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A Context-aware Middleware-level Solution towards a Ubiquitous Healthcare System

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***Abstract*—Recent advances in wireless technology, sensors and portable devices offer interesting opportunities to enable ubiquitous assistance to individuals in need of prompt help. Providing healthcare services to mobile users, such as, patients, elders, or potential drug abusers, is a rather challenging task. Novel middleware-level supports are required to integrate sensor infrastructures capable of detecting changes in the monitored subjects' health conditions and of alerting medical personnel, and the victim's relatives and friends in case of emergency situations. Along this line, the paper envisions a context-aware middleware-level solution dubbed Pervasive Environment for Affective Healthcare (PEACH). PEACH integrates together various sensors in a Wireless Body Area Network (WBAN) to detect alterations of monitored subjects' affective and physical conditions, aggregate the sensed information, and also detect potentially dangerous situations for the monitored subject. Finally, PEACH aims at providing outdoor assistance to the victim/patient by quickly promoting the formation of ad hoc rescue groups comprising nearby volunteers. Through encouraging results obtained from both simulations and a practical drug-rehabilitation application testbed, the effectiveness of the envisioned PEACH framework is verified.**

I. Introduction

The widespread diffusion of low-cost portable/embedded devices, and the proliferation of wireless networking solutions offer unique opportunities to avoid/postpone patients hospitalizations, with positive impacts in social, emotional, and economic contexts. Impaired individuals, patients affected by chronic diseases or engaged in rehabilitation therapies may take full advantage from pervasive healthcare systems deployed close to where they live and move, with the main goals of increased independence, safety, and quality of life on the one hand, and of care cost-saving on the other hand [1].

Various research proposals have recently appeared in the literature that suggest the development of solutions, which are able to record and analyze patients' behavioral patterns, to monitor users' mobility, to assist individuals with special needs in their daily activities, such as self-care, and so forth. The basic assumption of available research proposal is to rely on the visibility of patient context information, e.g., his/her physical condition and cognitive status to determine the best suited assistive operation to implement, e.g., remind elders to take prescribed medicines, avoid falls to vision impaired individuals, and so forth. The vast majority of available solutions rely on sensor platforms to obtain context information about user's conditions. The sets of data to monitor depend on the application scenario and may include, for example, user location and behavioral pattern.

In spite of the great interest towards healthcare service provisioning, several research questions are still open. First, we need to consider how to provide a solution capable of monitoring anywhere and anytime patient's bio-signals for determining whether prompt assistance is needed. In addition, we also need to address how to simplify patient assistance in emergency situations, specially in outdoor environments.

Based upon our previous research on pervasive healthcare [2], [3], this research work presents the PEACH (***P****ervasive* ***E****nvironment for* ***A****ffe****C****tive* ***H****ealthcare*) framework, a context-aware middleware-level solution capable of integrating together bio-sensors able of detecting alterations of a patient's psycho-physical conditions, of aggregating sensed information, of detecting potentially dangerous situations for the patient, and, in this case, capable of promoting and supporting the formation of groups of individuals willing to provide prompt assistance to the patient. These characteristics make PEACH appealing for the monitoring of patients affected by chronic diseases who may require prompt assistance, e.g., cardiopaths, or for the recovery of drug abusers who may be subject to overdoses. PEACH is also not only limited to indoor emergency detection and response, but also takes into account the fact that emergency situations may arise and need to be dealt with anywhere, anytime including outdoor scenarios.

The remainder of this paper is organized as follows. Section II presents relevant related researches. Section III presents PEACH model architecture and the implementation insights on response group members selection. Section IV sets the presented work within a state-of-the-art field to evaluate the performance of PEACH. Concluding remarks follow in Section V.

II. Related Research Work

In recent times, several research efforts have been directed [1] towards realizing pervasive healthcare solutions. The increased availability of relatively cheap Commonly On The Shelf (COTS) mobile devices, sensors, and wireless networking solutions promotes design and development of ubiquitous assistance solutions that integrate wearable devices and smart environments to assist people affected by severe disabilities, to facilitate diagnosis of diseases, and to detect possibly

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occurring emergency situations. Furthermore, the integration of affective computing in ubiquitous health care network is also an extremely challenging research area which deals with representation, detection, and classification of users' emotions. Emotions typically induce physical manifestations in human body, thus producing signals that can be measured through ordinary bio-sensors. The availability of wearable and low-cost bio-sensors opens the possibility to monitor individuals' emotional reactions anywhere and anytime [4]. Skin conductivity sensors may be integrated in shoes, blood volume pressure sensors can be deployed in earrings or watches, respiration sensors may be deployed in T-Shirts, and so forth [5].

