Pa2Pa: Patient to Patient Communication for Emergency Response Support

Abdelmajid Khelil
CS Department, TU Darmstadt
Hochschulstr. 10, 64289 Darmstadt, Germany.
Phone: +49-6151-16-3414, Fax: +49-6151-16-4310.
khelil@informatik.tu-darmstadt.de

***Abstract*—Usually, first responders estimate the medical needs in mass casualties scenarios from subjective observations gathered through uncoordinated emergency calls from non-experts in the incident location. Accordingly, they command specific teams to move to the location. At arrival the teams make local measurements, based on which they rank the priorities of patients, and give local treatments or decide to transport them to a specific hospital. Nevertheless the advances in the measurement of vital signs, still the human estimation may be error prone and not-in-time since usually the ratio of first responders to casualties can reach one to hundreds or even thousands in some cases.**

In this paper, we present a novel method to rank the urgency level of mass casualties through a localized ad-hoc sensor network and localized Real-Time (RT) sensor data processing. Our approach is based on plain patient to patient communication without relying on the existence of first responders nor a communication infrastructure. This allows for the first time to classify, rank and schedule casualties without experts in the loop. The casualties, the responders and the administration gains are very compelling.

I. Introduction

Traditionally, the concept of healthcare is based on the so-called *presence medicine*, i.e., physically bringing the patients, the medical staff, and the medical devices together. This presence requirement usually leads to explosive costs and delayed medical services, in particular for emergency scenarios such as mass casualties in disaster or stampede scenarios. Fortunately, seminal contemporary research efforts are being conducted to improve emergency support. For instance the GkmM project [1] proposes to combine advances in communications, sensor technology and robotics for emergency rescue support.

Communication is a critical element to improve patient care as healthcare systems are evolving from an Information Technology (IT) centric approach to a communications-centric approach. In addition, the continuous progress in sensor technology and computation miniaturization allowed to reduce the cost and improve agility of medical devices rendering them available for individual use at home. More recent advances allowed to use a medical Body Sensor Network (BSN) that is connected wirelessly to the patient's smart phone. Such BSNs comprise a computing unit system wristband on the patient, an oximeter on the patient's finger and an electrocardiogram (ECG) among other basic sensors. In the following, we refer to such a body area network as hCloudlet for Health Cloudlet (A cloudlet is a small cloud in Cloud Computing). An hCloudlet provides an easy way for patients to measure physiological data such as blood glucose levels and blood pressure readings. The measurements can be then shared with the personal care-givers through transmitting relevant data to a widely accessible IT infrastructure that we refer to as hCloud. The result is that patients can be remotely monitored by health staff, mainly enabled through telemedicine or *connected medicine*.

In this paper, we propose to push the limits of connected medicine through enabling *patient to patient (Pa2Pa)* communication in mass casualties scenarios. There, a patient-to-expert communication can not be assumed. We show how combining low-cost medical devices/sensors and mature near-field communication standards represents a chance for developing a modern first response system with immense benefits for both paramedics and patients. We focus on pure Pa2Pa communication patterns and show that these can fully unleash the promises of connected medicine. For instance, we propose to determine the number of injured and rank their urgency levels before the responders arrive. Obviously, this can improve the quality of emergency response and save life through a fair, accurate and timely scheduling of patients to the appropriate rescue team members. The benefits are even higher given that the number of disaster events such as tsunamis, tornados, mass event stampedes and floods are increasing while causing higher number of casualties and putting higher burdens on paramedics.

The current state of the art of connected medicine considers only patient-to-expert communication - often assuming either a smart home or smart hospital or both. We present a comprehensive discussion of state of the art in Section II. In Section III, we propose a detailed research roadmap for Pa2Pa in mass casualties scenarios.

II. Related Work

Our proposed research is based on the convergence of several networking and computing trends: BSN, Mobile Ad-hoc Network (MANET), and Wireless Sensor Network (WSN). We rely on BSN research results to build an hCloudlet. We identify also a mature MANET and WSN research enabling the interconnection of these BSNs/hCloudlets and an

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efficient distributed in-network computation and sensor data processing. Unfortunately, this research does not consider critical applications with highest node density and continuously changing and heterogeneous sensor data. In particular, there is no Pa2Pa research on supporting mass casualties scenarios. In the following, we briefly discuss the state of the art of using each technology in healthcare, while expressing the novelty of combining them to enable Pa2Pa communication for first response support.

