Mobile computing in mass casualty incidents (MCIs)

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Abstract: This paper illustrates the future role of mobile computing for the response in emergencies and mass casualty incidents (MCIs). Furthermore it describes the different components and functionalities which will be needed – in the form of a vision. This vision shows that a mobile system is capable to assist emergency teams and incident commanders in MCI operations. This mobile system has to contain functionalities such as information on patients, information on the scene, information on emergency teams, information on infrastructure, MCI knowledge, technical support, management tools, remote collaboration and flexibility. Due to the fact that various researchers performed research on these challenges a wide-spread overview on the state of the art is presented.

Finally this paper points out that a powerful user-interface which considers the unstable, time-critical and life-threatening context is indispensable for the successful introduction of mobile computing in emergencies and MCIs.

1 Vision

In his publication "The computer in the 21st century" [Wei99] Mark Weiser describes his idea that specialized hardware and software will be so ubiquitous that no one will notice their presence any more. This publication is especially remarkable for two different reasons: Firstly, his vision has become true - at least partially. Secondly, he describes how the live of *Sal*, a fictive character, changes by the means of ubiquitous computing. This demonstrative imagination extends his abstract vision of ubiquitous computing. His example enabled everyone to get a feeling for the scope of his approach.

In order to give a brief impression of long-term aims, we would like to draw a similar vision of the future emergency and MCI response. Provided that existing approaches and technologies are enhanced consequently, this vision could become real soon:

11.01 a.m.: It is a typical morning at an emergency medical service (RD) station. Susan, an emergency medical technician paramedic (RS / RettSan), and Rob, an emergency medical technician intermediate (RA / RettAss), are together on a basic life support ambulance (RTW) today [KBWC02]. They are informed of an emergency by their beeper. While they

are moving to their ambulance their mobile device presents them additional information on the emergency (as shown in Figure 1). A 81-year old woman has collapsed in a nursing home.

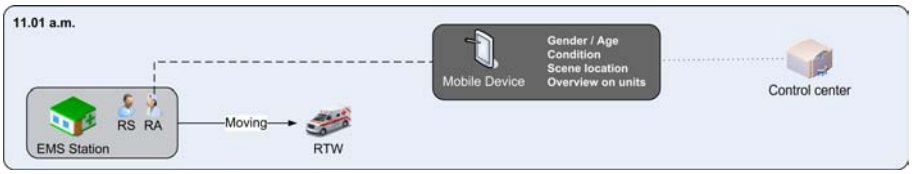

Figure 1: Alarm situation at 11.01 a.m.

11.04 a.m.: As soon as Rob puts their mobile device in the docking station, the navigation information is displayed on the device. The context-aware system detects that blue light and siren are used during the way to the patient. Consequently the system ignores one-way streets, ban on turns and further traffic rules which might delay the arrival at the patient (as shown in Figure 2). During the way to the patient Susan skims through the patient history. The lady was transported to hospital 9 months ago because of a collapse.

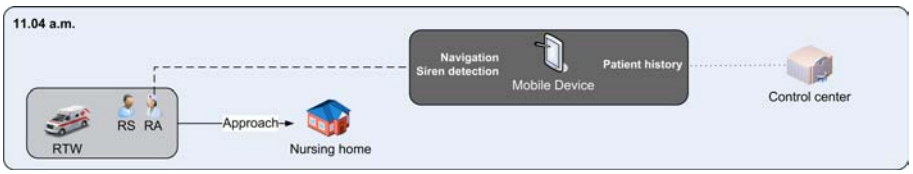

Figure 2: Alarm situation at 11.04 a.m.

11.11 a.m.: As soon as they arrive at the scene, the mobile device relays this information to the control center. Rob and Susan move to the patient's room. While Susan checks the patient's vital parameters Rob starts with the documentation. The emergency location and time as well as the patient's name are automatically included (as shown in Figure 3). He quickly checks if the system has completed the patient's particulars correctly.

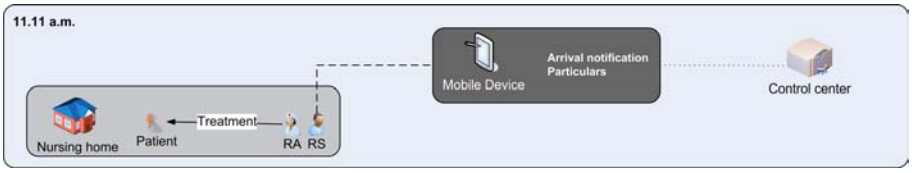

Figure 3: Emergency situation at 11.11 a.m.

