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Ubiquitous Healthcare Utilizing Semantic Interoperability

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Abstract

Ubiquitous healthcare monitoring provides a better way to monitor the patient. In this we sent an alert message on the doctor's smart phone or laptop to notify him about the patient condition but different devices may have different architectures, applications or operating systems so one of the major problems facing is the lack of interoperability among them. When signal sent to different devices then, substantial difficulties can arise in translating information from one application to the other. In this paper, we focus on resolving semantic difficulties that arise in software integration using Smart M3 platform. To circumvent this obstacle of lack of semantic interoperability, we need some way of explicitly specifying the semantics for each terminology in an unambiguous fashion. Ontologies can provide such specification. It will be the task in this paper to explain what ontologies are and how they can be used to facilitate interoperability between software systems using Smart M3 in ubiquitous healthcare.

Keywords

Semantic Interoperability; Ubiquitous Healthcare; ECG; Smart-M3; Mobile Computing; Ontology, Knowledge Processor; Semantic Information Broker.

I Introduction

The healthcare industry is facing a number of challenges including skyrocketing costs, medical error incidence, inadequate staffing in hospitals and lack of coverage in rural and underserved urban areas. Healthcare workers are under increasing pressure to provide better services to more people using limited financial and human resources. The one proposed solution to the current crisis is ubiquitous (pervasive) healthcare. The wide scale deployment of wireless networks, wearable computing will improve communication among patients, physicians, and other healthcare workers as well as enable the delivery of accurate medical information anytime anywhere, thereby reducing errors and improving access. At the same time, advances in wireless technologies such as intelligent mobile devices and wearable networks—have made possible a wide range of efficient and powerful medical applications. Ubiquitous healthcare is the application in the healthcare industry by mixing the applications of ubiquitous computing and wearable computing. Pervasive healthcare has the potential to reduce long-term costs and improve quality of service, but it also faces many technical and administrative obstacles. In this paper we have generated ECG waves from the real data taken from MIT BIH Hospital [1-3] and then diagnosis and analysis is done. To generate ECG waves we have used the PAN TOMSKIN [4-5] algorithm which is shown below in the flow chart in Fig. 1.

Semantics concerns the study of meanings. Semantic interoperability is the ability of computer systems to exchange data with unambiguous, shared meaning. Semantic interoperability is a requirement to enable machine computable logic, inference, knowledge discovery, and data federation between information systems. Semantic interoperability is therefore concerned not just with the packaging of data (syntax), but the simultaneous transmission of the meaning with the data (semantics). This is accomplished by adding data about the data (metadata), linking each data element to a controlled, shared vocabulary. The meaning of the data is transmitted with the data itself, in one self-describing "information package" that is independent of any information system. It is this shared vocabulary, and its associated links to an ontology, which provides the foundation and capability of machine interpretation, inference, and logic. After the analysis and diagnosis of electrocardiogram we send an alert notification on the doctor's laptop or any other device

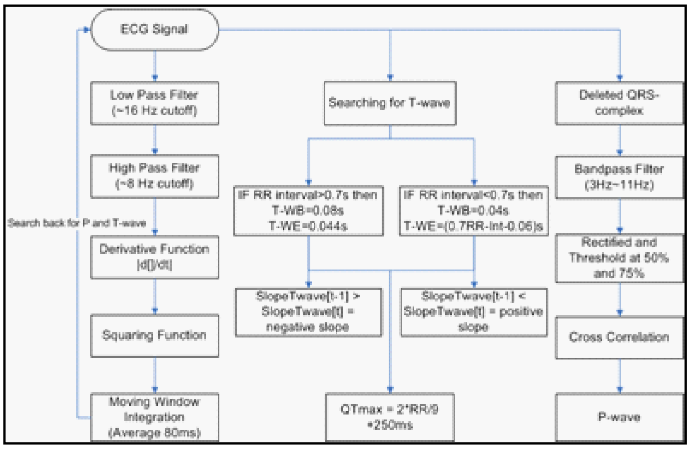

Fig. 1: Flow Chart of ECG Analysis Algorithm

to notify him about the patient health so that in case of any serious state patient can get medical help as soon as possible. As different devices may have different platforms, architecture & different semantics so here we face the problem of lack of semantic interoperability among them. The reasons for this problem can be:

- Translating information from one application to the other as the devices may have different architectures: For example in case of different operating systems for example one is Linux and another one is window 7. Linux is case sensitive whereas windows are not means they have different semantics and here we can face the problem of semantic interoperability.
- Applications may use different terminologies to describe the same domain: For example if we consider a terminology "card" then we can refer this in different domains. In case of computer system domain we mean punched card, graphic card whereas in domain "Poker" we refer card as playing card.
- Applications use the same terminology to describe different domain.
- Heterogeneous network: It means in a network we have different devices which have different capacity, semantics, protocols, resources etc.