In the last decades, established efforts have been successful in integrating progresses in sensor technologies and information and communication technologies into healthcare systems and processes. The main efforts can be classified into: Smart clinics (e.g., the use of RFID to improve logistic processes in hospitals) [2]–[4], development of low-cost portable medical devices that can be easily carried by users for self health monitoring or for automatic emergency calls (e.g., portable Bluetooth ECG), and the enablement of remote diagnosis and telemedicine (e.g., remote surgery). All these achievements are for connecting one patient with the health staff through an intelligent IT infrastructure (Fig. 1). We are the first to tangibly realize a pure patient to patient (Pa2Pa) communication with the main benefit of the localized and fully automated patient urgency ranking.

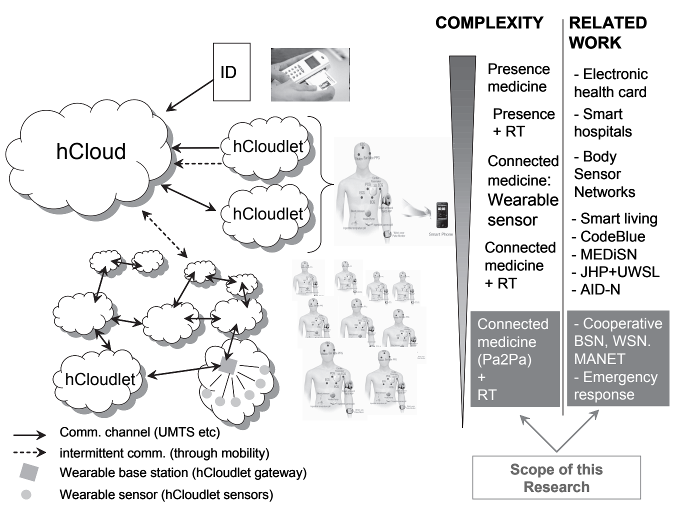

Fig. 1: Project scope and comparison to existing approaches

The closest project to our research objectives is the CodeBlue project [5], which is based on the so-called Advanced Health and Disaster Aid Network (AID-N) [6]. AID-N provides an interface to support overwhelmed responders in monitoring a large number of casualties. This is achieved through an ad-hoc mesh network that enables communication between responders and patients. As emphasized in [6]–[13], the evaluation of the urgency level is human-assisted. In this work, we propose to automate this task, i.e., without a human in the loop. We replace the human knowledge through ontologies. The CodeBlue Mercury platform (A Wearable Sensor Network Platform for High-Fidelity Motion Analysis) is able to automatically detect new types of health problems such as the Parkinson's disease and Epilepsy, which are not emergency cases. Though the detection is automated, it is not appropriate to automatically detect and rank the urgency level in mass casualties incidents as targeted in this work. The CodeBlue, AID-N and MEDiSN project target a network that is deployed after the arrival of the first responders. These emergency service staff will deploy BSNs on the patients and collect the vital sign data with their notebooks, thus building a mesh network. Our main focus is the phase of pre-arrival of first responders, where no human in the loop is assumed.

The John Hopkins University (JHP) project [2], [14], [15] and in particular MEDiSN [15] explains about the applications of WSN in health monitoring without scientific contributions to Pa2Pa communication. The University of Washington Saint Louis (UWSL) project [16], [17] is similar to the JHP project. End nodes can act as routers but not in the context of Pa2Pa communication and emergency level ranking.

Many BSN systems available today are proprietary systems. We identify four main existing generic/open approaches: MobiHealth [18], Myotel [19], Personal Health Monitor (PHM) [20], and the Shimmer health BSN [21]. In the Pa2Pa project, we propose to use the shimmer platform in order to realize hCloudlets as a generic and open BSN which can be customized to different needs.