11.21 a.m.: The lady is monitored by an oxygen sensor which transmits the pulse and the oxygen saturation to the control center. Susan decides that the patient should be trans-

ported to a hospital for advanced examination. When Rob looks for a hospital, he gets an MCI information (as shown in Figure 4). Rob quickly consults with Susan and then they decide that they can delay the transportation of their patient. He sets the oxygen sensor on global monitoring mode. The sensor will not send any information to his mobile device anymore. Instead the sensor information will be transmitted to the control center.

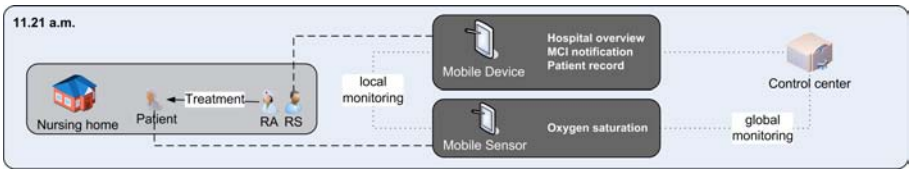

Figure 4: MCI situation at 11.21 a.m.

11.29 a.m.: While Susan and Rob are rushing down to their car, additional information regarding the MCI is displayed on their mobile device (as shown in Figure 5). A large traffic accident on a crossing has lead to 15 - 20 injured persons. According to the various callers the system supposes that probably one truck, five cars, one biker and two pedestrians are involved in the traffic accident. Furthermore many persons are injured severely and some of the car passengers are trapped.

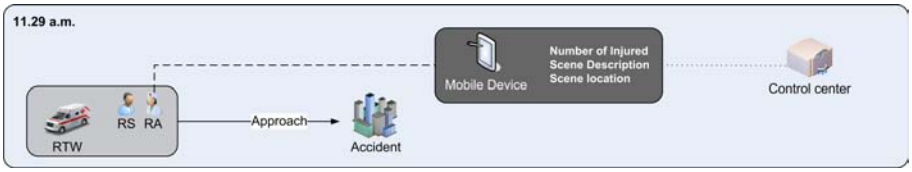

Figure 5: MCI situation at 11.29 a.m.

11.32 a.m.: The mobile device predicts that Susan and Rob will probably be the first unit at the MCI. Additionally their mobile system reminds Susan what to do first when arriving at the scene (as shown in Figure 6). Furthermore the system reminds Rob how to park his ambulance in a way that he will not have any difficulties at his departure later on.

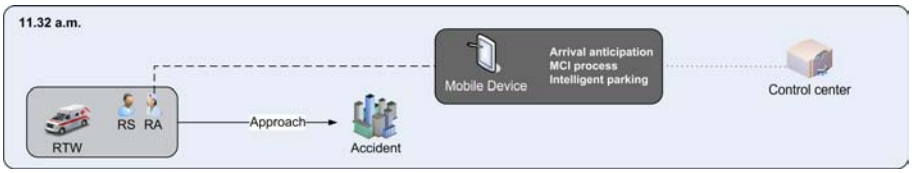

Figure 6: MCI situation at 11.32 a.m.

11.36 a.m.: They leave their ambulance and immediately they get an overview on all

ambulances currently approaching the scene and an estimation of the arrival dates. Due to the fact that the arrival of the next ambulance will be not before 8 minutes, Susan decides to start with the triage. Rob assists her in performing the triage according to the MCI triage algorithm. Rob documents the outcome of the triage processes by holding the appropriate RFID enhanced triage tag next to the mobile device (as shown in Figure 7).

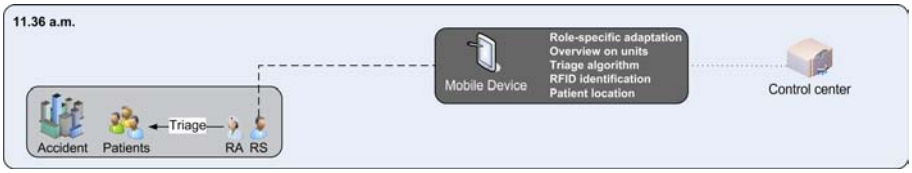

Figure 7: MCI situation at 11.36 a.m.