Recently, a lot of focus has been diverted towards building integrated smart environments. The Honeywell Laboratories' Independent Life Style Assistant (ILSA) [6], and more recently numerous work such as in [7], [8], are notable examples of such smart frameworks. In particular, ILSA adopts a multi-agent architecture where different agents are deployed that are able to support data monitoring via home-installed sensors. Further agents can assist individuals by controlling actuators deployed in their home environments. More in line with the basic ideas of affective computing, few solutions are promoting user-centric in-home assistance design approaches. For example, the system in [9] adopts a vision-based patient monitoring approach to identify, through Artificial Intelligence techniques, whether assisted individuals correctly perform basic daily activities. Recent researches also aim at extending the support provided by ubiquitous assistance solutions, and at promoting patients' engagement in rich socio-emotional relationships. For example, the work in [2], [10] introduce context-aware middleware solutions for the formulation and management of ad hoc assistance teams to provide emergency assistance to senior citizens in need of immediate help.

III. The PEACH Framework

PEACH offers a context-aware middleware solution, which facilitates healthcare service provisioning through various management roles. Each patient, in PEACH, is equipped with a portable device (e.g., Personal Digital Assistant or PDA). The patient conditions are monitored by deploying various Sensing Entities (SEs). These SEs are connected through a Wireless Body Area Network (WBAN), to the user access terminal (e.g., PDA), which on its turns, provides adequate support for gathering and aggregating sensed data and detecting situations where patient assistance is required. Upon detecting an emergency situation, the user access terminal can alert passersby for prompt assistance. In addition, a Surveillance Center (SC) is also alerted for promoting a prompt response group composed of nearby volunteers willing to help the patient.

Evaluating possible disorder at the user access terminal level. According to the patient's pathology, SEs may monitor relevant emotion-related (i.e., affective) and physical information, such as patient's heartbeat, gesture, skin conductivity, and so forth. SEs not only sense patient context information but also continuously forward collected data to the PEACH support installed on the user access terminal, e.g., a PDA with smart phone features. According to collected SEs readings, the

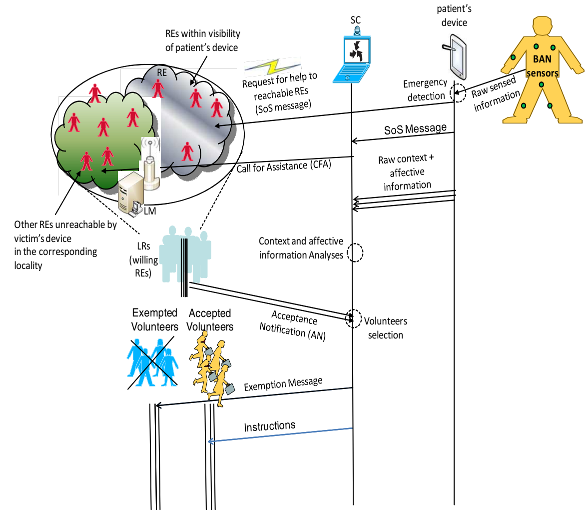


Fig. 1. The messages exchanged between different entities in PEACH framework upon detection of an emergency event.