The Smart-M3 (multi-vendor, multi-device, multi-domain) architecture [12] is designed to achieve semantic information based interoperability. Smart- M3 architectural elements are shown in Fig. 2. Information in the Smart-M3 architecture is represented using ontology models. Ontology allows description of the semantic model within a specific knowledge domain by means of an explicit data format. In Smart M3, ontology is used for representing semantic information and reasoning about it. Entities called Knowledge Processors (KP) and Semantic Information Brokers (SIB) form a Smart-M3 network. A KP is an entity that produces or consumes information according to the ontology relevant to its defined functionality. A SIB is an entity, in which high level information for a smart space is stored and maintained. This information can be used and updated by a KP. For example, a producer-KP can collect real data of the patient for ECG analysis and provide semantically meaningful information to the SIB. Similarly, a consumer-KP can subscribe to such information of patient available at the SIB to notify the doctor regarding patient health status and make queries about the same. KPs and SIBs run the Smart Space Access Protocol (SSAP), which is a simple set of primitives to insert, remove and access data in a SIB, and can be used on top of transport technologies such as TCP/IP or Network on Terminal Architecture (NoTA). A KP can use SSAP for several transaction types such as join, leave, insert, remove, update, query, subscribe, and unsubscribe.

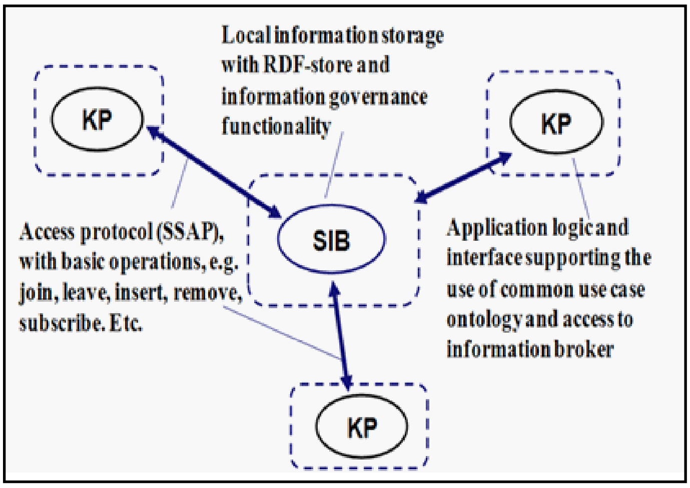

Fig. 2: Smart M3 Architecture

In this paper we propose a scenario in which alert message will be sent form one device to another and resolve the issue of lack

II. Literature Work

Projects	Properties
PERSIST[21] (Personal Self-Improving Smart Spaces)	Interoperability is established based on a context sharing using semantic web technologies, where a context management system is designed which stores and retrieves context information in a distributed manner.
MAVHome[22] (Managing Adaptive, Versatile Home)	Interoperability is established based on a context sharing using an Internet based interface which provides interaction capabilities with users and resources. Adaptation of services using a simple learning algorithm and a neural network approach.
SOUPA [20] (Standard Ontology for Ubiquitous and Pervasive Applications)	Context sharing is done using a standard ontology (i.e. context ontology based on OWL) for ubiquitous and pervasive applications, where supports to describe devices on a very basic level (e.g. typical object properties is bluetoothMAC), but it has no explicit support for modeling more general device capabilities.
GUPSS [16] (Gateway-Based Ubiquitous Platform for Smart Space)	A gateway-based ubiquitous platform is used for information sharing between sensors/actuators and web based server in Smart Spaces.
CISE [23] (Context-based Infrastructure for smart environment)	Interoperability for context sharing is established based on a web infrastructure using a Frontier on a Macintosh.
ISHEWS[24] (Interoperability for Smart Home Environment Using Web Services)	SOAP (Simple Object Access Protocol) and XML technologies are considered for interoperability solution due to the standard way of data representation and the format, where extensible to deal with changing requirements.
METEOR-S [19]	XML repositories are used for managing (storing, searching and reusing/sharing) the ontologies.
PBA [17] (Platform Broker Architecture)	PBA is proposed as a framework for programmable smart spaces It discusses the properties of integration of resources (software, and hardware) through a synthetic file system, extendibility (i.e. extensible property of a smart space) and smart space programmability
UMONS [18] (Ubiquitous Monitoring System in Smart Spaces)	UMONS discusses the requirements of a smart space such as adaptation, resource and service management (i.e. monitoring of objects and services; easy addition and deletion of objects), Reasoning (i.e. to infer the current state of an object by processing of information collected).

