Healthcare Systems in Rural Areas: A Cloud-Sensor Based Approach for Epidemic Diseases Management

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Abstract. The recent advances in wearable and integrated sensing devices, such as Wireless Body Area Networks (WBANs), have enabled a wide range of advanced and real-time sensing and monitoring issues. However, as stand-alone systems, WBANs are likely to face many challenges in terms of communication range, data security and privacy, storage and processing of the huge amount of data collected. In this context, we propose in this paper a novel healthcare system that relies on a cloud-sensor based approach for epidemic disease management in rural areas. The proposal tries to optimize epidemic diseases detection and tracking through the management of alerts generated by WBANs carried by individuals and belonging to public and private clouds. It also tries to report on the evolution of particular diseases and implement a query management system allowing cooperative answers from the aggregated clouds.

Keywords: WBAN · Sensor-cloud · Rural areas · Diseases · Continuous querying

1 Introduction

In recent years, the world has witnessed an exponential escalation in the occurrence of many epidemic diseases such as the Ebola virus. Such epidemic diseases are among the major threats that affect public safety in its large-scale and cause untold suffering to mankind [15]. In this context, governments and international organizations such as the Pan African Union and the World Health Organization (WHO) have set up healthcare surveillance systems to monitor diseases and to predict epidemic's occurrence [11]. Consequently, designing efficient healthcare systems can assist caregivers to diagnose, monitor, and manage critical health indicators, as well as to provide appropriate medical treatments once epidemic's occurrence is confirmed.

The recent advances in mobile communication systems as well as wearable and integrated sensing devices, such as Wireless Body Area Networks (WBANs), have given tremendous opportunities to enable advanced sensing purposes including monitoring, tracking and controlling systems and health states [4]. Accordingly, networks of WBANs can be utilized as ad-hoc mobile sensor infrastructures to actively monitor patient's health status, to provide early diagnosis of disease-related symptoms, and ultimately to prevent the occurrence and the spreading of epidemiological diseases.

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Managing epidemic diseases in rural areas is, however, a challenging task that may impede the undertaken of a well-coordinated decision. In addition, when the WBANs are implemented as stand-alone systems, they are likely to face many limitations and challenges in terms of communication, reliability, security and privacy, the mobility of the monitored users, and the scarcity of wireless network resources. Besides, communication infrastructure in the monitored area may be overloaded in case of emergency, destroyed and even non-existent as is the case of many rural areas. Consequently, there is a growing need for implementing an infrastructure to enable ubiquitous, convenient, on-demand access to a shared pool of configurable computing resources (e.g., networks, storages, servers, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction [5].

Cloud computing provides a configurable platform to support collaborative services and presents a huge transformation in the information and communication technology [2, 6]. According to [10], the major benefits of cloud computing in healthcare applications are: (a) Enabling on-demand access to a shared pool of computing and large storage services; (b) Supporting huge amount of health-related records as well as burdensome medical tasks including radiology images and genomic data offloading from many hospital departments; (c) Providing an easy sharing of information among authorized physicians and hospitals in various geographic areas; and (d) Enabling more real-time access to health-related information and minimizing the need for duplicate testing. Accordingly, the management of WBANs, despite their aforementioned limitations, can be tackled by exploiting Cloud computing to provide an integrated cloud-sensor based platform that provides a scalable and distributed storage system in rural areas. The presence of backup copies in the cloud reinforces data reliability and guarantees that the applications can continue running in the cloud without interruption [16].

Several solutions for the integrating WBANs with cloud computing have recently been reported in the literature [3, 7, 12, 14]. In these works a typical healthcare application is described. It aims at providing ubiquitous collection, access, process, and sharing of patient data from different hospitals in dedicated health services networks. The mobility of patients is restricted to the hospital environment or to the area within the communication ranges of the WBAN system, his house for example. In addition, the proposed querying mechanisms in these works only take into consideration data already stored in the cloud servers. The stored data should satisfy temporal and freshness requirements to reflect the current status of the monitored phenomenon. Nevertheless, epidemic diseases management is a mission-critical application where WBAN users, typically, deliver data in streams continuously at defined time intervals. These streams have to be processed in real-time manner as data arrives and need active real-time querying that implements cooperation among the cloud platform and the distributed WBAN nodes.

Motivated by all these observations, we propose in this work a novel healthcare system that relies on a cloud-sensor based approach for epidemic disease management in rural areas. The major contributions are summarized in the following.

- We propose a system model that, specifically, considers different networks of wearable sensors in the form of WBANs carried by individuals moving in a rural area and belonging to public and private clouds. This system allows continuous collection and transmission of health-related and environmental information and tries to optimize epidemic diseases detection and tracking through the management of alerts generated by distributed WBANs.