PEACH framework permits to aggregate context information and to detect the presence of a possibly imminent emergency state. Let us assume that a disease or an abnormal health condition (e.g., due to drug abuse) has developed in the patient's body. For example, diseases can vary diversely, from a simple outbreak of flu to a serious case of heart attack or appendicitis. Emotional abnormalities, on the other hand, may be illustrated with examples of panic attacks, paranoia, and so on. In case of certain abnormalities such as drug abuse or overuse, patients exhibit both physiological and emotional symptoms. Based on the set of symptoms observed by the SEs, PEACH is able to estimate the probability of these various combinations of physiological and/or emotional disorders. Let there be a set of disorders and a set of observable symptoms, denoted by F_j and x_i^j, respectively, where $i = 1, 2, ..., n$ and $j = 1, 2, ..., m$. If the probabilities associated with the disorders, i.e., $(p(F_j))$s are known, and further, if the symptoms $x_1^j, x_2^j, ..., x_l^j$, are known (where $\{1 \leq l \leq n\}$) for the j^{th} disorder such that their conditional probabilities $p(x_1^j|F_j), p(x_2^j|F_j), ..., p(x_l^j|F_j)$ are statistically independent and known, then from Baye's rule, we have the following:

$$p(F_j|x_1x_2, ..., x_n) = \frac{p(F_j x_1^j x_2^j, ..., x_l^j)}{p(x_1^j x_2^j, ..., x_l^j)} \quad (1)$$

As a consequence of the assumed statistical independence of $p(x_1^j|F_j), p(x_2^j|F_j), ..., p(x_l^j|F_j)$, we have the following:

$$p(x_1^j x_2^j, ..., x_l^j) = \sum_{k=1}^{m} p(x_1^k|F_k)p(x_2^k|F_k)...p(x_l^k|F_k)p(F_k) \quad (2)$$

and

$$p(F_j x_1^j x_2^j, ..., x_l^j) = p(x_1^j|F_j)...p(x_l^j|F_j)p(F_j) \quad (3)$$

By substituting Eq. 2 and Eq. 3 into Eq. 1, we have:

$$p(F_j|x_1x_2,...,x_n) = \frac{p(x_1^j|F_j)p(x_2^j|F_j)...p(x_l^j|F_j)p(F_j)}{\sum_{k=1}^{m} p(x_1^k|F_k)p(x_2^k|F_k)...p(x_l^k|F_k)p(F_k)} \tag{4}$$

where $p(F_k)$ and $p(x_i^j|F_j)$ represent the probability of having the k^{th} disorder (i.e., physiological, emotional, or combined) and that of observing symptom x_i, given that the patient has the j^{th} disorder (denoted by the functional value F_j), respectively.

PEACH communications framework and response group management. Upon detecting a probable disorder (i.e., a possibly dangerous situation), the patient access terminal promptly promotes suitable response operations. In particular, a response group of volunteers allocated nearby the patient is promptly composed. In addition, aggregated context information are forwarded to the SC by exploiting available networking support, e.g., Wi-Fi, Femto, or cellular networks. In the following, details of response group formation and management are discussed.

While the patient is roaming, his/her access terminal belongs, as a node, to a Mobile Ad-hoc Network (MANET) topology. When the patient's access terminal/PDA detects abnormal context information that are indicative of an emergency event, it sends plea for help to surrounding ad hoc peers. To discover these peers, the patient's device can employ Bluetooth technology that uses the free and globally available 2.4GHz Industrial-Scientific-Medical (ISM) radio band. This is unlicensed for low-power use and allows the patient's device to communicate with peer devices within a range of 10-100 m. For increased range of communications, IEEE 802.11 ad hoc mode may also be employed. These peers in the concerned locality (i.e., in the locality of the patient) are called Roaming Entities (REs). As demonstrated in Fig. 1, the patient's device sends plea for help to the REs within its visibility. This emergency notification message issued by the patient's PDA is referred to as SOS. However, there may be a number of undiscovered REs in the corresponding locality that are unreachable by the victim's device. In order to include all the REs in an effective manner, PEACH uses the Local Manager (LM) entities. For each locality, a LM is deployed in the access point. Upon handoff, a device switches to the new access point of the new locality, and this information is delegated and stored in the LM of the corresponding locality. In the mean time, the patient's PDA also notifies a SOS to the SC regarding the event (e.g., by writing a SMS or by placing an emergency call to the SC). On the other hand, the REs representing the roaming individuals, who are positioned in the same locality as the victim and have been requested by the victim's PDA for assistance, also apprise the SC whether they intend to assist the victim or not through Acceptance Notification (AN) messages. The SC then finds out the available REs in the concerned locality by contacting with the LM of that locality and issues a Call For Assistance (CFA) message to the rest of the REs, which were not discovered and contacted by the victim's device. The contents of a CFA message include basic personal information of the victim such as his age and sex, his current location, his physical and cognitive characteristics, the kind of assistance he requires, his current health status (e.g., high blood pressure, eye-popping conditions, and so on that are typical of drug overdoses).