The trends for pushing more operational intelligence towards network elements to achieve more context-aware and self-managing behavior often requires elements to gather network knowledge without necessarily binding explicitly to all of the potential sources of that knowledge. Though event-based publish-subscribe models allow efficient distribution of knowledge where the event types are known globally, dy namic service chains, ad hoc networks and pervasive computing application all introduce a more fluid and heterogeneous range of context knowledge. This requires some runtime translation of knowledge between sources and sinks of network context. This paper builds on existing mapping techniques that use ontological forms of existing management information models to examine the extent to which these can be employed for runtime semantic interoperability for network knowledge. It presents results in developing a management knowledge delivery framework based on existing models and platforms, but which offers a more decentralized knowledge exchange mechanism.

Thonas Bittner [7] concluded that ontologies are used to overcome historic incompatibilities between software system in the domains of Computer Aided Design, Architectural Engineering & Geographic Information Processing and to facilitate semantic interoperability among those systems. The role of terminology systems in communication processes and how ontologies are used to specify the semantics of the terms in those systems. We distinguished two major kinds of ontologies: logic-based and non-logic based ontologies. We also distinguished two major strategies of applying ontologies in order to facilitate interoperability: the use of data standards and the use of reference ontologies.
The related projects for semantic interoperability architecture is discusses in Table. 1.

III. Proposed Architecture and Implementation

The proposed architecture is shown in Fig. 3. ECG KP is the system where ECG real data analysis and monitoring is done. KPI (Knowledge Processor Interface) is integrated with ECG analysis and monitoring system which helps the system to communicate with SIB through that interface. SIB (Semantic Information Broker) is an entity, in which semantics for a smart space is stored and maintained. General ontologies are stored in SIB. This information can be accessed by the ECG KP and mobile KP. Mobile KP is the smart phone or laptop of the doctor on which we want to send the notification about the patient health status.

