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# Smart algorithms for patient assignment in disasters

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**Abstract**

We describe the design and implementation of a system to automate patient handling and assignment to hospitals in mass disasters involving a large number of injured victims over a wireless network. In addition, the previously developed MEDTOC system is modified and enhanced to include location-aware features at the disaster site, as well as quick classification and assignment of patients to nearby hospitals. We present the designed implementation and the results from a simulated disaster involving a fictitious 20-story apartment building located in Ras Al Khaimah, United Arab Emirates. It is expected that chaotic mass-disaster situations can be more suitably controlled and stabilized by using the techniques from this project, thus saving more lives.
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*Keywords:* Mass disaster; Location aware; Disaster management; Revised trauma score; Vital signs

## 1. Introduction

In any mass-disaster situation such as a building collapse, earthquake, or flash floods, it is expected that many agencies would rush to aid the victims. Given the possible large number of victims, the situation can quickly become unmanageable, and chaos can reduce the chances to save lives. In addition, chaos can limit the ability of area hospitals to identify and treat the most critically injured victims in a timely manner.

The current procedure of dealing with disasters includes setting up triage rooms at the disaster site and nearby hospitals. Patients are tagged according to their condition, and the critically injured patients are immediately transferred to nearby hospitals, where the emergency room physicians treat them. The number of first responders to a mass disaster is naturally limited as the available medical equipment and resources are never sufficient to tackle these disasters. Moreover, there might be a considerable delay in the arrival of additional medical personnel and equipment, and in soliciting medical advice for the patients in critical condition. Consequently, there is a need to bridge this gap and reduce the delay, because human lives are at risk in such situations. In addition, the paramedics are not the decision makers for the most critical patients, and the lack of physicians on the triage site shortly after the occurrence of a mass disaster aggravates the condition of the critically injured patients.

The delay in the first encounter with the physicians can be substantially reduced using our previously proposed Medical Data Transmission Over Cellular Network (MEDTOC) System [1,2]. MEDTOC provides a mechanism to integrate the patient data collected on site using vital motes [3] and send it to hospitals using the cellular network. Vital motes are sensors that capture the vital signs of patients and transmit them wirelessly to a nearby on-site computer. A web portal is designed to let the authorized users obtain vital statistics about the overall disaster management scenario.

The idea of real-time wireless transmission of patient medical data has been presented earlier, and several schemes have

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been developed for this purpose [4–6]. However, most of these schemes are limited to single-patient data. On the other hand, the data aggregation for multiple patients tested in [3,6] is confined to internal usage in triage rooms either on site or within hospitals. The CodeBlue sensors [7] can be used to aggregate information in vital signs for multiple patients, including temperature, blood pressure, SpO2 saturation levels, and pulse rate. Similarly, in the MEDTOC system [1,2], the vital signs of a large number of patients can be integrated, optionally compressed, and transmitted over the cellular network to nearby hospitals for monitoring of patients. In the hospital, the received data are decompressed and segregated to be displayed to the physicians. MEDTOC features specific packet-header formats, patient-grouping criteria, and a web portal to provide a secure and familiar interface to the physicians.

In this paper, we outline an updated MEDTOC-based framework to manage the flow of patients to nearby hospitals in a situation resulting from a mass disaster. The previously defined system is modified and enhanced to adapt to the available resources. In the next section, we discuss the state of the art in mass-disaster management. In Section 3, we present the previously defined architecture of the MEDTOC system, the enhancements, and the algorithm to assign patients to hospitals based on their Revised Trauma Score (RTS) value and other factors. Section 4 discusses the regional hospitals in Ras Al Khaimah (RAK), United Arab Emirates (UAE) used as an example for conducting simulations and the simulation results of MEDTOC handling a disaster situation from the collapse of a fictitious 20-story building. Conclusion and future work are discussed in Section 5.

## 2. Current disaster management schemes

In [8], the design of a healthcare information system named Advanced Health and Disaster Aid Network (AID-N) is presented. This system facilitates patient care, resource allocation, and allows real-time communication for triage. However, AID-N is an expensive system due to medics training, system maintenance, and database system management at the server side.

The researchers in [9] focused on solving the logistic problems at the disaster site by proposing an emergency response system based on the Disaster Aid Network. The researchers in [10] designed an IT application to improve the care of patients at the disaster site. They designed the Wireless Internet Information System for Medical Response in Disaster (WISARD) to enhance the tracking and quality of the patient information in mass-casualty events. The WISARD has some limitations by factors such as the external bandwidth for communications and the complex design of the electronic health records. A disaster planning strategy for the management of medical records in health facilities is presented in [11,12].