A RE, willing to help the patient by dispatching an Acceptance Notification (AN) message to the SC, is referred to as a Local Rescuer (LR). Each LR is identified by a unique User IDentifier dubbed as UID. The AN message consists of the LR's UID, current position, and the estimated time frame within which he may be able to arrive at the target spot. Each LR is obviously a subscriber of the PEACH service. A LR may be a family member, friend, or neighbor of the victim, or may also be a total stranger (e.g., from a common pedestrian to a professional caregiver/medical specialist). SC stores the profile information of every LR including his/her identity, current physical location, medical background, track record in providing timely assistance to victims. The devices subscribed by LRs are trusted by the SC so that they may discover, join, and leave dynamic rescue groups. A LR that joins a particular group is also able to fetch from the SC the visibility information and also the profiles of other members in that group who are located nearby. In this way, PEACH avoids the situation where the patient's PDA would have to provide information to all the peers in the locality, which would (i) flood the network with redundant information increasing congestion and communications delay, and (ii) exhaust scarce battery power of the patient's PDA that should remain switched on as long as possible. In addition, PEACH also facilitates message exchanges among the ad hoc group members (i.e., the LRs), thereby allowing them to collaborate swiftly to assist the victim. It should be noted that unlike the work in [3], PEACH can deal with emergency situations arising in outdoor environments by exploiting its communications framework described so far.

Determining and responding to emergency states. We now describe the manner in which the PEACH framework deals with emergency states through the Emergency Response Decision Making (ERDM) module installed at the SC. As the SC receives plea for help from a patient's device, it needs to decide which LRs may become REs. Consequently, it faces a Multiple Attribute Decision Making (MADM) problem in terms of the LRs' current locations, skills, medical expertise, history of previous rescue attempts, and so forth. In order to solve this problem, for each LR, LR_k, that subscribes to the PEACH service, a set of attributes $(X_{k,j}, j\epsilon\{1,2,...,t\})$ is assigned as shown in Table I. These attributes include: (i) the expertise and skills of the LRs, (ii) their history records in providing assistance, and (iii) the trust levels that SC associates with them. SC constantly updates and maintains these attributes. The PEACH implementation assumes that there are M emergency levels predefined at the SC. As shown in Table II, for each emergency level, e_i $(i\epsilon\{1,2,...M\})$ and each attribute X_j $(j\epsilon\{1,2,...,l\})$, SC assigns a weight $w_{i,j}$ and three additional parameters, namely the minimum response time within which the victim should be assisted, the acceptance threshold for selecting LRs, and the maximum waiting time SC should wait for receiving AN messages from the LRs, denoted by θ_i, γ_i, and τ_i, respectively.

TABLE I
FORMAT OF LRS PROFILES.

LR ID (LR_i)	Attribute 1, X_1	Attribute 2, X_2	Attribute 3, X_3		Attribute t, X_t
LR_1	$X_{1,1}$	$X_{1,2}$	$X_{1,3}$		$X_{1,t}$
LR_2	$X_{2,1}$	$X_{2,2}$	$X_{2,3}$		$X_{2,t}$
LR_3	$X_{3,1}$	$X_{3,2}$	$X_{3,3}$		$X_{3,t}$
.	.	.	.	.	
.	.	.	.	.	
.	.	.	.	.	
LR_N	$X_{N,1}$	$X_{N,2}$	$X_{N,3}$		$X_{N,t}$

TABLE II
EMERGENCY LEVELS AND THEIR ASSOCIATED PARAMETERS.