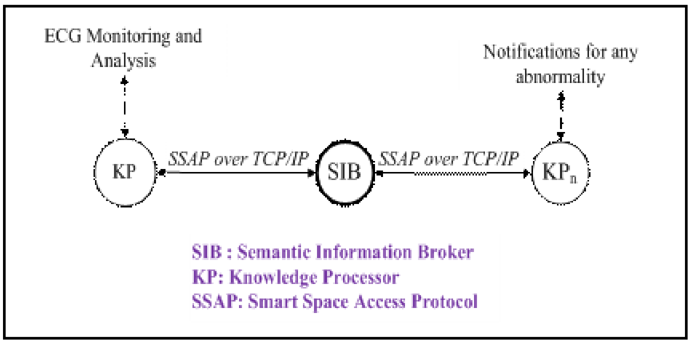

Fig. 3 : Proposed Architecture

SSAP is Smart Space Access Protocol used on the top of TCP/IP. It defines simple set of primitives to insert, remove and access data from SIB. A KP can use SSAP for several transactions such as join, leave, insert, remove, update, query, subscribe, and unsubscribe to manage information in a smart space. Since SSAP is transport layer independent, the same SIB can serve KPs over several transport technologies at the same time.
The proposed architecture with implementation details is shown in Fig. 4.The main objective of the proposed architecture is to make heterogeneous systems semantic interoperable. As shown in figure on one laptop we have Window 7 operating system and .Net C# language. On this system we have ECG simulator GUI which generates ECG waves from the real data and analyse them. KP interface is integrated with ECG GUI simulator so that interaction with SIB can take place. Any state of abnormality in patient heart rate will be notified to the doctor's mobile or notebook. Notebook has Linux Ubuntu operating system and implemented in Python. On this system three terminals are there terminal one i.e. T1 is for SIB, T2 is for TCP (responsible for transmission of data) and T3 is consumer KP named as Mobile KP in figure. In order to initiate the SIB in terminal we used CLI mode and run sibd command for the same. After that to initiate TCP we use CLI mode of terminal to and run sib-tcp command. In T3 we execute consumer Mobile KP file coded in python and we get a GUI of doctor's mobile

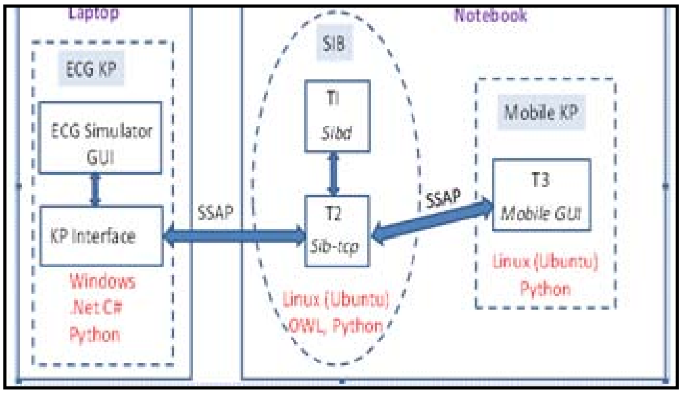

Fig. 4: Implementation of proposed architecture.

SIB stores and maintains general ontology for creation of graph node, patient node and ECG node. The ontology model [13] plays a major role in exchanging information across various devices. The ontology provides a shared vocabulary among these. The proposed architecture uses such a shared vocabulary of device resource and service availability. Generally, types of objects and/or concepts that exist, their properties and their relations are listed in an ontology. Ontology descriptions in this work use Resource Description Format (RDF) [14] as the main data structure. These descriptions are exchanged among ECG KP, SIB and Mobile KP. RDF format is described in terms of "properties" and "property values" using RDF statements. RDF statements are represented as triples, consisting of a Subject (S), a Predicate (P) and an Object (O), i.e. {S, P, O}. The information represented in this triple format is used by ECG KP and Mobile KP for interacting through SIB using SSAP transactions, namely, join, leave, insert, remove, update, query, and subscribe. OWL (Web Ontology Language) [15] is used for ontology. Subscriptions are persistent queries that notify the subscribing KP every time when the data pointed by the query changes shown in Fig. 5 and Fig. 6 in the next section.
Subscription and Update links for information exchange: The working of subscription and update is shown in Fig. 5 and Fig. 6 respectively. They work as follows: In case of subscribe ECG results; Mobile KP subscribes the ECG results from SIB. ECG KP publishes patient's ECG results in SIB. SIB updates the results in SIB. In case of subscribe ECG results mobile KP do not need to query for the results again form the SIB as shown in Fig. 5, if any update is publish in SIB from ECG KP it will automatically update them in Mobile KP.In case of query ECG results, ECG KP publishes ECG results in SIB. Mobile KP query for ECG results from SIB. Then SIB update results in Mobile KP. In this case as shown in Fig. 6, update of ECG results will be done in Mobile KP only when it will query for those results each time.

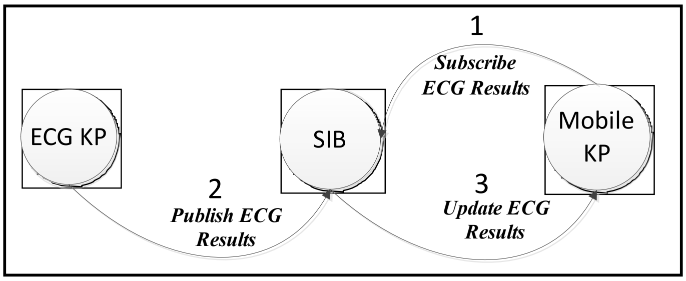

Fig. 5: Subscription Link for Information Exchange.