The online Victim Tracing and Tracking System (ViTTS) was presented in [13] and is based on a wireless network using routers on the ambulances and the direct online registration of victims. The ViTTS challenges include linking the pre-hospital data to the in-hospital data that requires modification at some stage in the healthcare system. Other researchers [14] focused on developing an optimal response strategy to a catastrophic event by minimizing the response time and related costs. However, their model only considers transporting victims with non-life-threatening injuries needing medical attention.

In this paper, the extended MEDTOC system presents the following features. The system allows tagging each patient at the disaster site with an ID and a triage tag that represents an approximate RTS value [15]. It implements a disaster management algorithm at the client (disaster) side that finds the nearest hospitals and automates the process of patient data flow to the hospitals. In addition, it implements another disaster management algorithm at the server (hospital) side that assigns patients to nearby hospitals based on several factors including the distance, trauma rank and available capacity of the hospital.

## 3. MEDTOC architecture

MEDTOC has been designed as a client–server application to manage the processing of patients at a disaster site. MEDTOC was introduced as a system to establish communication between the triage site and the nearest hospital to exchange patient information and perform remote monitoring [1,2]. The vital signs being monitored as well as the associated data rates and packet headers were determined according to the CAN 2.0A (i.e., Controller Area Network Protocol). Furthermore, an integration, compression, and transmission protocol was specified to integrate the data before transmission and segregate it on reception. An OPNET simulation was conducted to configure the UMTS-based transmission of patient data from a moving ambulance to a hospital. The transmission passes through various node-B stations with medium to heavy loads and repeated handoffs.

This study was based on the use of vital motes, described in Section 1. However, after consultation with the emergency room physicians from a hospital and trauma center, we also considered the option of using triage tags. There are certain difficulties in the use of triage tags instead of vital motes, including the delay in the manual processing of triage tags, as opposed to the automated processing of vital motes and zero-delay updates of the patient condition. However, the vital motes are not widely available and the paramedics are well-trained to mark each patient's condition with a color-coded triage tag. Moreover, the paramedics are largely unfamiliar with the use and administration of vital motes. Hence, if a disaster management scheme is widely implemented, it cannot only rely on something that may not be universally available. The colors of the triage tags translate to approximate RTS values for patients. Therefore, the scheme for patient data transmission is greatly simplified, and only the information of patient ID and RTS value of the triage tag are transferred to the hospital. The emergency room physicians also recommended that the process must be location aware and it must act proactively to assign patients to suitable hospitals. Hence, we extended the MEDTOC system by introducing location awareness and specifying the parameters that control the assignment of disaster victims to area hospitals using a series of software programs.

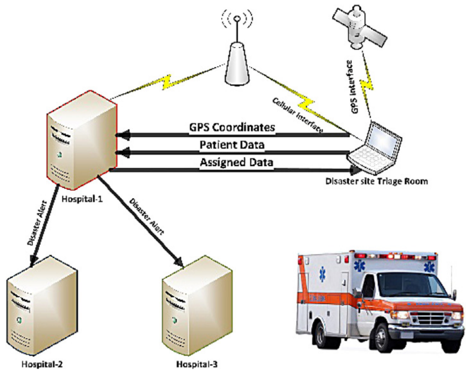


**Fig. 1.** MEDTOC client–server interface.

The enhanced MEDTOC system identifies the nearest hospitals to a mass-disaster location and automates the process of patient data flow and patient assignments. To the best of our knowledge, none of the existing patient-data communication schemes handle the patient assignment problem. Pre-assigning patients to most suitable hospitals can reduce the chaos and confusion in a triage room dealing with a mass disaster. The MEDTOC client can be configured in the portable computer used by paramedics who respond to disaster calls. The MEDTOC server can be configured in the hospital computer that waits for the client to share the disaster information. In the following, we describe the operation of the MEDTOC client and server in the event of a mass disaster [1].

When a disaster occurs, the first responders reach the site, designate a triage area, and boot the client-side MEDTOC software on a portable computer. This computer is assumed to contain a GPS interface and a cellular network interface. The following steps are taken by the MEDTOC client and server as shown in Fig. 1, and explained in Algorithms 1.1 and 1.2.