III. Our Proposed Research Roadmap

In the following, we outline our vision and sketch the main planned tasks in order to realize the target application.

A. The Vision

Imagine medical BSNs are an integrated part of every first aid box in buildings. Subsequently in case of emergency, one can wear a BSN that is available in the vicinity and that requires little setup time. One's smart phone detects the BSN, executes a pre-configured hCloudlet that immediately collects first diagnosis reports. In mass casualties scenarios, BSNs can be thrown from helicopters so that casualties and endangered people wear them. These wearable health systems should take over the diagnosis task and communicate the diagnosis results to the emergency response team directly. Imagine that the communication infrastructure is unavailable, but fortunately, the hCloudlets are interconnected and automatically schedule for each available/arriving healthcare expert (paramedic, nursery, etc) the next most urgent case. This futuristic vision would fundamentally revolutionize the first response for both casualties and paramedics. Developing a set of techniques for enabling this futuristic vision is the focus of our proposed research.

B. Overview of Our Proposed Research

We first propose to build a health monitoring mini computing cloud (hCloudlet) running on top of a BSN connected to a sink (e.g., smart phone). In order to realize our critical application in mass casualties scenarios, we propose dependable distributed ontology-driven sensor data processing running on top of the mobile ad-hoc network built by the sinks of these hCloudlets. An important aspect of our work requires automatic routing of computing tasks to available computing elements. Yet, in our work this has to be accomplished in a fully decentralized manner. It is noteworthy that one should learn from the existing concepts of Cloud Computing in wired networks in order to provide for a flexible and on-demand in-network-processing in the interconnected hCloudlets/BSNs.

The main research challenge is to design the safety critical application on top of a network which is composed of strong heterogeneous unreliable wireless links and nodes. It is also crucial to decide where to put the intelligence while providing for a dependable system operation, i.e., high accuracy and timeliness for ranking and scheduling and high resource efficiency (bandwidth, processing, energy, etc). Overall, the following two key research questions need to be further addressed: (a) Design of the critical application, and (b) dependable networking and data processing.

C. Design of the Critical Application

We tangibly target the design of algorithms that (1) efficiently collect live sensor data and process it, (2) compare and rank the urgency of different patients, and (3) schedule their treatment order for the available health staff or alternatively propose the number and the disciplines of the required additional responders.

Our approach is to develop ontologies in cooperation with medical experts in order to informatize their knowledge on how (i) to rank a given set of patients according to their urgency level, and (ii) to schedule the different patients to a given set of first responders. Accordingly, novel algorithms are required to execute these ontologies in the network of hCloudlets in order to rank the urgency of patients and schedule their treatment. The implementation of these algorithms should be broken into the traditional query and event models. This includes selecting suitable strategies for data dissemination/collection, data processing and query execution while achieving efficient use of dynamic network/computing resources.

It is crucial to find a satisfactory trade-off between (1) collecting all required data on a centralized entity & running the ranking/scheduling algorithms on this entity, and (2) running data management & the application fully distributed in the ad-hoc network of hCloudlets. The optimized configuration should take into consideration the probability of a future connectivity of the hCloudlets to a computation infrastructure (e.g., hCloud). At the beginning only the hCloudlets resources are available. Afterwards, resources on surrounding mobile devices (e.g., those of curious onlookers) can be allocated. Then, the arrived emergency team can provide higher processing resources (powerful computer in the emergency vehicle, laptops carried by responders, etc). This access will allow to fine-tune the available historic data of each patient, which can be exploited to refine the results of ranking and scheduling.

A vital step in the application design is to break down the developed ontologies into distributed queries on live data streams and to execute these queries through in-network processing. The main query operations are:

- *Query Formulation:* A key query is "which patient should be treated by which responder next". Usually, this query should be broken into many elementary data queries (average, max, min, count, etc) according to the ontologies.
- *Query Processing:* Basically, an elementary distributed query can be processed according to one of the following methods: (a) The query is disseminated in the network of hCloudlets and answered through in-network processing, or (b) partially answered through scoped data collection on a few dedicated hCloudlets, or (c) the query is answered after complete data collection at the querying node. The suitable processing method depends on the type of the query, its frequency, and the ratio of queried hCloudlets to the total number of hCloudlets.
- *Event Detection:* A specific type of queries is the continuous query, which is equivalent to event detection. An example is "whenever the heart beat rate exceeds a certain maximum or minimum value, notify all responders".