- We implement an epidemic diseases management system that tries to report on the evolution and intensity of particular diseases and adapts an active querying management approach that allows cooperative answers from the aggregated clouds, which facilitates the decision making process in health related issues.

The remainder of this paper is organized as follows. In Sect. 2, we propose a cloud-sensor based architecture for epidemic diseases management in rural areas. A continuous querying approach is proposed in Sect. 3 to allow cooperative answers from the aggregated clouds and to facilitate the decision making process in healthcare issues. Section 4 proposes the tracking of a specific disease as a case study to evaluate the proposed approach. And the last section concludes the work.

2 A Cloud-Sensor Based Architecture for Epidemic Diseases Management

The core idea behind this section is to propose a healthcare system that relies on the interaction between cloud platforms and WBANs as an infrastructure for continuously tracking epidemic diseases' occurrence in rural areas.

2.1 Epidemic Disease Propagation

An epidemic may be defined as the occurrence of disease or health related condition in excess of the common frequency in a given area or among a specified group of people over a particular period of time. It spreads through human populations by direct contact between individuals carrying the disease's virus and susceptible members of the population to which they belong. The spread intensity of epidemics varies depending on the related disease and the geographic locations of infections. In addition, high human density would increase the spread of epidemic diseases. Some epidemics such as Ebola are introduced into the human population through close contact with infected animals such as chimpanzees, bats, monkeys, mosquitoes, parasitic worms, and so forth. The major signs and symptoms for deciding whether an individual has critical health condition include fever, fatigues, diarrhea, and muscle aches. An investigation of a given epidemic should take into consideration the detection time and place of the person under test.

2.2 A Cloud-Sensor Based Architecture in Rural Areas

We describe in this section the general architecture of a cloud-sensor based approach for epidemic diseases management in rural areas. The whole architecture is illustrated in Fig. 1. As we can see, it integrates three main layers, namely a central public cloud, a private cloud as well as a cloudlets of WBANs.

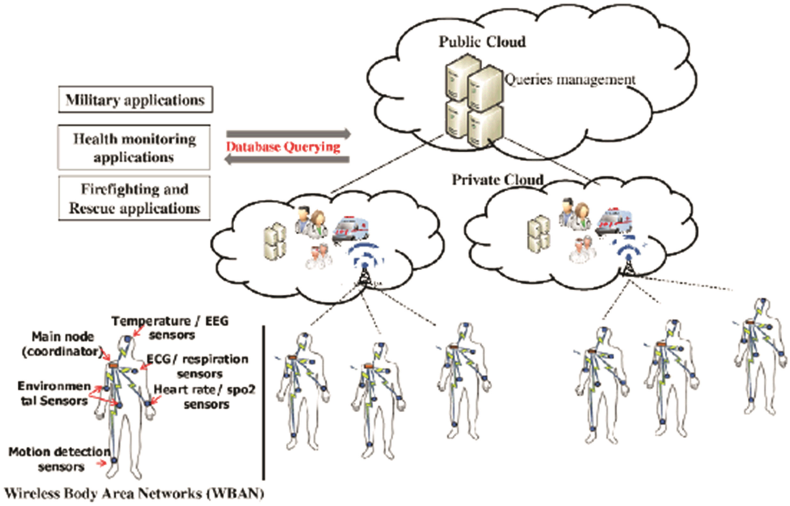

Fig. 1. A cloud-sensor based architecture for epidemic diseases management

The first level defines networks of wearable sensors embedded on mobile individuals in the form of WBAN systems to measure health parameters, motion parameters, and environmental parameters. Every WBAN node should be able to continuously collect vital signs parameters such as body temperature, electrocardiogram (ECG), electromyogram (EMG), oxygen saturation, blood pressure, breathing rate, among other parameters. The environmental sensors aim to measure parameters that may be favorable to epidemic disease propagation such as the ambient temperature and humidity, the water pollution, and the presence of particular types of flora and fauna. Indeed, by monitoring environmental conditions as well as by providing localization information, the wearable healthcare system is able to record the location and the time of disease detection and the related geographical expansion. The WBANs act together in a given monitored area in order to establish a common target of epidemic disease diagnosis. In this context, we consider that the different WBAN nodes in close vicinity of each other are able to form mobile cloudlets. The latter is a new architectural element that emerges from the improvement in mobile communication systems and cloud computing. It represents a fully cloud system capabilities but in small scale in order to bring the cloud capabilities closer to the users [13]. Any WBAN node in the cloudlet domain is in charge of collecting disease-related data.

