Internet of Things for a Smart and Ubiquitous eHealth System

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Abstract — **Connected data has always been considered as a primary source to knowledge. Internet of Things uses the virtue of connecting this data from different entities and creates a pool of knowledge for providing smart services to users, based on rigorous analysis and processing over the knowledge. The communication in this context scales to not only between machine to machine but also between a large number of heterogeneous entities and persons. This genius technology of Internet of Things holds paramount importance and application in healthcare technologies. Considering health technologies, a large number of devices generate huge amount of data related to a patient. Assimilating the data from heterogeneous sources and using it to generate intelligence is one of the primary tasks in a smart environment. In the context of eHealth, Internet of Things is of immense importance since connected data about patient would facilitate treatment with more efficiency and comprehensive knowledge. Virtually storing the patient data and making it ubiquitously accessible to concerned healthcare personnel would be the first step toward mutual knowledge sharing. Another important aspect of using this connected data is the design of an intelligent clinical decision support system which would assist the doctors in every possible way during the treatment phase. A model has been proposed with an inclusive approach of Internet of Things in eHealth scenario for a smart medical environment and providing ubiquitous services at its best. Several issues pertaining to the system has also been discussed accordingly. Nevertheless, the enormous spread of Internet of Things for efficient and intelligent healthcare services holds quite inevitable. Rather it adds to the foundation notion of ubiquitous services by making available to everyone and everywhere. The new age eHealth facilities are expected to enable end-to-end monitoring systems even at remote scenarios, helping medical services reach the unreached.**

Keywords – cloud; eHealth; healthcare; internet of things; smart; ubiquitous

I. INTRODUCTION

With the advancement in digital technologies, the number of digital entities has seen a sharp rise in the recent years. Since it has been a common goal to use data efficiently and acquire knowledge, innovative methods were employed to make the most of it. In this context, the notion of connected data came into being for the generation of enhanced knowledge. Using this knowledge, the machines and devices can be programmed for working with intelligence for better and customized output. Making use of the connected data obtained from homogeneous sources has been a common sector in communication system between computers. However the notion to make use of connected data from heterogeneous sources and obtain intelligence from it holds the foundation of Internet of Things (Fig. 1).

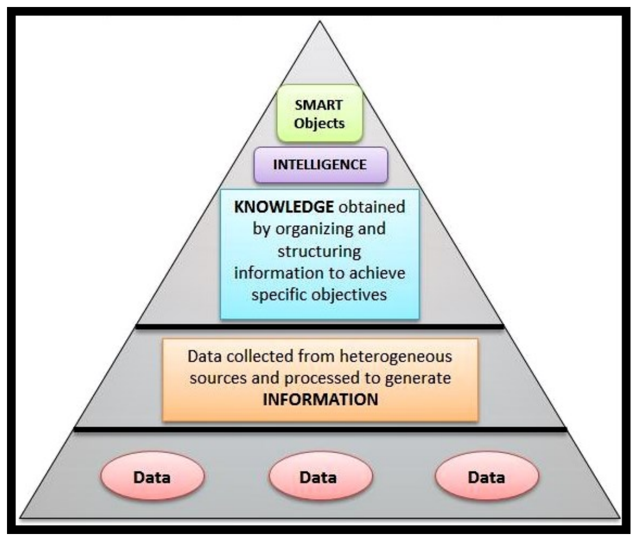

Figure 1. Generation of intelligence from data.

A trivial goal of Internet of Things (IoT) is to achieve the apex of the pyramid (Fig. 1) and to use the intelligence to provide customized and user-specific services. Basically, Internet of Things (IoT) actually harnesses the power of connected data and applies it for multifarious aspects of smart living.

Typically, IoT is expected to offer advanced connectivity of devices, systems, and services that goes beyond machine-to-machine communications (M2M) and covers a variety of protocols, domains, and applications [1]. The interconnection of embedded devices working intelligently has been cultivated for employing automation in every sectors ranging from home control to smart cities. With the evolving number of devices, the number of connected devices is expected to touch 50 billion by 2020 [2]. And this enormous power of connected data holds IoT as a high potential technology for the upcoming days. The predictions of Cisco IBSG also pointed out to the enormous increment of the number of connected devices per person, which could be 6.58 by 2020 [3].