11.42 a.m.: Larry, the emergency medical chief (LNA), is still on the approach to the scene as well as Joe, the on-site organization chief (OrgL). Nevertheless both see a first map of the scene including the patients which have already been triaged by Susan (as shown in Figure 8). As soon as the current triage process is finished, the mobile device reminds Rob to approve the scene description. The next two arriving ambulances will triage all untriaged patients whereas Susan and Rob try to get an overview on the overall situation. Susan confirms that they are faced with an MCI in the traffic environment. She counts the involved vehicles and victims and updates the number in their mobile device. She acknowledges that there are trapped passengers and in summary counts four of them.

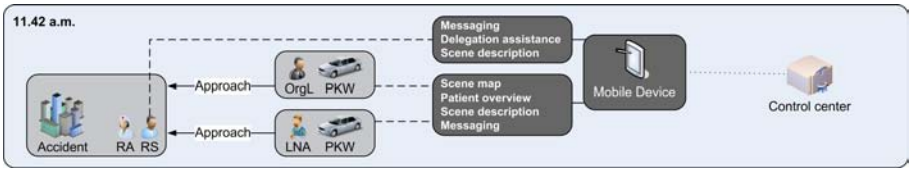

Figure 8: MCI situation at 11.42 a.m.

11.46 a.m.: They take a look at the overview of all ambulances currently approaching the scene and see, that two advanced life support ambulances (NEF) have already arrived and four further RTW as well as two NEFs will arrive during the next 5 minutes. Within the next 15 minutes five additional RTWs will arrive at the scene. Susan realizes that in summary there will be four NEFs and ten RTW - including herself and Rob - available soon. She assigns treatment, medication and transport of severely injured patients to all approaching units. Susan decides to generate an automated information message as soon as triage is finished (as shown in Figure 9).

11.49 a.m.: The mobile device informs Susan that the two NEFs have started with triage. Susan and Rob decide to take a closer look at the trapped patients. Two of them are triaged red, one is triaged yellow and one is still untriaged. She quickly triages the patient

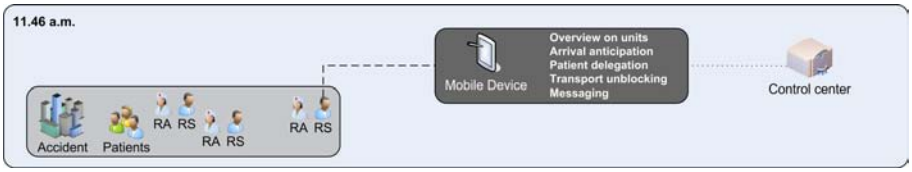

Figure 9: MCI situation at 11.46 a.m.

- he is yellow as well - and Rob applies a patient tag. Susan is irritated because the fire brigade has not arrived yet. She uses their mobile device to call the fire brigade directly and finds out that they are blocked by a traffic jam. She receives the information that the triage is finished and that two triage teams are starting with the treatment, medication and transport of two red patients (as shown in Figure 10). She sends the amount of patients in each category to the control center which forwards the detailed information to all probably concerned hospitals.

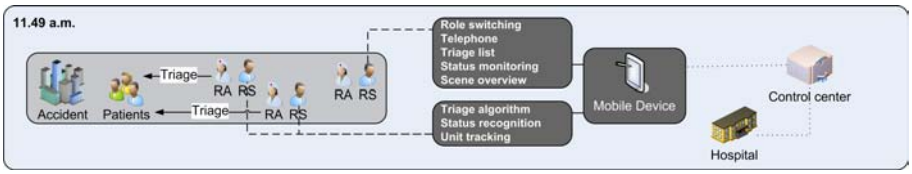

Figure 10: MCI situation at 11.49 a.m.

11.54 a.m.: Susan looks for free hospital capacities for the eight severely injured patients and is able to reserve seven beds in different hospitals close to the scene. While she is unsure what to do with the eighth patient, Larry arrives at the scene and his mobile device navigates him to Susan. While Susan gives Larry a short scene overview face-to-face, both enter on their mobile devices that Larry is now in charge of the scene. Susan and Rob start to find the closest red patient and start with treatment and medication, whereas Larry gets the information that the fire brigade has arrived in the meantime (as shown in Figure 11). Larry decides to transport the eighth patient to a hospital a little bit further away. A few seconds later he gets the information that Joe has just arrived.