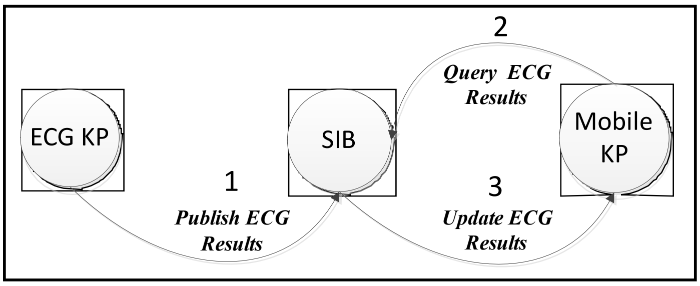

Fig. 6 : Update Link For Information Exchange.

Data Exchange Mechanism in KPs: The proposed mechanism of data exchange is shown in Fig. 7. It follows steps:
Step 1: Mobile KP and ECG KP join SIB for information exchange.
Step 2: SIB confirms the connection with both KPs.
Step 3: Mobile KP subscribe for ECG result in SIB.
Step 4: ECG KP update ECG results in SIB.
Step 5: As Mobile KP subscribe for ECG result so update of ECG result sent automatically to the Mobile KP.
Step 6: Mobile KP queries for ECG result to SIB.
Step 7: SIB sent last updated ECG result to Mobile KP.
Step 8: ECG KP publishes ECG result regularly to SIB with the specified time frame and so on.

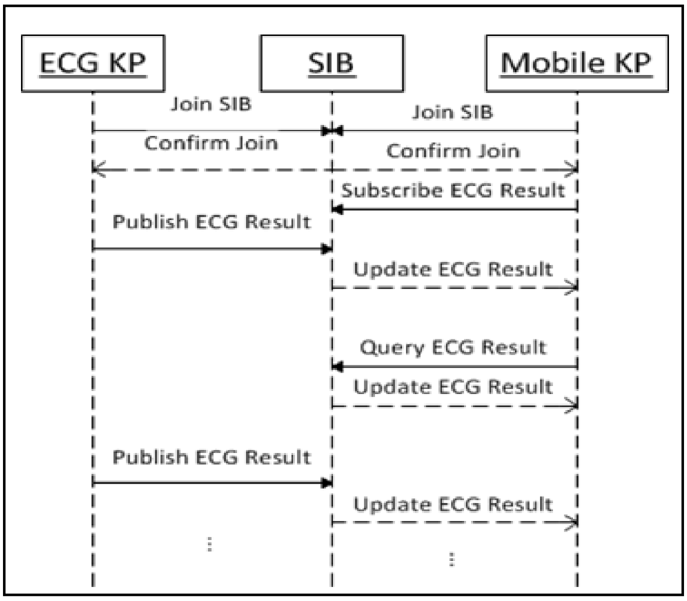

Fig. 7: Information Exchange Mechanism.

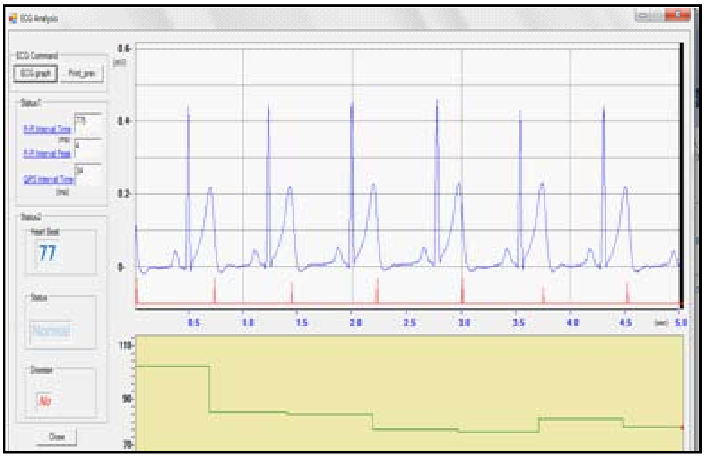

Fig.8 : ECG KP

ECG KP is shown in fig 8. Window 7 and dot net paltform is used for this. In this waves are generated from real data(taken from MIT BIH Hospital). Heart beat, P wave, T wave & QRS complex is calculated and analysis & diagnosis is done. Figure 9 shows terminal one i.e. T1 which represents semantic information broker in which we have used Linux and python programming language. ECG data is being transferred between various KPs. So TCP connection is established between them which is shown in figure 10(terminal T2). Mobile KP is shown on terminal T3 shown in figure 11. We run the file of mobile KP(consumer KP) & we get the mobile GUI of doctor's smart phone which is shown in figure 12. Doctor query for patients QRS Complex & heart rate report which is shown in figure 13 & figure 14 respectively. In this condition the ECG data published on SIB will be sent on the mobile KP so that doctor can analysed that data.