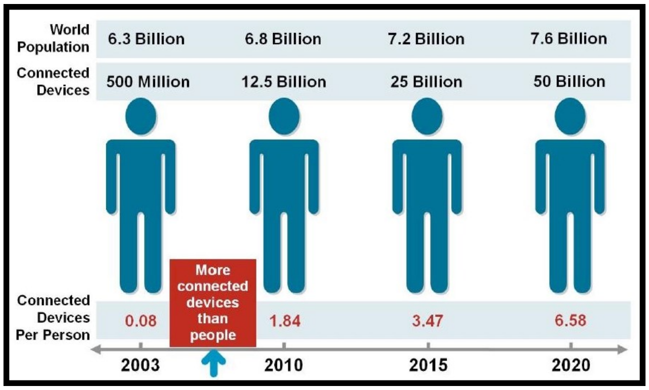

Figure 2. Evolutionary Outline of Humans vs Devices.
(Source: Cisco IBSG, 2011)

However, the connected devices could be only used to its best with the help of a mutual sharing platform. Also in a typical IoT, not only the Internet-enabled devices like smartphone, PC are under consideration. For an efficient service, heterogeneous objects like car, refrigerator and lights are also taken into consideration and fastened to the same connectivity platform. Real-time communication between the heterogeneous connected devices enables intelligent user-specific services.

As a part of reaching every sector with the connectivity of IoT, eHealth is an important area of concern. Primarily eHealth is a healthcare practice supported by electronic process and communication. But with the extensiveness of communication, mutual sharing between healthcare entities has become inevitable. Inducing IoT technologies in healthcare, the standard procedure of monitoring, investigation and treatment would be ushered in with a digital revolution of connectivity. One of the focal goals in this context is to embed the computing power inside the devices and communication channel so that the entire system remains subtle and ubiquitous. In this connection, an eHealth model has been illustrated, considering different aspects of the system.

II. FOCAL AREAS OF E-HEALTH

To induce IoT as an embedded technology in the existing healthcare applications, the focal services need to be addressed first.

TABLE I. FOCAL HEALTHCARE APPLICATIONS

Service	Description
Health Records	A lot of records linked to a patient are generated during a treatment phase. Also for a chronic treatment, a lot of patient's medical history needs to be taken into account for efficient treatment. Efficient management of all the patient data is an important task to perform.
Diagnosis	Detailed treatment involves a large number of diagnoses very often. These diagnosis process is often distributed which needs a comprehensive assimilation for finalized reports. This entire process is often tedious.
Monitoring	The entire monitoring process involves huge amount of real-time data. This data is processed and analyzed (mostly manually).
Post-medication phase	Even after the medication phase is over, the rehabilitation phase also involves recording patient's data which is also very vital in the context of ensuring complete cure.

The chief reason why the induction of IoT in healthcare systems has been taking over is quite clear. Most healthcare applications and processes work distributed and remotely. Especially the areas where active manual intervention is inevitable (like medication, prescription) work as remote entities and data sharing has been quite tedious. IoT comes in as the connecting platform for all the respective entities involved in a typical healthcare system. Moreover it supplies the subtle and embedded power of computing which extracts the data from the environment and exchanges it mutually for a ubiquitous information system, heading toward a ubiquitous intelligent system. Transforming to a healthcare system based on IoT, the resultant system performs much more to a typical clinical information system. The main objective of IoT is not to cater a mere information system but to provide an automated decision support system. However, the level of autonomy is extremely variable from case to case. This gives emphasis on the method of passive monitoring and medication. In many cases, even after the end of an active treatment phase, this passive treatment is an important phase which is one of the focal areas of interest in IoT based healthcare systems.

III. PROPOSED E-HEALTH MODEL BASED ON IOT

To promote a ubiquitous and smart environment of healthcare services, an IoT based model of eHealth has been proposed. First, the objective of such system needs to be addressed. Accordingly the connecting entities along with their method of interaction would be discussed.

A. Patient Records

Maintaining the patient data electronically has been quite common in all major healthcare facilities. However the increasing number of distributed healthcare entities results in generating redundant data. Also the historic data of a patient couldn't be used efficiently if the data belongs to another entity. To make use of the power of connected data, the entities dealing with patient data needs to be linked up via a common and ubiquitous platform. IoT would serve as this connecting link between the entities dealing with patient entities. Primarily, the mutual exchange of patient records within remote entities would simplify the record maintaining purpose. Likewise, keeping track of the medical history of a patient would also become easier. Mere sharing of data requires a distributed database but using the IoT approach, it works little different. Getting deeper into the system, the patient is the center of all data in the environment. Hence whatever interactions take place between the sharing nodes would use patient's ID as the unique key. Accordingly a virtual storage (cloud) space for every new patient is proposed. The registration to this storage space could be done on the first encounter with the health services. Alternatively, every persons registered with a National Unique Identity (UID) could be allocated this storage space specially meant for health records. However, the storage mechanism needs to be efficient for systematic access when required. Accordingly the data system needs to be structured properly in an efficient schema so that even if the data is entered by different remote entities, storing the data uses a common form for easier and systematic access.