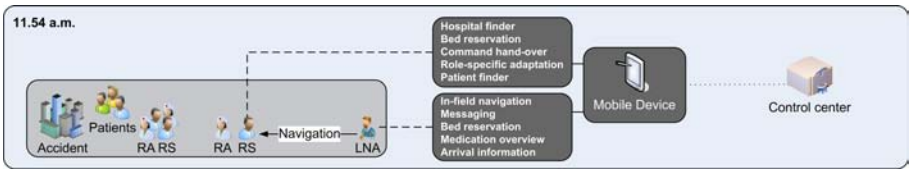

Figure 11: MCI situation at 11.54 a.m.

11.58 a.m.: Joe's mobile device shows him the shortest way to Larry in order to enable them to plan the next steps face-to-face. They decide that all free units should start with treatment and medication of the not severely injured patients and transport them as soon as the patients are stabilized (as shown in Figure 12). Furthermore they recommend to transport a sitting patient together with a lying patient in the same ambulance. Due to the fact that this instruction occurs quite often, they do not have to enter the instruction manually. Instead they can easily select this instruction from a drop down list of the most common commands in this phase of the MCI response.

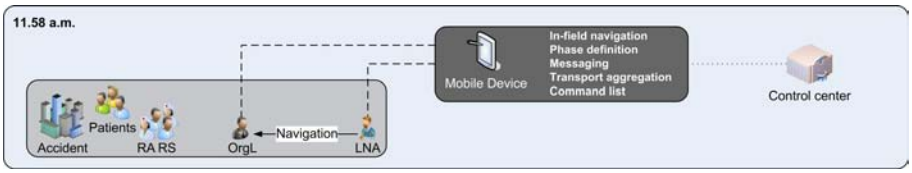

Figure 12: MCI situation at 11.58 a.m.

12.06 p.m.: The vital functions of Susan's patient are affected seriously. Rob requests an emergency physician by the means of his mobile device (as shown in Figure 13). The system looks for the closest physician which is most likely to be available. Donald, the emergency physician with the best matching, is immediately notified. The highly unstable condition of Susan's patient convinces him to medicate her patient personally. Before leaving his current patient he advises the paramedics to continue the further treatment without him. By the means of the mobile device he advises Susan and Rob to prepare an infusion. While Donald and Susan are medicating the patient, Rob documents all treatments and medications on his mobile device. As soon as the patient is stabilized they transport him to their ambulance and request a destination hospital. While Rob puts the mobile device in the docking station in the front of the ambulance and uses it for navigation, Susan is still able to display the patient information on an external monitor mounted in the back of the ambulance and to enter additional information via an external keyboard.

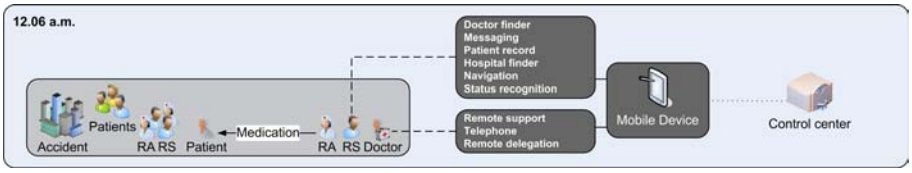

Figure 13: MCI situation at 12.06 p.m.

12.14 p.m.: Two units decided to treat a sitting patient in addition to a lying patient and consequently all patients are treated and medicated according to their injuries (as shown in Figure 14). However, one of the patients is very irritated because she cannot see her husband. The paramedic who treats her decides to search in the patient database for her

husband. He cannot find her husband by searching after his name, but the mobile device tells him that the names of two patients are not registered, yet. The lady luckily has a photo of her husband in her wallet. The paramedic quickly takes a photo with his mobile device and sends it to the two teams which medicate the nameless patients. Susan recognizes her patient on the photo and confirms the request.

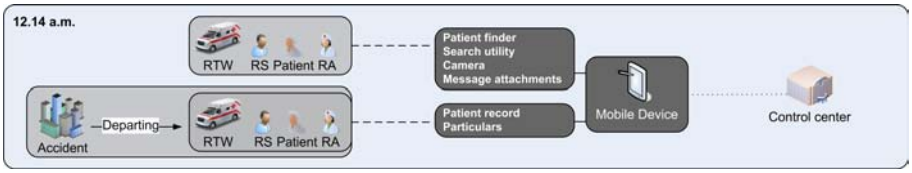

Figure 14: MCI situation at 12.14 p.m.

