC algorithm and the BB the same solution is obtained. Still there was a difference: the ABC completed the test after 4h 31min and 54sec and the BB after 4h 27min and 54sec (4 minutes faster). This difference can be explained by the fact that the ABC doesn't have at every moment the best available solution. It takes seconds for the ants to train the pheromone and converge to the desired solution. Still in this case this behaviour didn't influence the final result. What is surprising in this test is that using the nearest neighbour strategy one more patient is cured in the green state than using ABC and BB. It can happen that a less effective decision at one moment will lead in the future to a better global solution. The RF doesn't behave too good and it lose two patients more than his competitors.

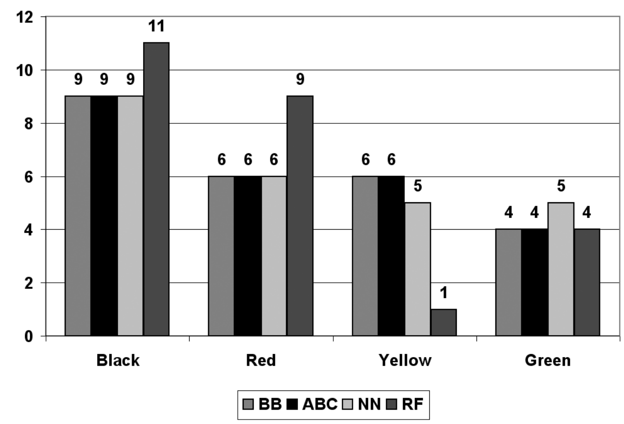

Fig. 7. Middle of the road scenario: 25 casualties and 2 doctors

In the same context we increased the number of medics to five (Figure 8). Again ABC got almost the same score as BB, the difference being present on the green-yellow columns: one green more for BB to one yellow more for ABC. RF scored this time better than NN but less than the other two algorithms. It was expected that, with enough rescuing personnel, helping the victims according to their priorities will give better results.

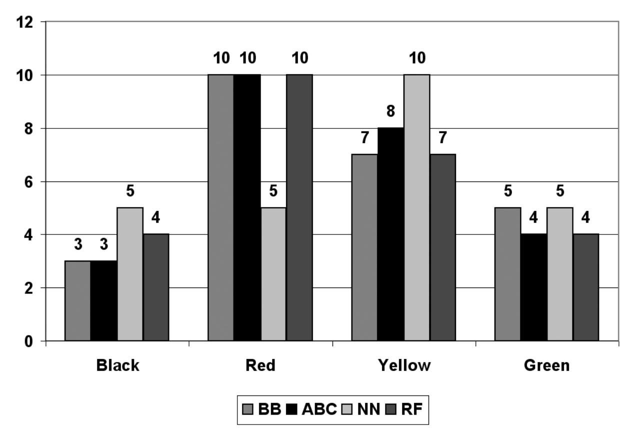

Fig. 8. Middle of the road scenario: 25 casualties and 5 doctors

6.2. *Escalation scenario*

For the second "escalation scenario" we raised the number of casualties to 100: 20 green, 40 yellow and 40 red. We tested a case with 10 medics in the field and one with 20 medics. The results are shown in Figure 9 respectively Figure 10.

The first observation can be made is the absence of the results for the BB. It could not keep the rhithm with the frequency of dynamic changes caused by the scale of the test. If more than 10 patients in parallel are waiting for help in the field, the computational time for the BB is growing from seconds to minutes which is far from the required performance

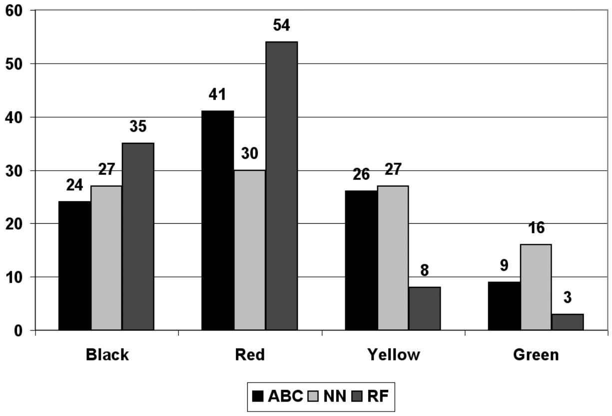

Fig. 9. Escalation scenario: 100 casualties and 10 doctors

for our problem. This is while the computational time at each iteration of the ABC is below one second and same for NN and RF. ABC registered 24 casualties, with 3 less than NN and with 11 less than RF.