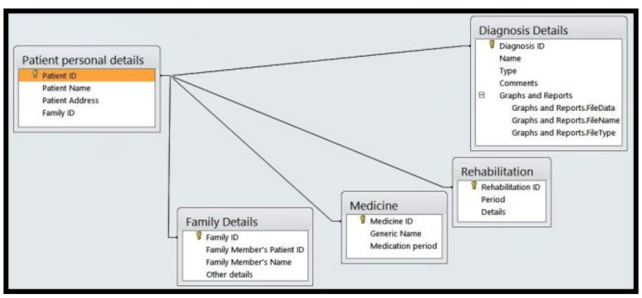

Figure 3. Relationship schema for storing patient related records.

Holding *patient_id* as the unique key, separate tables has been used for storing records related to diagnosis, investigation, medication and rehabilitation of a patient (Fig. 3). For every set of records at a single instance a separate ID would be created at that table itself. Another important table for family details has also been put up. Here a respective *patient_id* is linked with other unique *patient_id* of their family members with the relationship details. It could be excellent is treatment where knowing family traits is of paramount importance. Also specific family traits would generate precautionary alerts which could help many diseases get detected well beforehand.

The mechanism to operate this system would also be different compared to ordinary e-record management system. The primary difference is that unlike ordinary electronic record management system, in this system any healthcare unit or even a private doctor could upload the medical records of a patient in the proper format. Since the key to this personal storage space of the patient is the UID, a login system needs to be made functional ubiquitously. Using this portal any authorized person could access the patient data. However, to restrict access, the authentication could be based on some biometric information and password. Also the diagnostic information could be classified into hierarchical and historic levels. Like for a cardiac treatment, the medical team would have primary access to the cardiac reports only. However, secondary and tertiary access could be granted based on the nature of request.

B. Clinical Decision Support System

Providing a decision support system for the physicians based on connected knowledge would be of immense help. The system consists primarily of three key parts – the knowledge base, an inference engine and a communication mechanism. Basically in an IoT system for clinical decision support system, the connected data of patient's history is primarily taken into concern. This includes specific allergies and sensitivities. Also the decision system is trained with conditional statements which would take the historic data and current data, match with the inbuilt logic and would pose specific alerts and decisions as an advice to the medical personnel. For example, if a patient has past history of disease 'A', drug 'B' could be potentially risky. In that case drug 'C' needs to be applied instead of drug 'B'. The decision system would work like –

```
if (apply_drug(B) then
        check_history(A);
        if (check_history(A) == 'true') then
                apply_drug(B) = 'false';
                apply_drug(C);
        end if
end if
```

The effectiveness of this IoT based decision support system is that, the patient need not to exclusively keep track of all prior medical history. Also a new physician handling the case needs not to search the entire medical history before applying a drug. Rather the trained decision support system performs the search process and generates alert if a drug creates potential risk in connection to prior medical issues. However the training phase is extremely vital for a good performance decision support system. Primarily the system is divided into knowledge based and non-knowledge based approaches [5]. IoT acts as the missing link in this context. The knowledge is obtained from the input and logic provided to the system beforehand. Also several conditional logics are also provided to the system as pre-inputs. The intelligence works on the patterns obtained from the recorded data linked to the patient, dealing with the machine-learning mechanisms [6]. Considering the knowledge and intelligence, the system would provide the best support to the doctor for prescribing the best thing for the patient.

C. Real-time and Remote Monitoring

The IoT based healthcare system could also work for passive medication or lifestyle. But to record lifestyle data, real-time recording is needed. However, real-time recording involves generation of huge data. Lifestyle data could be obtained through embedded sensors. Sensors could be embedded in devices having bodily contact like smart watches and wrist bands. However, the data obtained in this way contains only non-invasive data. To address the problem of voluminous nature of real-time data, a method has been proposed. The sensors need to be provided with minimal processing capacity. On collection of data, at specific time intervals, running average is calculated. Periodic peak values which stand far away from the average are recorded. While storing the data to the virtual storage, only two values would be stored – the average value and the peak value (that do not comply well with the average). Metabolism rates, calorific values, pulse, blood glucose levels could be some of the recordable data from this non-invasive real-time monitoring process.

Figure 4. Scheme for real-time monitoring and reporting .

Considering a typical monitoring system of heart pulse (Fig. 4), the running average taken at every 12 seconds is 70.416. The normal pulse being pre-programmed at 72 along with the normal range being given, the average value remains within normal range. However at a particular instance, the value drops to 65 which is beyond the normal range and needs to be reported separately. So during storing the summarized value of this report, only two attributes (*average*, *peak*) are taken into concern. Hence at every twelve seconds the values are being refreshed, the first dataset being reported as (*70.416*, *65.0*). Definite alerts could also be generated if the dataset goes beyond normal range, approaching to potential emergency. It is good to take the home-recorded data of a patient than the recorded data at doctor's place because home-recorded data is more likely to be realistic since it corresponds more to a normal condition [4]. Also abnormal values addressed beforehand helps tackle many critical health issues in an early and better way.