12.24 p.m.: Susan and Rob arrive at the hospital with a complete patient dataset including the patient's particulars. The hospital staff has already been able to read the protocol while the ambulance was still on the way to the hospital (as shown in Figure 15). Consequently the handing over can be done quickly and the physicians and nurses can focus on the patient. Susan and Rob tidy up their ambulance and drive back to the old lady whose transport has been delayed due to the MCI and transport her to hospital as well.

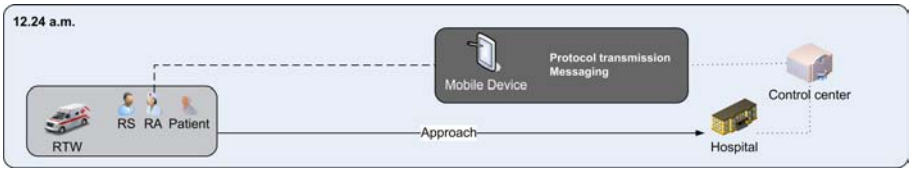

Figure 15: Transport situation at 12.24 p.m.

12.54 p.m.: They arrive at the RD Station where Rob puts the mobile device in the charging station.

2 Challenges

A lot of different technologies and functionalities have been mentioned in the vision. We would like to give a brief overview of these technologies and functionalities. A system which contains these functionalities is capable of assisting emergency teams and incident commanders in MCI operations best:

- The first group of information which has been described in the scenario is **information on patients** as shown in Table 1. This type of information includes all

Table 1: Information on patients

Information	**Technologies**	**Functionalities**
Gender / Age	Emergency network	Transmitting age and gender from the control center to the scene
Condition	Emergency network	Transmitting the patient condition from the control center to the scene
Particulars	Information input	Entering particulars on a mobile device
Patient history	Emergency network	Presenting information on the history of specific patients
Patient record	Information input	Creating a patient record with all information which has been gathered during the MCI
Patient location	GPS tracking	Showing GPS location of the patient
O_2 saturation	Oxygen sensor	Logging oxygen saturation of the blood
Patient overview	Patient record	Presenting an overview on patients groups (e.g. grouped by triage results)
Patient finder	GPS tracking	Searching the next patient which matches certain criterias (e.g. ”red” AND ”not medicated”)

Table 2: Information on infrastructure

Information	**Technologies**	**Functionalities**
Hospital overview	Emergency network	Presenting information on all hospitals
Hospital finder	Emergency network	Searching hospitals which match certain criterias
Bed reservation	Electronic triage	Reserving the required amount of beds in a destination hospital
Navigation	Region map	Navigating to the scene and from the scene to the hospital

Table 3: MCI knowledge

Knowledge	**Technologies**	**Functionalities**
MCI process	Scene overview	Presenting the general MCI process to the emergency teams on their way to the scene
Parking	Scene map	Assisting in the creation of a parking structure (which is not limited to ”first-in-last-out”)
Triage algorithm	–	Assisting during the MCI triage by presenting the triage algorithm

Table 4: Flexibility

Flexibility	**Technologies**	**Functionalities**
Role-specific adaptation	Role detection	Changing the roles of emergency teams during MCI management (e.g. first team at the scene is likely to play the role of the incident commanders until the ”real” incident commanders arrive)
Command hand-over	Information input	Guaranteeing that both - the ”old” commander and ”new” commander - are aware of the command hand-over
Transport aggregation	Scene state	Aggregating patient transports in order to increase transport capabilities

information which is related to a single patient or to the group of all patients at the scene.

- The information which is required by the emergency teams and the incident commanders is not limited to the scene. Different **information on infrastructure** as shown in Table 2 is additionally required to cope with emergencies and MCIs best.

- Besides information on patients, scene, emergency teams and infrastructure, the emergency teams require special knowledge in MCIs. Due to the fact that MCIs occur in a low frequency, assisting with **MCI knowledge** as shown in Table 3 is feasible.

- An important part in the development of mobile devices is the **flexibility** in the management of the MCI as shown in Table 4. Mobile devices should assist emergency teams in the successful handling of the scene without limiting the teams to standard defined procedures. Due to the fact that in MCIs unexpected events may occur, unexpected behavior of the emergency teams may not be excluded in advance.