D. Dependable Networking and Data Processing

The scheduling of the patients to the medical staff is a critical application and should guarantee high accuracy and precision. Therefore, it is fundamental to develop dependability and fault-tolerance techniques to ensure the fulfillment of the hard application requirements. In particular, we have to cope with several challenges that complicate the design. For instance, patients usually are equipped with different sensor collections and some of them are even not instrumented with medical sensors but with a smart phone only. Furthermore, sensors may have samples of different accuracies or may be even erroneous. In addition, the network of hCloudlets may form a highly dynamic network topology, which complicates network functionalities, data management and application execution. There are many factors that make the network topology highly dynamic: (1) The patients may run to search for rescue, and (2) there will be continuous joins of hCloudlets and assist nodes to the network (as the disaster progresses) or as some hCloudlets get disconnected (e.g., due to failures). In particular the following research challenges should be addressed:

- Data Quality: The system must be able to cope with different levels of sensor data accuracy, varied communication and node perturbations, and sensor availability (e.g., patients without any sensor data should be also considered in the schedule). Considering that hCloudlets may be used by technically average skilled persons and medical staff with little training, loss in quality due to operator misuse is a big concern. Moreover, because hCloudlets enable continuous collection of physiological data under harsh conditions, the collected measurements may be polluted by a variety of noise. For example, motion can impact the quality of heart beat rate and respiration measurements.
- Massive Data: Depending on the number of involved causalities, and the operating sensors, massive data can

be generated and should be in-network processed in a short time. In particular, ECG sensors generate a high data rate.

- Extremely High and Varying Density of Nodes: In mass casualties, node densities around 1 node per m^2 are normal. Such high densities require careful data transmission strategies given the limited bandwidth and the high data rate. Intuitively, we should efficiently maximize the usage of the broadcast nature of the wireless channels. It is noteworthy that such high node spatial densities are usually not considered in ad-hoc network research community. In addition, massive joins and leaves of sensors may take place. E.g., when a person wears a new hCloudlet, or takes it off, or gives it to another patient. The algorithms design should address these artefacts in order to maintain high application fidelity.
- Computation-Communication-Energy Efficiency: The computation communication trade-off should carefully be investigated depending on the available dynamic resources. For instance, if there is a closer computational entity, probably hCloudlets should route their data to it, and then have the data pre-processed there before forwarding it to the querying node. If the computing element is far from the hCloudlets, each hCloudlet should degrade data sampling rate and maximize local processing without sacrificing the accuracy level required for correct scheduling of patients to responders. Upon arrival of first responders, resource-powerful data sinks are injected to the network and can be involved for computation-intensive tasks.

  A key research question is how to transfer the data to the right computing element. The computations required to support functionalities as described above should be delegated to the most powerful and most energy rich computing device that is reachable from the vicinity of the hCloudlet.

  Usually, energy-awareness is an important issue in ad-hoc and sensor networks. In our settings, the energy efficiency is only important to some extent, as the entire application is needed to run for maximum a few hours. This is acceptable to most of expected battery powered devices since for current commercial devices an operation time of a few hours is expected for use in full power mode.

IV. Conclusion

Electronic and mobile health are increasingly considered to be a key driver for the progress of health systems. They are not less relevant than the development of new medicaments or treatment processes. However, there is still only little work for supporting rescue in mass casualties scenarios, though these scenarios are one of the most cover demanding health disciplines. We recall here the recent events in natural disasters that show the demands for a better information & communication technology support in disaster/rescue scenarios. We have proposed Pa2Pa communication to address critical difficulties of current emergency response processes. We have presented how to take advantage of interconnecting wearable BSNs in order to provide for timely diagnosis and accurate scheduling of treatment as enhancement to the error-prone/subjective manual human interaction in mass causality scenarios.

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