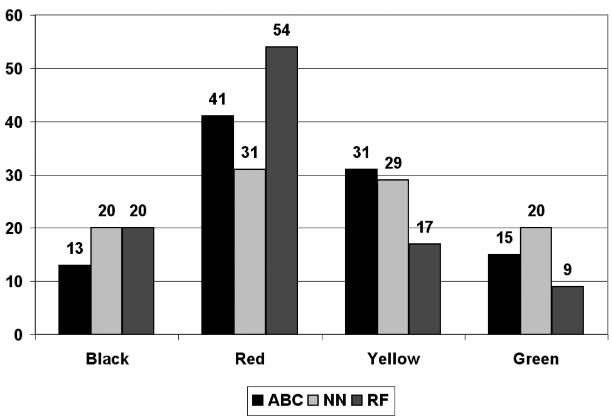

Fig. 10. Escalation scenario: 100 casualties and 20 doctors

When 20 medics were sent into the field, 13 casualties were counted at the end for ABC, and 20 for NN and RF which again performed similar.

6.3. Saturation scenario

The last scenario we used was a ”saturation scenario”. 250 casualties are discovered during the first three hours after the disaster. 50 have the green triage level, 100 yellow and 100 red. Also this time we tested two situations, one with 25 medics available and one with 50 medics available. The results are displayed in Figure 11 and Figure 12.

With only 25 medics active we obtain similar results for ABC and NN, despite the scale of the scenario. This is because of the high density of the casualties which offers many choices in the close neighbourhood of each doctor. Only RF performs bad with 65 losses.

The gap between an ant based algorithm and a greedy strategy becomes visible when we tested the case with 50 rescuers in the field: only 19 losses for ABC, but 31 for NN and 35 for RF.

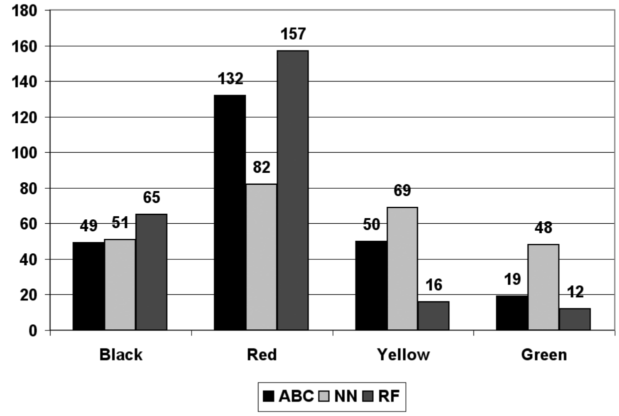

Fig. 11. Saturation scenario: 250 casualties and 25 doctors

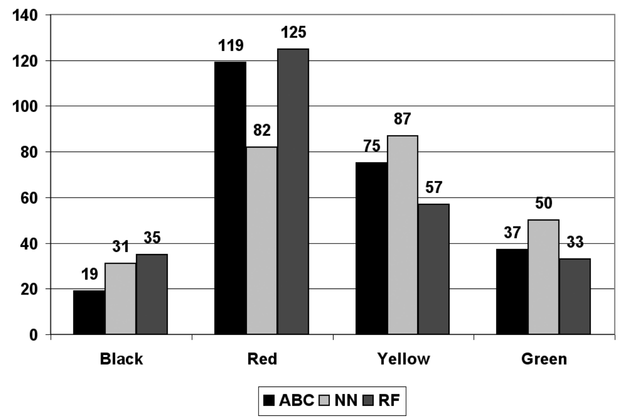

Fig. 12. Saturation scenario: 250 casualties and 50 doctors

The results of the Ant Based Control algorithm were better then the greedy competitors in all the cases and almost the same with BB in the small scale scenarios. Because of the huge computational time necessary for larger cases, the branch-and-bound method proved to be inadequate for the problem discussed in this paper. ABC shows a better gain in cases with a balanced proportion between casualties and medics. When the number of available rescuers is very small for the scale of the disaster, choosing the nearest neighbour proved to be more efficient than making the choice based on the triage level. This situation changes once with the number of available medics increases.

7. CONCLUSION

In this paper we proposed an approach to addressing the issue of communication infrastructure reliability at the beginning of a crisis, which a major concern in disaster-preparedness and emergency. We introduced a Mobile Ad-Hoc Network (MANET) with topologically organized nodes that facilitate the dispatching of emergency functions during crises. 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. On the top of this infrastructure we developed a service that uses an Ant Based Control (ABC) algorithm for emergency coordination.

We tested the ABC algorithm in a simulated crisis environment that illustrates how coordination strategies can help crisis response organizations to deal with complex, dynamic crisis situations. The ABC algorithm was compared with two greedy and one branch-and-bound strategy. It proved to be efficient and able to reduce the amount of deceased casualties during a crisis. The ABC algorithm was capable to keep track of all the occurring modifications by continually optimizing and finding good solution in all the tested cases. The approach seam to be suitable to solve other similar dynamic optimization problems.

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