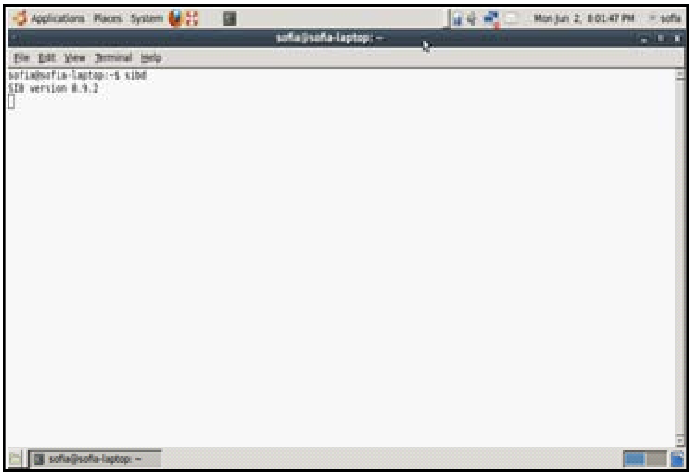

Fig.9 : SIB

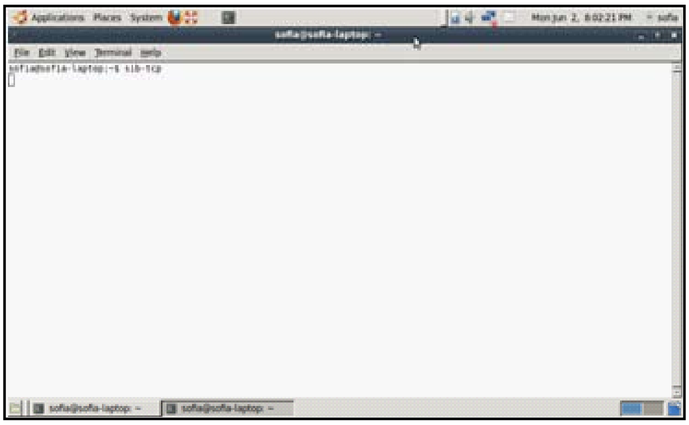

Fig. 10 : SIB TCP

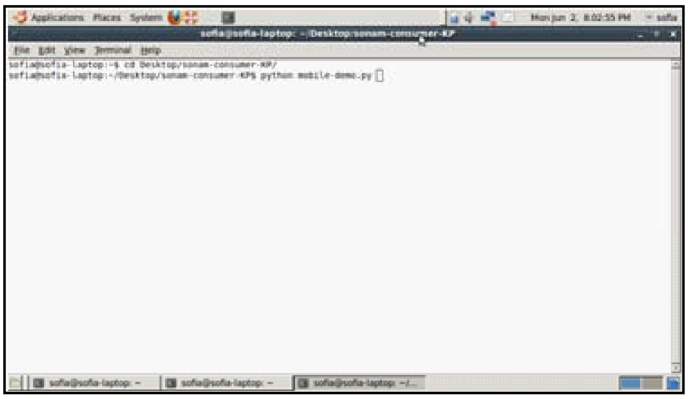

Fig.11: Mobile KP

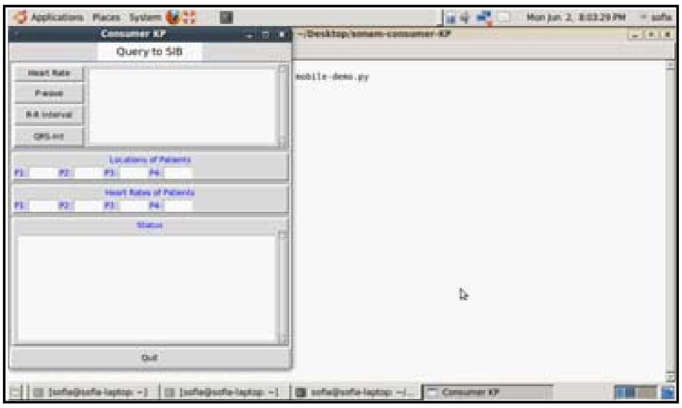

Fig. 12: Mobile GUI

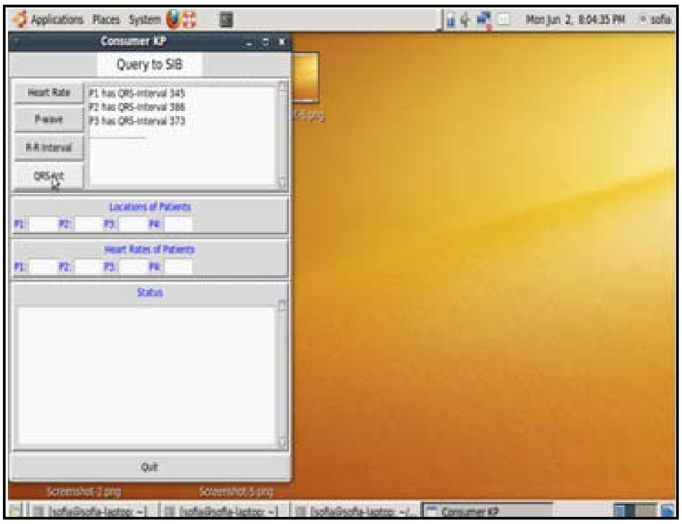

Fig.13: Mobile GUI showing QRS interval

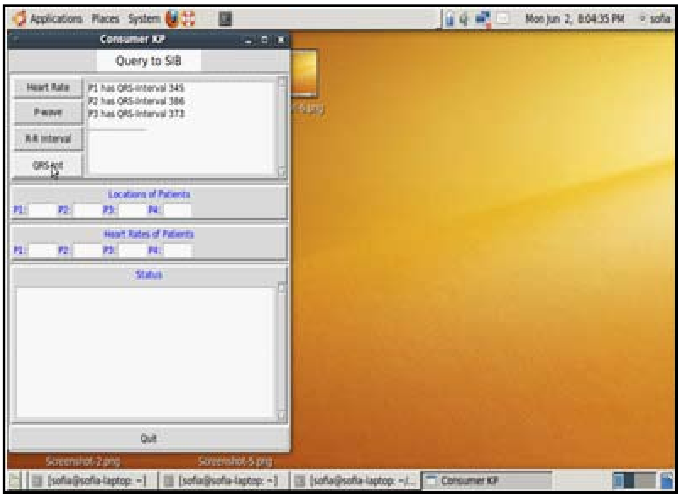

Fig.14 : Mobile GUI showing heart rates

IV. Analysis Results

In evaluating the delay performance, we consider action (A) and reaction (R) times in the ubiquitous healthcare system. Applications can be defined action and reaction for the