The client uses the GPS system for self-location. Based on its position, it searches for nearby hospitals using public data and connects to the server-side software in the nearest hospital. The position of the client is then transferred to the server to determine the disaster location. The server software attempts to establish connection with the server nodes in 2 to 5 additional nearby hospitals within 50 km. The paramedics attach vital motes to the patients, and the motes start sending the corresponding vital signs to the local client. In absence of vital motes, the paramedics use color-coded paper triage tags. The six color codes include white (nonurgent), green (less urgent), yellow (urgent), red (emergent), blue (extremely urgent), and black (dead). Based on the available information, the server checks the queue and assigns a physician from a given hospital to a patient. Next, the server notifies the client about the assignments for all the patients.

The RTS of a patient can be used as the most important factor in assigning the patient to a physician in a specific hospital. If vital motes are used, the paramedics should assign an RTS value to each patient. If triage tags are used, the colors represent a specific range of RTS values, and these values can be transferred to the command and control center for further processing.

MEDTOC defines the Total Treatment Capacity (TTC) of a hospital based on the individual Critical Care Capacity (CCC) of every physician. The TTC of a hospital $h$ with total number of physicians $p$ available to treat victims is

$$TTC_h = \sum_{i=1}^{p} CCC_i. \tag{1}$$

When a patient is assigned to a physician, both the physician and the hospital capacities are updated. MEDTOC updates the CCC of the selected physician by subtracting the difference of patient RTS value and the maximum possible RTS value of 7.8408. The equations for updating the treatment capacities after the assignment of patient $m$ to a physician $n$ at hospital $h$ are shown below as reported in [1].

$$CCC_{n,new} = CCC_{n,old} - (7.8408 - RTS_m) \tag{2}$$

$$TTC_{h,new} = TTC_{h,old} - (7.8408 - RTS_m). \tag{3}$$

The assignment of a patient to a specific hospital is determined by the distance to the hospital, the hospital trauma rank and TTC as shown in Eq. (4).

$$Priority(h) = \frac{TR_h}{TR_{max} * RTS} + \left(1 - \frac{D_h}{D_{max}}\right) + \frac{TTC_{h,current}}{TTC_{h,initial}}. \tag{4}$$

Eq. (4) establishes the priority of a hospital in the assignment of patients based on three factors. The first factor considers the trauma ranking of the hospital. This rank, between 1 and 5, is calculated from five parameters as shown below. These parameters were validated in collaboration with the Head of Emergency from a major Hospital and Trauma Center.

a. 24 × 7 emergency service
b. 24 × 7 ambulances with trained paramedics
c. 24 × 7 emergency room physicians
d. Ample Blood supply always available
e. Well-equipped intensive care and modern OT for emergency surgeries.

The patient RTS value, determined from either triage tags or vital motes, also has an influence on the selection of the hospital. Lower RTS values increase the priority of the hospital having the best trauma rank within the specified region. The second factor contributes to the priority of the hospital based on its distance from the disaster site (or travel time depending on the current traffic), and the third factor considers the impact of the updated TTC value for the hospital. The value of Eq. (4) determines a hospital priority, and the hospital with the highest priority would receive the next patient from the disaster site. After each assignment, Eqs. (2), (3), and (4) are updated for the next patient. The complete algorithms are shown in Algorithm 1.1 and Algorithm 1.2 of Tables 1 and 2.

## 4. Simulation settings and results

We conducted an interview with physicians to determine the most important factors in dealing with a mass-disaster

**Table 1**
MEDTOC client-side algorithm.

| **Algorithm 1.1: MEDTOC disaster management algorithm at client side** |
|---|
| 1. Create_Disater_Area (Location, Hospitals, GPS) |
| 2. EstablishSecureConnection(Server$_{hi}$,Disaster_Area Coordinates)<br>3. for m=1,……,n // where n is the no of patients<br>Send(RTS$_m$,patId$_m$, Server$_{hi}$) |
| 3. for m=1,…..,n |
| 3.1 Retrieve(hospID, physlID, Server$_{hi}$)<br>3.2 Dispatch(patId, hospID) |
| 4. (optional): EstablishSecureConnection(physID) |