Emergency Level	Attribute 1, X_1	Attribute 2, X_2		Attribute t, X_t	Action Time	Acceptance Threshold	Waiting Timeout
e_1	$w_{1,1}$	$w_{1,2}$		$w_{1,t}$	θ_1	γ_1	τ_1
e_2	$w_{2,1}$	$w_{2,2}$		$w_{2,t}$	θ_2	γ_2	τ_2
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
e_M	$w_{M,1}$	$w_{M,2}$		$w_{M,t}$	θ_M	γ_M	τ_M

Whenever potential rescuers are selected, ERDM forwards them a "request to join" the group. The request to join message includes information such as, the Group ID (GID) associated with that group, a set of instructions to attend the patient, last confirmed location of the patient, information pertaining to the shortest route to access the victim, and so forth. To this end, the ERDM module awaits for acknowledgments (i.e., AN messages in Fig. 1) from potential helpers during a timeout period of τ_m. When either τ_m expires or the system receives the responses from at least the required number of skillful and/or non-skilled helpers for this emergency level, ERDM sorts out the helpers based on the information within their AN messages (e.g., physical proximity and availability of the LRs) and also based on the minimum response time (θ_i), specific to the emergency level. Out of these already sorted LRs, only those with attributes that satisfy the following condition are selected to assist the victim:

$$A_k \cdot W_m = \sum_{p=1}^{t} X_{k,p} \cdot w_{m,p} \geq \gamma_m \tag{5}$$

where A_k and W_m represent the vector of attributes of LR_k and the weight vector associated with the emergency level (i.e., $W_m = \{w_{m,1}, w_{m,2}, ..., w_{m,t}\}$), respectively.

Thus, when the set of volunteers willing to help the patient is determined, ERDM coordinates with the group communications services at the SC to enable group collaboration.

IV. PERFORMANCE EVALUATION IN A DRUG ADDICTION SCENARIO

An application prototype of PEACH is deployed in a testbed to detect drug-overdoses and to also promote assistance groups on the fly. We describe the experimental settings followed by the results, which demonstrate the practicality of PEACH.

A. Experimental Set-up

The experimental set-up considers three basic entities, namely the patient, rescuer(s), and SC roles. The patient's WBAN consists of GPS location support, along with several bio-sensors including blood pressure sensors, respiration sensors, and skin conductivity sensors. Indeed, sensors are selected on the basis of the application scenario. In our experiments in drug overdose avoidance domains, we have reduced monitoring to only the key symptoms including rapid/irregular heart beats, elevated pulse rate, elevated blood pressure, rise in body temperature, change/rise in hormone levels, and so forth. Depending on patient's needs, however, it is also possible to enrich the sensing platform by augmenting further elements. Each patient is equipped with a Xybernaut MA-V wearable computer comprising Linux, J2SE 1.5, and PEACH services which gather and aggregate context information from the SEs in the WBAN. The patient's Xybernaut MA-V device is connected to several SEs via Bluetooth connectivity. In addition, it is also provided UMTS networking support so that it may maintain continuous remote connectivity and interact with the remote SC in case of emergency.

On the other hand, the potential rescuers in the testbed are provided with wireless-enabled iPAQ PDAs, running Linux and Java SE 1.4, along with PEACH group communications services. The rescuers devices are also equipped with hands-free communications through JAVA Speech Application Programming Interfaces (APIs) on top of the IBM Via Voice speech engine.

In our experimental setting, a PC running Linux and J2SE 1.5 is configured as the SC. The SC also runs the PEACH services responsible for assessing and responding to plea for help from the patients devices, and also for promoting ad hoc assistance teams. In addition, for each locality, a PC is configured as a LM, which operates on Linux and is attached with the local access point.

The Xybernaut MA-V devices of the patients and the iPAQ PDAs of the rescuers are connected via a MANET based on IEEE 802.11 standards. Without lack of generality, the IP addresses are statically determined at deployment time, and the "Ad hoc On-demand Distance Vector" (AODV) protocol provides the needed network routing support.

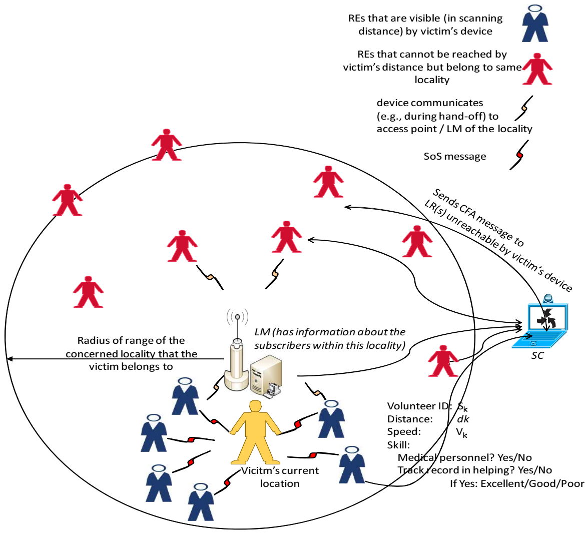


Fig. 2. A sample experimental scenario.