system such that an action of an entity (an object or a service) finds response with a certain reaction of another entity as shown in Fig. 15. The end-to-end delay from 'entity X' (action A) to 'entity Y' (reaction R) is a determining factor for the minimum time interval between successive reactions. The time interval between any two consecutive reactions of the same type (e.g. ECG update) at 'entity Y' must be greater than the delay between A and R for stable operation.

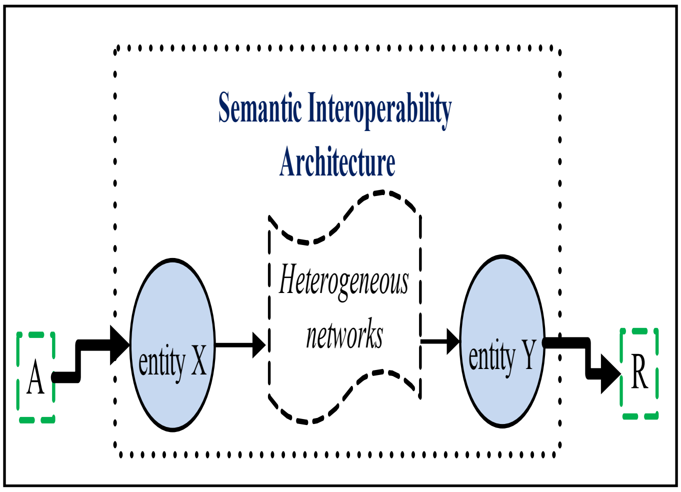

Fig. 15: The concept of action and reaction in the ubiquitous healthcare system.