**Table 2**
MEDTOC server-side algorithm.

| **Algorithm 1.2: MEDTOC disaster management algorithm at server side** |
|---|
| 1. alert=Wait(H1); //Wait for disaster alert from client side |
| 2.RetrieveInfoDisater(disaterID, GPS) |
| 3. list=GenerateList(H$_1$,H$_2$,H$_3$) |
| 4. for each hospital h$_i$ ∈ in the list |
| 4.1 Initalize(TTC$_{Hi}$,D$_{Hi}$, TR$_{Hi}$) |
| 5. D$_{max}$= maxDistance(list) |
| 6. RetrievInfoPatient(patID, RTS) |
| 7. For m=1 to N// where n is the number of patients<br>7.1 for each Hi in the list<br>7.1.1 $\boldsymbol{Priority(hi) = \frac{TR_h}{TRmax*RTS} + \left(1 - \frac{D_h}{Dmax}\right) + \left(\frac{TTC_{h,current}}{TTC_{h,initial}}\right)}$<br>7.1.2 *h= Max(Priority (H1), Priority (H2), Priority (H3))*<br>7.1.3 *physID=Choose(\|CCC\|, h)*<br>7.1.4 *Assign(Pm,physID)*<br>7.1.5 $\boldsymbol{CCC_{n,new} = CCC_{n,old} - (7.8408 - RTS_m)}$<br>7.1.6 $\boldsymbol{TTC_{h,new} = TTC_{h,old} - (7.8408 - RTS_m)}$ |

situation. We surveyed the hospitals in the RAK region, and interviewed the Head of Accident and Emergency from the Al Rashid Hospital and Trauma Center (Dubai, UAE). In the following, we present our observations and summarize the obtained information.

To evaluate a patient, the emergency physicians use condition type, condition severity, and vital signs. In addition, they heavily rely on the patient observation. At a disaster site, the paramedics may not have enough time to determine the RTS. However, they are well trained to quickly determine the triage tag color for each patient. The classification of patients by trauma type and score can help clustering the patients for their assignment to suitable physicians. The main strength of MEDTOC is to distribute the load of an emergency situation across several nearby hospitals based on their capacity and

**Table 3**
Comparative patient assignments.

| RTS range | Hosp 1 | Hosp 2 | Hosp 3 |
|---|---|---|---|
| 0.0–0.5 | 0 | 0 | 67 |
| 0.5–1.0 | 2 | 23 | 28 |
| 1.0–1.5 | 24 | 44 | 83 |
| 1.5–2.0 | 26 | 16 | 53 |
| 2.0–2.5 | 60 | 23 | 37 |
| 2.5–3.0 | 42 | 16 | 25 |
| 3.0–3.5 | 41 | 11 | 25 |
| 3.5–4.0 | 30 | 9 | 15 |
| **Grand total** | **225** | **142** | **333** |

the assistance of physicians who may not otherwise be able to help.

The data collected in the RAK region about various hospitals were used for a simulation using the MEDTOC client and server software. The simulation aimed to assess if the high number of victims resulting from a multistory building collapse could be accommodated in the local hospitals. To simulate the disaster scenario, we selected a fictitious 20-story apartment building in the Al-Hamra area of RAK, UAE. This building is supposed to have between 8 and 10 apartments of various sizes on each floor. The simulated disaster is the building collapse due to an earthquake, affecting several hundred inhabitants present in the building at the disaster time.

We used a series of C and MATLAB programs to simulate the condition of victims in the disaster by generating RTS values from a Poisson distribution within the range 0.0–4.0. The client program, written in C, uses a GPS interface to determine the location of the disaster. An interface with Google public libraries searches facilities within a 50 km radius and selects those identified as hospitals. The client side establishes communication with the server side at one of the closest hospitals. The location of the disaster is registered with the hospital server.

The client then prepares and forwards a data file, using a client–server software written in C, in which the patient IDs are bound with their RTS values. The server, written in MATLAB, runs the algorithms to assign patients to specific hospitals and assigns a physician (*PhysID*) and hospital (*HospID*) to each patient. For the purpose of this simulation, the RAK Hospital, Saqr Hospital, and Saif Hospital were selected. The RAK Hospital (*Hosp1*) is the closest to the disaster site but it has the lowest trauma rank. The second closest one is the Saqr Hospital (*Hosp3*) with the best trauma rank. Finally, the Saif Hospital (*Hosp2*) is the farthest with a mid-level trauma rank. In Table 3, the results of patient assignment to these three hospitals are shown when the number of patients is 700. It can be seen that the patients in the most critical condition are assigned to *Hosp3*, because it has the highest trauma rank. As the RTS value increases, the patients are assigned to the other hospitals.

The average load of physicians in the hospitals was calculated, and it varied between 3 and 3.5 when considering 700 patients. The average RTS value for patients in *Hosp3* was 1.20, whereas that for *Hosp1* and *Hosp2* was 2.98 and 1.93, respectively. The ranges of RTS values in the first column of Table 3, are mapped to triage-tag colors as discussed in

Section 3. The average RTS values are the lowest for *Hosp3*, which has the highest trauma rank among the three hospitals, because the patients in the most critical condition are assigned to the hospital with the best trauma facilities.