B. Rescue Teams Formulation

When a patient/RE device enters a locality, it attaches to the new access point and LM. Upon noticing an abnormal situation (generally interpreted as a function of the exhibited physical and/or emotional symptoms), the patient's device switches to ad hoc mode. Then it broadcasts SOS messages to the portable devices of the nearby PEACH subscribers (Fig. 2). These nearby people comprise the REs and they may be either professional caregivers or unskilled (i.e., ordinary passersby having no prior medical or caregiving experience). The REs' devices are spread at varying distances (few to one hundred meters) from the victim for the sake of constructing a realistic scenario. The REs, who are willing to respond to the victim's plea for help, become LRs and accordingly notify the SC. In the mean time, the victim's device also gets in touch with the SC. The SC, by contacting the LM, finds out and issues CFA messages to those REs which could not be discovered/reached by the victim's device. Finally, the SC promotes a rescue group comprising the LRs, which confirm their willingness to assist the victim. For this purpose, the SC creates the appropriate GIDs and UIDs to set up the rescue group profiles. The selected LRs devices join the group while the non-selected LRs devices display a negative message to their owners. After a LR joins the new group, the SC provides the "group view" containing the LR's profile information, current position, estimated time to reach the victim, and so forth. This view-based concept is rather dynamic in nature and context-dependent views may indeed change to incorporate variations in the nearby pedestrians (who turned into rescuers) while the victim awaits assistance.

As mentioned earlier, the non-selected LRs are provided with a negative message. By this way, the system tries to proactively avoid possible bystander effects. Upon receiving emergency signals for assistance by the SC, the applications installed on the selected LRs' devices require them (the respective LRs) to explicitly respond to this event. The SC that receives acknowledgments from the willing LRs build a list of volunteers, who are indeed ready to help. In our PEACH implementation, the application at a LR-end keeps playing an emergency beep at an increasing volume up to the point where the user explicitly accepts or rejects to offer assistance. Our observations from previous work [2] have indicated that such sound-signal based implementations indeed function well in clearly informing the passersby that it is not a drill, i.e., an emergency situation is at hand and their assistance is needed on an urgent basis.

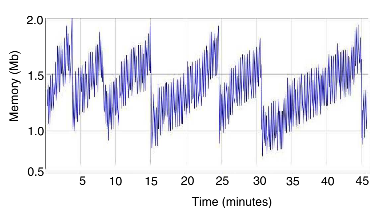
C. Experimental Results

The main results obtained from the testbed are mentioned in this section. We consider two performance metrics, namely (1) responsiveness, (2) power consumption, and (3) memory requirements of PEACH. First, we analyze the responsiveness of PEACH in formulating the rescue group which is a critical aspect in our system. The responsiveness of PEACH is defined as the time required to construct a group of responders following to an emergency notification. To be practical, PEACH needs to be able to form the response groups within a short time so that the patient/victim may be promptly assisted. Second, the PEACH power consumption (i.e., battery degradation on mobile nodes) is evaluated. Battery degradation is a crucial aspect in evaluating the performance of the anywhere anytime assistance since both patients and potential users are assumed to be able to take advantage of their devices. Third, the memory overheads of the victim/LRs devices are analyzed to verify whether it is, indeed practical, to deploy PEACH applications on portable devices, which are verily resource-constrained.