- Another group of information is **information on emergency teams** as shown in Table 5. Information on emergency teams can be gathered by logging actions of teams and tracking location of units as well as by analyzing the information exchange between different teams.

- The next group of information is **information on the scene** as shown in Table 6. Scene information is a combination of information which can be gathered by emergency teams at the scene, information which has been reported by civilians and information which is available in central databases.

- At wide-spread MCIs (e.g. traffic accidents, train accidents) emergency teams cannot always collaborate face-to-face. A system for **remote collaboration** as shown in

Table 5: Information on emergency teams

Information	**Technologies**	**Functionalities**
Unit tracking	GPS tracking	Tracking the location of all units at the scene
Arrival anticipation	Discrete simulation	Anticipating the arrival of additional emergency teams or the incident commanders
Arrival notification	Emergency network	Informing of all arrivals
Status recognition	Information input	Acquiring status information on all units
Overview on units	Status recognition	Grouping units by their status
Status monitoring	Status recognition	Monitoring the status and connecting commands with status changes
Doctor finder	GPS tracking	Searching the next available doctor

Table 6: Information on the scene

Information	**Technologies**	**Functionalities**
Scene location	GPS tracking	Identifying the exact scene location by GPS tracking of the emergency teams
MCI notification	Emergency network	Informing the next available emergency teams that an MCI has occurred
Scene state	Electronic triage	Estimating the overall number of injured by summarizing triage results
Scene description	Information input	Entering a short description of the assumed reason of the MCI
Scene map	Emergency network	Transmitting available satellite maps and specialized maps
Scene overview	Information input	Summarizing all information of outstanding importance

Table 7: Remote collaboration

Collaboration	**Technologies**	**Functionalities**
Remote support	Emergency network	Providing help if problems occur and immediate feedback from a doctor
Remote delegation	Emergency network	Delegating the preparation of tools which will be needed in advance (e.g. preparation of an infusion)
Protocol transmission	Emergency network	Transmitting the patient protocol from the scene to the hospital

Table 8: Technical support

Support	**Technologies**	**Functionalities**
RFID identification	RFID Reader	Tagging the patients with RFID chips for foolproof identification
Messaging	Information input	Using pre-defined text modules for simplified entering of information
Message attachments	Emergency network	Attaching images and additional data to messages
Telephone	Phone module	Providing an integrated telephone for advanced communication
Camera	Camera module	Providing a possibility for documenting the scene and the patients
In-field navigation	Detail maps	Presenting passable paths to the emergency teams
Search utility	Scene database	Searching for patients, emergency teams, special equipment and transport vehicles
Siren detection	Microphone	Changing the system behavior in critical driving maneuvers

Table 9: Management Tools

Tools	**Technologies**	**Functionalities**
Patient delegation	Patient record	Delegating the medication of specific patients to specific teams
Delegation assistance	Emergency network	Delegating complex tasks (e.g. retriage of all red patients by a doctor)
Triage list	Electronic triage	Presenting the results of the triage processes
Transport unblocking	Triage list	Unblocking the transport if enough emergency teams are at the scene
Phase definition	Information input	Defining the phase (e.g. triage phase, immediate treatment phase, general treatment phase, transport phase, clean-up phase)
Medication overview	Patient record	Presenting the status of the patient treatment processes
Command list	Messaging	Enabling the incident commander to issue frequently needed commands

Table 7 is not a telemedicine system, it does not replace the face-to-face collaboration in MCIs. In the vision remote collaboration is just an additional communication channel for emergency teams and doctors before they can collaborate face-to-face.

- In the vision we mentioned some functionalities which are already well established in other fields. Due to their technical origin we call them **technical support** as shown in Table 8.
- The incident commanders (the emergency medical chief and the on-site organization chief) are the scene managers. Their management of the emergency teams can be assisted by certain **management tools** as shown in Table 9.

3 State of the art

Various researchers and groups have performed research on many of the challenges mentioned above. In available literature we missed, however, the overall problem statement as described in the last section.