The second level defines a private storage system of a given healthcare institution that is in charge of monitoring and tracking patients' health statuses as well as epidemics evolution. The private cloud includes the set of WBANs' cloudlets. The geographical proximity of private cloud and WBANs using the set of cloudlets enables a reduced access and communication delays. The private cloud provides a centralized management along with storage points where data collected by different mobile WBANs are stored in order to be processed and queried in real-time manner. In addition, the private cloud stores sensitive and private information, including the patient's profile, the patient's health-related information, the history of medical treatments, the history of special diseases' occurrence and the medical staff information. All this information is useful in order to monitor patients' health status and track epidemic diseases. Real-time measurements must be sent to the destination within a specified deadline; otherwise, the collected information expires and is no longer useful.

Disease management may require the intervention of more than one healthcare organization and in critical cases such as in epidemic detection the intervention of other organizations and safety providers would be needed. To this end, the third layer in the proposed architecture defines a global, centralized and public storage infrastructure where abnormalities and irregular measurements reported by the private clouds are logged to be available for other organizations that are interested in a certain type of data and for further investigation.

2.3 WBANs for Epidemic Diseases Management

To efficiently manage epidemic diseases the following properties should be considered: (a) Every WBAN node acts as a temporary storage system that enables instantaneous monitoring and tracking of patient-related information; (b) The WBAN encompasses heterogeneous sensors in charge of generating priority-based traffic including critical information in form of alerts, real-time information, and normal information; and (c) Every WBAN node is in charge of collecting both, health-related and environmental information. The major objectives of using WBAN systems for epidemic diseases management in rural areas are:

Providing a Communication Platform: the WBAN nodes provide a mobile platform for data collection and processing according to traffic priority. At any given instant, a mobile WBAN user in the rural area can be in one of following scenarios: (i) it is in the communication coverage of a private cloud, then the user can transmit data packets directly to the associated private databases; (ii) it is only in the communication range of another WBAN node, which is directly connected to a private cloud. Then a cloudlet domain may be formed and the WBAN user can transmit data packets to the private databases using multi-hop communication; (iii) it is out-of-coverage where no communication infrastructure is available. In this case, a priority-based communication approach is implemented. If the WBAN node tries to transmit a high priority traffic, the WBANs in its vicinity are solicited to form a mobile cloudlet domain that will be in charge of relaying the generated traffic; otherwise, the WBAN node should delay transmission until one of the previous scenarios becomes available.

Building Epidemic Disease Databases: the proposed architecture will provide a useful support for medical professionals (such as doctors, therapists, and caregivers) as well as governments to manage large-scale epidemics through the fast identification of epidemic's sources, the prediction of its geographical expansion and the number of affected individuals, and the provision of appropriate medical interventions and treatments to moderate future aggravation. The system must provide building multi-databases as a service by invoking autonomous and private clouds to contribute to the collection and monitoring of health parameters.

3 Querying Databases

In contrast to traditional real-time cloud databases querying model, rather than collecting, storing and then analyzing large amount of real-time data, we describe here a novel querying mechanism that allows immediate evaluation of the incoming data before being stored. Managing continuous data streams imposes new requirements on querying approaches to handle the unbounded nature of data streams. Based on the proposed architecture two levels of queries are considered: the Ascendant Queries (AscQ) and the Descendant Queries (DesQ).

3.1 Continuous Query Language

We use the Synchronized SQL (SyncSQL) language as a reference to manage continuous data streams generated by the WBAN nodes. SyncSQL is among the continuous query languages that support stored data and continuous data streams. A continuous query over n tagged streams, S_1 … S_n, is semantically equivalent to a materialized view that is defined by an SQL expression over the time-varying relations, $R(S_1)$ … $R(S_n)$. The output of a query can be provided either as a COMPLETE output, where, at any time point, the query issuer has access to a table that represents the complete answer of the query (the output in this case is non-incremental), or as STREAMED output, where the query issuer receives a tagged stream that represents the deltas (the output in this case supports incremental changes) to the answer. Then, considering SynchSQL semantics, a simple query may be expressed as follows:

SELECT [STREAMED—COMPLETE] <select-item>ψ
FROM R(Si)
[WHERE <condition>]

Typically, in healthcare application the arriving streams may comprise private tuples (e.g., personal information of patients). Restricted access to such information can be achieved in SyncSQL by means of views that projects out the private attributes [8]. Based on privileges attributed to user groups multiple views can be defined. SyncSQL implements views as a means for enhancing data privacy.