D. *Remote treatment*

Many health issues get addressed at a much later stage due to lack of immediate connection with the healthcare personnel. This issue is severe in case of rural and remote areas where healthcare facilities are not always at the fingertips. Due to this issue, often it is seen that patients are more inclined to follow previous medication (medicines prescribed earlier for similar health problems) rather than consulting a physician afresh. In this context, remote treatment counts significant because it helps connecting to healthcare facilities in a better way. Telemedicine and Cybermedicine have been quite popular terms these days but using IoT based smart platform would make the things simplified and efficient together. The foundation of this IoT based platform of remote treatment is based not only on symptoms as reported by the patient but also on the health data remotely collected from the embedded sensors at the patient's end and transmitted through the IoT platform to the concerned physician.

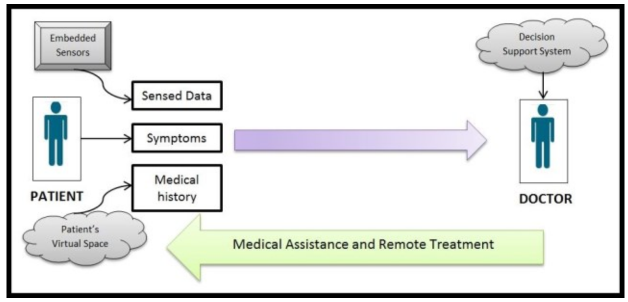

Figure 5. Schematic Diagram of IoT based Remote Treatment Model.

Basically the entire process of remote treatment works as an event management procedure (Fig. 5) which is described briefly as follows. As the patient generates the request for remote care, the system asks for the symptoms. Once the symptoms have been recorded, the request is transmitted to the healthcare personnel, the request containing the *patient_id* and primary symptoms. Analyzing the request, the doctor could ask for more symptoms if required. Then she sends query to the patient's system for the recent (or previous, if needed too) health data, sensed through embedded sensors (smart band etc.). The decision support system at the doctor's end assists in choosing the right medicine for the patient, considering previous medical issues and special sensitivity towards a drug. Analyzing the data obtained, the doctor either generates an e-prescription, or expresses the inability to treat remotely (after giving primary advice). This could be an efficient method for reaching the unreached with the best possible medical assistance, remotely.

IV. DISCUSSIONS ON THE MODEL

The focal concept of the IoT based eHealth system is using the ubiquitous network to communicate with the concerned entities and using the knowledge from the data to take intelligent actions. However, there have been several issues involved. First, availability of a live data connection would have been essential for maintaining a constant connection. But it is never recommended to maintain a live connection between all the entities, nor is it possible also. Alternatively, periodic updates of the system could be broadcast to all the concerned entities to refresh the status pages. Embedded chips providing data connection would be immensely helpful in this context. Second is the security structure of the system. Since the system deals with patient's data, utmost care is essential. However the data becomes more vulnerable when it moves across several networks, often unspecified beforehand. In this case, maintaining the data locally is recommended. The devices and entities seeking remote data need to use a query service with a request which would be granted with the exact (or summarized) value, as required. This minimizes the chance of bulk data leakage and putting the security at stake. Also specific gateways need to be employed at strategic points to ensure security. Another important issue is the fate of the patient's data stored in the personal virtual space. This area is vital because it would contain all the medical history related to a person. To ensure non-fabrication of the data, it is recommended to put up any modification facility. Only authorized entities would be able to write new data (medical records) and access previous data, based on query services only.

V. Conclusion

Inclusion of technologies in health sector has been quite enthusiastic in the recent times. Just with the advent of IoT, inclusion of this technology for eHealth sounds significant as a part of the ubiquitous revolution. Moreover the proposed system of eHealth based on IoT would not only provide a smarter approach toward health services but also makes the decision making process intelligent. On a whole this system could address several health issues as a mass. Since the foundation of the proposed eHealth model is based on Internet, it would be easier to transform the outputs to second screen and mobile devices. Accessibility to remote monitoring would receive a thrust in this way. Scalability is also an important advantage of this system. Performing big data analytics on the connected data obtained from the patients' virtual storage of medical records, health issues of the mass could be identified at its best and could be addressed efficiently. So the benefits of this connected data would not only be personal but also significant in the larger aspect. It would also help in exchanging the medical issues for worldwide research which would help addressing the problems and providing better solutions. Despite several issues of connectivity and security, IoT based health services truly hold a promising future for extending the services on a larger vision.

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