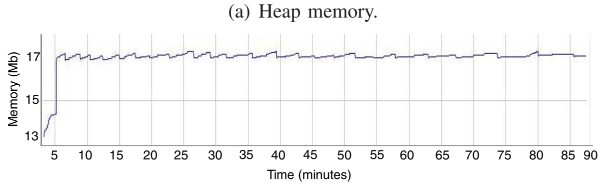
*(1) **Responsiveness of PEACH.*** The experiments in the drug-overdose case-study are constructed with the help of students in a campus-based testbed. A staff member was in charge of controlling the single patient's access terminal and 20 students acted as potential responders in the experiments. One SC is deployed over the whole testbed. The students, equipped with their respective PDAs, freely roamed around the campus. By executing an ad hoc software component on the patient-device to add abnormalities to the sensed data acquired from the SEs in the WBAN, several emergency situations were simulated at different locations at arbitrarily selected times. The time required for the students acting as potential rescuers to notice the incident, join the group, and finally reach the victim was computed. The results demonstrate that the patient-device requires only few milliseconds to alert the SC after it detects an emergency event. Furthermore, it spends about one second, on average, to gather information about the nearby passersby. On the other hand, the SC needs about three seconds for gathering the users profile information and formulating a group. However, PEACH responsiveness degrades to the order of a few minutes when it comes to the users to actually notice and respond to the invitation to join the response group. On average, group formation needs about two minutes while two additional minutes are needed for all the selected LRs to reach the victim.

In order to validate the responsiveness of PEACH over a larger scenario, Network Simulator (NS-2) [11] is used to simulate an IEEE 802.11 based MANET deployed in an area of $1km^2$. This simulation consists of one patient and a several potential helpers who are all connected to the SC (simulated by a NS-2 agent) through UMTS links. The simulation results demonstrate that the time needed for formulating a response group is associated with the number of potential helpers lying in the patient's locality. As a result, the time required to establish a rescue group varies from few seconds to tens of seconds for 50 and 100 nodes, respectively. This increases up to few minutes in case of 500 deployed nodes.

(2) ***Power Consumption at the user access terminals.*** In mobile healthcare applications, power consumption is a critical aspect. The PEACH services use up the battery at the portable devices by (i) running computation and/or (ii) performing networking operations. The computation to solve the MADM problem in order to effectively formulate a group is only performed on the fixed server operated at the SC. Furthermore although PEACH minimizes, as much as possible, the network cost by reducing the need for communicating large amounts of data between entities running over mobile terminals, com munications overheads still remain as the dominant reason for consuming the battery power in the system. Specifically, the distribution of group views over the MANET requires both senders and receivers to consume a fraction of their available battery budgets. We investigate this issue by deploying the PEACH application on 10 Apple iBooks that simulate potentia responders and are connected through a MANET. Several tests have been conducted by varying the time between consecutive group view disseminations ranging for few tens of seconds up to few minutes. The resulting average battery life of the individual devices is found to be within 3:30 to 4:40 hours which indicates that PEACH has a scarce impact on the overall device energy budget. Application of the PEACH services on the patient device in the same way reveals a similar outcome also.



(a) Heap memory.



(b) Non-heap memory.

Fig. 3. Memory usage over time on a particular LR device.

(3) ***Memory Overheads.*** From hereon, the memory requirements of the individual devices, which execute PEACH services, are evaluated. For this purpose, we consider one out of the three LR devices, subscribed with PEACH, in a locality. By using JConsol profiling tool, we obtain the necessary data for a relatively long time, and then evaluate the memory requirements of the considered LR device over time as depicted in Fig. 3. Fig. 3(a) demonstrates that the total amount of the used heap memory lies between 0.8 MB and 2.1 MB. The average value in this case is approximately 1.3 MB. On the contrary, Fig. 3(b) depicts non-heap memory involving data, code, and stack. As shown in this graph, the non-heap memory over time approaches a consistent value of approximately 16.5 MB. These results clearly demonstrate the viability of installing the PEACH group management services onto a PDA or a smart phone.

V. Conclusion

In this paper, we envision a novel context-aware framework called PEACH for rapidly forming and managing ad hoc rescue groups of individuals willing to provide prompt assistance in emergency situations. In contrast to previous approaches, PEACH considers probabilistic functions of roaming victims' physiological and affective symptoms, collected from the biosensors deployed in the patient's wireless body area network, for detecting a potentially emergency situation. We have designed and developed prototypes to be used in responders' PDAs, which are contacted by the victim's device asking for emergency assistance. The empirical results demonstrate that the proposed PEACH framework is viable and will inspire further research work to extend the current prototype along various directions.

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