CREATE [STREAMED] view <view-name>ψ as
SELECT <select-item>ψ
FROM R(Si)

[WHERE <condition>]

The view is refreshed when either the streaming S_i is updated or Now is changed. This query encompasses a window that is defined by the clause WHERE and that allows to output a relation containing all the items collected by a WBAN node and referenced in the clause SELECT up-to current time Now.

3.2 Descending Queries (DesQ)

Descendant Queries (DesQ) are reading queries that can be completed by the content of a query on a database, but can be also inserted using additional lecture from the cloud or the WBAN nodes. DesQs are, typically, generated after a query sent by a user. When the answer to the received query is not available in the database, the database management system decomposes the global query into a one or several sub-queries, which are sent to appropriate private cloud databases.

The implementation of a query (we specify, precisely, the implementation of queries on real-time video streams) is coordinated by a broker that, after receiving a query, checks the validity of the stored video streams and accordingly generates a query execution plan.

(i) If the required video data is available in the private database and is recent enough to reply the query within its response delay, Timestamp + maxvalid > timequery, then the query may be implemented locally in the public databases and the requested information is sent back to the user. The maximum validity (maxvalid) of a real-time video streaming should be short enough to guarantee the freshness and validity of its content. Such a query can be answered in SyncSQL by maintaining a COMPLETE (not STREAMED) query that contains the videos that are currently available in the database as follows.

$$SELECT\text{-}[COMPLETE]<video\clubsuit segment—value>\psi$$

$$FROM\text{-}R(S_i)\text{-}$$
$$[WHERE\text{-}<condition>]\text{-}$$

We consider that a query on a stored video may specifies videos, segments of videos, or values of variables related to the environment where the video was filmed. A video is retrieved from a WBAN node, a segment from a video, and a value may be deduced from a segment. The clause WHERE may specify temporal, spatial, spatio-temporal, and application query conditions.

(ii) If the requested video content is not available or it does not satisfy the temporal and validity requirements, then the broker should send the query to the nearest cloudlets (which normally provides fresher data than those stored in the private database) that execute similar processes. If the video is not available, each cloudlet targeted by the user query solicits its affiliated WBAN nodes to collect live video streams for more detailed views of the monitored phenomenon, if any.

3.3 Ascending Queries (AscQ)

The Ascendant queries (AscQ) are generated by the WBAN nodes to implement write and read transactions on the private cloud databases. In addition, they are useful to provide cooperative answer among aggregated actors of the cloud-sensor based system. Ascending data stream collection is, generally, triggered by an event occurrence and alerts generated by a WBAN user. TinyDB is a distributed query processor for smart sensor devices that supports events as a mechanism for initiating real-time data collection using ON EVENT clause. Every time an event occurs, the query is issued from the detecting node and the required parameters are collected from nearby WBAN nodes [13]. In this context we propose a new language that integrates, both TinyDB and SyncSQL languages to provide a uniform ascendant query. The latter may be expressed by:

ON-EVENT-event-detection-():-
SELECT-[STREAMED|COMPLETE]<select-item>ψ

FROM-$\mathcal{R}$(Si)-

[WHERE-<condition>]-

The AscQ queries can be also executed to read from the private cloud databases and to request on-demand services. For example, if the WBAN user is unable to move to a hospital in case of emergency, it can request the cloud to look for a doctor in its entourage. In this case, we consider that medical staff, in rural areas, including doctors, nurses, and other health providers should be equipped with a WBAN system to enable additional medical measurements and enhanced communication supports.

4 Case Study

In this section, we propose a cloud-sensor based network to continuously manage the evolution of a specific epidemic. In particular, to validate the effectiveness of the proposed approach, a detection scenario of Ebola virus disease (EVD) is investigated. The diagnosis of suspected patients begins by monitoring the early symptoms of Ebola, following an incubation period of 2/21 days, including fever, severe headache, shivers, muscle aches, and weakness. With the progression of the disease, suspected patients may develop other additional symptoms such as vomiting, abdominal pain and diarrhea, nausea, difficult breathing, hypovolemic shock, pharyngitis, conjunctivitis, to dysfunction organs, and bleeding. The terminal phase of this disease is the death. Accordingly, we propose a scenario where patients and medical personnel equipped with WBANs are moving in a large scale area. This area is divided into adjacent sub-areas. Each is supervised by at least one cloud or one WBAN. Two types of WBAN systems are considered. The Patient-WBAN system is embedded on the monitored patients and the Medical-WBAN system is embedded on medical staff. Under these assumptions we describe an active querying approach using successively descending queries and ascending queries. We consider that the Patient-WBANs-Collection and Medical-WBAN-Collection streams are referring to the set of continuous streaming generated by the Patient-WBAN system and Medical-WBANs system, respectively. The corresponding tagged stream and time-varying relation are denoted $WBAN_{MCOL}$ and $R(WBAN_{MCOL})$, respectively.