In our proposed system, there is a mode of transmission between a KP and a SIB. The system is evaluated considering this mode of transmission based on the end-to-end delay performance from A to R. In particular, we show how the system behaves for a given ECG KP updates on SIB, status update on mobile KP from SIB and occurrence of successive actions and reactions.

The end-to-end delay is defined as the time taken for information to be processed and transmitted across a network from source to the destination. The transmission delay from a ECG KP to a SIB is given by ΔtEKPtoSIB, and is calculated by (1), where tEKPtoSIB,Tx and tEKPtoSIB,Rx are the measured times for the sending and receiving information. The delay for the Mobile KP to update and retrieve information at the SIB is given by ΔtMKPtoSIB and ΔtSIBtoMKP respectively. The calculations are given by (2) and (3), where tMKPtoSIB,Tx and tSIBtoMKP,Tx; and tMKPtoSIB,Rx and tSIBtoMKP,Rx denote the information sending and receiving times, respectively.

$$\Delta t_{EKPtoSIB} = t_{EKPtoSIB,Rx} - t_{EKPtoSIB,Tx} \qquad (1)$$

$$\Delta t_{MKPtoSIB} = t_{MKPtoSIB,Rx} - t_{MKPtoSIB,Tx} \qquad (2)$$

$$\Delta t_{SIBtoMKP} = t_{SIBtoMKP,Rx} - t_{SIBtoMKP,Tx} \qquad (3)$$

The processing delay at SIB is defined as ΔtSIB. The end-to-end delay (Δte2e) in the ubiquitous healthcare system is calculated based on a complete state of A to R. For example, an action taken by entity (ECG KP) creates a reaction at Mobile KP. This means that the update on Mobile KP dependent on information from ECG KP, which is a complete state required for the end-to-end delay (i.e. te2e) and given by (4).

$$\Delta t_{e2e} = \Delta t_{MKPtoSIB} + \Delta t_{SIBtoMKP} + \Delta t_{SIB} \qquad (4)$$

The calculation of end-to-end delay in (6) helps to estimate the time for the next successive action occurrence for Mobile KP.

Table.2 : Delays measurements

Calculations	Delays (milliseconds)		
	ΔtEKPtoSIB	ΔtSIBtoMKP	ΔtSIB
Average	175.63	176.71	15.98
Std.Dev.	16.92	17.79	1.19
Minimum	144.32	145.55	13.28
Maximum	243.17	244.19	18.72

The delay measurements are performed by capturing the network traffic that flows through the SIB while using a wired Unshielded Twisted Pair (UTP) network. The delay between the KPs and the SIB are measured by the clock synchronization. The results of the measurements are shown in Table 2. The measurements show that the delay between a KP and the SIB is rather large with a considerable variance as compare to the processing delay at the SIB.

V. Conclusion and Future Direction

In this paper we have concluded that proposed extensions using Smart M3 provides better healthcare to the patient. Patient is constantly monitored by the doctor as his ECG results are being sent to the doctor's mobile. In case of any acute state he will get medical help as soon as possible. Information of ECG results is exchanged between different devices and network using ontology based semantic interoperability architecture, namely Smart M3. An alert condition send to different devices independent of their underlying architecture.End to end delay evaluation results shown that use of Smart M3 in ubiquitous healthcare provide better healthcare because delay is very low.

In future we can enhance the architecture using N number of nodes and increase the scalability of the architecture. As the number of nodes increases there will be more chances of failure of nodes and unavailability so reliability, availability, throughput should be investigated. In order to provide better healthcare, the notification can be send on the systems of the near and dear ones of the patient as well so that they can also help the patient especially in case of elderly persons living alone at their homes.We can use smart gateways which provides more flexibility to achieve semantic interoperability.

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