The task of recording the **patient history** is essential but too time consuming during a MCI and requires the usage of wearable patient records. The content of these records can be transmitted to the incident commands by the means of mobile devices. Furthermore the **patient's position** can be tracked indirectly by GPS-equipped mobile devices [GMS+07]. The **oxygen saturation** sensors are among the most commonly used sensors in the field of unobtrusive ubiquitous health monitoring. These sensors are capable of determining the percentage of hemoglobin saturated with oxygen and the heart rate [Kz07]. The information stored in **patient records** can be classified in three different types: personal data, technical data and medical data [PWLP99]. Presenting a **patient overview** to the emergency team, which can be sorted according to treatment and transport priorities helps them to keep an overview. [KCB+06]

In many GIS-based disaster management information systems one of the steps is the creation of **scene maps** for sensitive areas [Vat03]. The precise **scene location** is a crucial and volatile information as a recent misconception in Germany showed. The fire brigade was led to the wrong place; they headed to the right street address but in the wrong city [SRKS08].

The incident commander must be supported with an **arrival anticipation** in order to assess the potential impacts of unexpected events. On the basis of this anticipation he can decide whether to continue following planned courses of action or to pursue alternate activities [MBW03]. A location aware wireless sensor network assists emergency teams in providing efficient emergency response. Among the functionalities of this network is the **doctor finder** [CFK+08]. Research investigated the recognition of emotional cues. Developing computers that have the skills involved in emotional intelligence could be the basis of the **status recognition** [HBL+98].

Ambulance **navigation** is a computationally well understood problem. Many factors, apart from the length of the trip, influence how long it will take to arrive at the destination (e.g.

traffic jams, traffic density, number of intersections and turns) [ATMK03]. A realistic scene assessment is the basis for optimizing the reservation of emergency-related resources and personnel, e.g. the **bed reservation** [SM08]. The Medical Admission Station allows the coordinator to find all hospitals available in the region. One of the main functions of the **hospital finder** is the search for the best destination for a patient on the basis of his condition [CARQ01].

Our own implementation of a **triage algorithm** on mobile devices assists paramedics during triage. The **MCI algorithm** is a standard defined procedure which helps the incident commanders to manage the MCI successfully [BBFKS05].

The Navy has developed a passive **RFID identification system** which supports storage and retrieval of medical data on a medical "dog tag" [LPCR05]. The combination of indoor tracking systems (on the basis of infrared senders) and outdoor tracking systems (with GPS) facilitates the **in-field navigation** in emergencies and MCIs [BKW02]. In the MIND system the scene documentation can be done with the help of a **camera**. The visualization includes photograph views which include time stamps and text annotations [MJT00].

Different **phase definitions** for MCIs exist. One concept distinguishes between the chaos phase, the medical organization (command) phase and the restoration phase. [WAM+06]. An **delegation assistance** helps to perform tasks such as the scene triage. All triage processes in larger incidents cannot be carried out by the emergency medical chief in a medically efficient time frame [GHZ+06].

The hospital staff must prepare themselves for the incoming patient [ATMK03]. The **protocol transmission** could be a possibility to reach this aim. Physicians should be dispatched depending on the patient's condition and the kind of emergency [GZB+06]. This decision if a doctor is needed could be assisted by **remote support**. In telemedical systems the standard operational mode is a point-to-point connection to an expert physician at a fixed location [DKK04]. The **remote support** by physicians being on the way to the patient seems to be less common.

The **role-specific adaptation** of the reliable overview on the complete situation is important for the successful scene management [LWC+06].

4 Discussion

Even if **information on patients** is rather important for the successful management of MCIs, the solution which is needed for this scenario is not just a powerful mobile patient information system. Whereas **information on the scene** and **information on infrastructure** is very important in MCIs, just a mobile context-aware system does not solve all problems which occur in this scenario. Collecting **information on emergency teams** and assisting by the means of mobile **management tools** is important, nevertheless coping with this scenario best is more than just a mobile management game. Assisting emergency teams with **MCI knowledge** is feasible, but just a mobile knowledge database does not automatically lead to a successful handling of this scenario. Despite the fact that vari-

ous mobile technologies can provide **technical support** for emergency teams, solving this scenario is more than just choosing the right technologies. Although supporting mobile **remote collaboration** can increase efficiency, just the introduction of a telemedicine system is not a solution for this scenario.

The important factor for the success is a powerful user-interface which 1) is capable of overly complex functionality from user, 2) enables easy access to all functionality and 3) helps the user to focus on the essential. Only by combining all existing solutions in one system, mobile computing can be used in emergencies and MCIs. The vision can become true when we reduce the complexity with which the user has to deal without taking his **flexibility** away.

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