Case 1. The medical department executes a descending query on the private database that consists to continuously keep tracking of the temperature measurement of all patients in the monitored area that have temperature greater than 38°C. Such a query may be expressed by:

```
Query-1:-SELECT-STREAMED-id‘ψtemperatureψ
FROM-R(WBANCOL)Rvψ

WHERE-Rv▷temperatureψ>ψ38-
GROUP-BY-idψ
```

In this query, the keyword STREAMED indicates that the output includes either insert or update operations for patients that qualify the predicate “R.temperature > 38” and/or delete operations for previously quali_ed patients that disqualify the predicate.

Case 2. As we are dealing with Ebola virus, the medical institution is interested at a given point of time T by monitoring additional vital signs of all patients in the monitored that have temperature greater than 38°C for the last two days. The inputs of such a query are the WBAN id, the temperature level, the sweat level, and the blood saturation.

```
Query-2:-CREATE-STREAMED-view-TwoDaysWindow-as-
SELECT-id,ψtemperature,ψsweat,ψbloodψ
FROM-R(WBANCOL)Rvψ

WHERE-Nowψ↖←2-<ψRv▷Timestampψ≤←Nowψ
GROUP-BY-idψ
Query-2-1:-SELECT-STREAMED-id‘ψtemperature‘ψsweat‘ψbloo
dψ
FROM-R(TwoDaysWindow)Rvψ
WHERE-Rv▷temperatureψ>ψ38-
```

In this query a sliding window over WBANCOL of size 2 time units (i.e., two days in our case) is created. This sliding window defines a view that, at any point of time, contains all the required information reported between times Now-2 and Now. To report information belonging to patients that qualify the predicate “Rv.temperature > 38”, a query 2-1 can be expressed in terms of TwoDaysWindow view.

Case 3. In this case, we generate a cooperative querying approach between the WBAN nodes and the private clouds. To this end, we consider that at a given instant of time, an alert generated by the WBANs generates an ascending query that reports all the information concerning the patient. The generated alert that we call HealthDegradation(temperature, blood) defines the rapid degradation of vital signs (e.g., the temperature and the blood saturation) of the patient in a short period of time.

```
Query-3--ON-EVENT-Health-Degradation-(temperature,-blood):-
CREATE-STREAMED-view-ALERT-as-
SELECT-*-
FROM-R(WBANCOL)Rvψ
```

Upon receiving this query the healthcare institution, precisely the medical staff, generates a descending query that aims to keep tracking the location of the concerned patient.

Query 3-1: SELECT *STREAMED id, location*
FROM $\mathcal{R}$(*ALERT*)

ALERT is a view that contains all the information concerning the WBAN node that detected the event Health-Degradation (temperature, blood). Upon receiving the output of this query the healthcare institution generates a second descending query that aims to check the availability of healthcare providers (e.g., doctors or nurse) in the close vicinity of the patient.

Query 3-2: SELECT STREAMED id, location, video
FROM R(WBANMCOL)Rv
WHERE distance(R.location, p(id)) ¡ dmin and R.status = 0

Where p(id) returns the location of the WBAN node contained in Query 3-1 and status is a Boolean parameter that refers to the availability of medical staff (available: 0, not available: 1). This query outputs the id, the location and video from all available medical staff (status = 0) located at a maximum distance dmin from the patient.

5 Conclusion

In this paper, we investigated the benefits of integrating WBANs and Cloud Computing to build a Cloud-sensor platform to support medical diagnosis of epidemic diseases monitoring in rural areas. First, we proposed an architecture that integrates three main layers, namely distributed WBAN nodes for data collection, private clouds that manage WBAN collections (e.g., real-time analysis, continuous querying and secure storage) and a central public cloud that attributes privileges to other groups of users in order to retrieve disease-related information. The proposed solution tries to optimize epidemic diseases detection and tracking through the management of alerts generated by WBANs carried by individuals and belonging to public and private clouds. It also tries to report on the evolution of particular diseases and implement a query management system allowing cooperative answers from the aggregated clouds. In our future work we will evaluate, through simulations, the performance of the proposed approach to ensure effective and real-time monitoring of epidemic diseases. For this purpose, the following metrics will be assessed: (i) The effectiveness of the proposed model to generate real-time alerts and forward them timely in case of epidemics detection; (ii) The effect of user mobility on responses to queries containing real-time constraints; and (iii) The impact of the number of the deployed clouds and users per cloud on the quality of service.

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