## 5. Conclusion and future work

In this paper, we described the automated patient assignment to physicians in nearby hospitals in a mass-disaster situation. Ubiquitous cellular and GPS connectivity, as well as a smart computing infrastructure of hospitals are assumed. We have developed the patient assignment scheme as part of the overall MEDTOC framework, which entails the disaster management with patient data transmission via the cellular network to designated hospitals. The patient assignment to hospitals is handled using several factors including the triage tags assigned by on-site paramedics to victims, the perceived trauma rank of a hospital, the driving distance to the hospital from the disaster site, and the TTC of the hospital derived from the CCCs of the physicians. Several programs were developed in C and MATLAB to generate the simulated patients' data, transfer the location and patient data to the server, and finally transfer the hospital and physician assignment of patients to the disaster site, aiming to expedite the process of patient transportation. The simulation results of a mass disaster caused by the collapse of a fictitious apartment building in RAK, UAE are presented based on the information gathered from three regional hospitals. The results show a smooth and intelligent assignment of patients with the most critical patients first assigned to the hospital with the best trauma rank, followed by a controlled distribution of patients to other regional hospitals. Future work includes expanding the scope of the project by relating patient data obtained from vital motes with triage tags, and including secondary or lower trauma rank hospitals for automated transfer decisions.

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## Conflict of interest

The authors declare that there is no conflict of interest in this paper.

## References

[1] R. Olson, J.A. Zubairi, A. Biliciler, A software framework for patient data handling in emergencies and disasters, in: Int. Conf. Collab. Technol. Syst., CTS, 2014, pp. 553–557.

[2] J.A. Zubairi, S. Misbahuddin, I. Tasadduq, Emergency medical data transmission systems and techniques, in: Handbook of Research on Advances in Health Informatics and Electronic Healthcare Applications: Global Adoption and Impact of Information Communication Technologies, IGI Global, 2010.

[3] T. Gao, L. Hauenstein, A. Alm, D. Craw, Vital signs monitoring and patient tracking over a wireless network, Johns Hopkins APL Tech. Dig. 27 (2006) 66–74.

[4] P.T. Campbell, et al., Prehospital triage of acute myocardial infarction: wireless transmission of electrocardiograms to the on-call cardiologist via a handheld computer, J. Electrocardiol. 38 (2005) 300–309.

[5] P. Giovas, D. Thomakos, O. Papazachou, D. Papadoyannis, Medical aspects of prehospital cardiac telecare, in: M-Health Emerging Mobile Health Systems, Springer, 2006, pp. 389–400.

[6] B. Chen, D. Pompili, Transmission of patient vital signs using wireless body area networks, Mob. Netw. Appl. 16 (2011) 663–682.

[7] D. Malan, T. Fulford-Jones, M. Welsh, S. Moulton, Codeblue: an ad hoc sensor network infrastructure for emergency medical care, in: Int. Workshop Wearable Implant. Body Sens. Netw., 2004.

[8] T. Gao, et al., The advanced health and disaster aid network: a light-weight wireless medical system for triage, IEEE Trans. Biomed. Circuits Syst. 1 (2007) 203–216.

[9] A.-K. Chandra-Sekaran, A. Nwokafor, L. Shammas, C. Kunze, K.D. Mueller-Glaser, A disaster aid sensor network using zigbee for patient localization and air temperature monitoring, Int. J. Adv. Internet Technol. 2 (2009) 68–80.

[10] L.A. Lenert, et al., Design and evaluation of a wireless electronic health records system for field care in mass casualty settings, J. Am. Med. Inform. Assoc. 18 (2011) 842–852.

[11] E. Smith, R. Macdonald, Managing health information during disasters, Health Inf. Manag. J. 35 (2006) 8–13.

[12] P. Moore, Disaster Planning for Healthcare Facilities, People's Medical Publishing House Ltd, USA, 2013.

[13] G.M. Marres, L. Taal, M. Bemelman, J. Bouman, L.P. Leenen, Online victim tracking and tracing system (ViTTS) for major incident casualties, Prehosp. Disaster Med. 28 (2013) 445–453.

[14] M. Muaafa, A.L. Concho, J. Ramirez-Marquez, Emergency resource allocation for disaster response: an evolutionary approach, in: Probab. Saf. Assess. Manag. Conf., PSAM12, 2014.

[15] H. Champion, et al., A revision of the Trauma Score, J. Trauma Acute Care Surg. 29 (1989) 623–629.