ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
FACULTY OF COMPUTER AND MATHEMATICAL SCIENCES
DEPARTMENT OF COMPUTER SCIENCE

Context Aware Pervasive Healthcare System for HIV/AIDS Patients (CAPHS)

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Acronyms and Abbreviations

3TC	lamivudine
ABC	abacavir
AAU	Addis Ababa University
AIDS	acquired immunodeficiency syndrome
ART	antiretroviral therapy
ARV	antiretroviral
ATV	atazanavir
AZT	zidovudine (also known as ZDV)
BAN	Body Area Network
CAPHS	Context Aware Pervasive Healthcare System for HIV/AIDS patients
CD4 cell	T-lymphocyte bearing CD4 receptor
d4T	stavudine
ddI	didanosine
DNA	deoxyribonucleic acid
DRV	darunavir
EFV	efavirenz
ETV	etravirine
FPV	fos-amprenavir
FTC	emtricitabine
HBV	hepatitis B virus
HIV	human immunodeficiency virus
IDV	indinavir
LPV	lopinavir
LPV/r	lopinavir/ritonavir
NNRTI	non-nucleoside reverse transcriptase inhibitor
NRTI	nucleoside reverse transcriptase inhibitor
NVP	nevirapine
OIDB	ontology instance database
OWL	Web Ontology Language

PI	Protease Inhibitor
RDF	Resource Description Framework
RTV	ritonavir
SPARQL	SPARQL Protocol and RDF Query Language
TB	Tuberculosis
TDF	Tenofovir disoproxil fumarate
WHO	World Health Organization

Abstract

These days, healthcare services are enjoying the application of pervasive computing systems. Advances in wireless technologies— such as intelligent mobile devices and wearable networks can 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. However, transmission of vital signs, frequency of transmission of vital signs, network communication cost, context refinement, and management of large contexts are still problems of pervasive healthcare systems. In this work, we propose a context aware pervasive healthcare system for HIV/AIDS (Human Immunodeficiency Virus/ Acquired Immunodeficiency Syndrome) patients (CAPHS). The architecture of the system consists of three constituents: the patient unit, the healthcare unit and the doctor/nurse unit. The patient unit consists of a group of body sensors for detecting vital signs data from patients and transmitting it to the patient's smart phone via Bluetooth. After preprocessing, the smart phone transmits vital signs context information to the healthcare unit via Internet for further processing and reasoning if there is any abnormality. This preprocessing helps to determine the frequency of transmission of vital signs and reduces the network communication cost to transmit vital sign data. At the same time, it also increases the efficiency of the healthcare unit because this operation reduces its task of context refinement. The healthcare unit is rich in ART (Antiretroviral Therapy) ontology knowledge that we developed. For better management of large contexts, we use a hybrid context management approach in which the high level schema ontology stored in OWL/RDF (Web Ontology Language/Resource Description Framework) format and the ontology instances stored in ordinary relational database. The doctor/nurse unit is the thinnest of all units in terms of number of components. It communicates with the healthcare unit via Internet/SMS so that physicians can remotely monitor their patient. We have developed a prototype implementation for the system and we see that it is promising.

Key Words: Pervasive Healthcare, Context Awareness, Ontology, ART, CAPHS.

Chapter One: Introduction

1.1. Background

The healthcare industry, especially in Africa, has a number of problems, including high costs, insufficient human resource, and lack of coverage in rural and underserved urban areas. Especially in most of Sub-Saharan Africa, health care remains the worst in the world. According to WHO's (World Health Organization) 2006 World Health Report, Sub-Saharan Africa accounts for 11 percent of the world's population, yet bears 24 percent of the global disease burden and commands less than one percent of global health expenditure. Moreover, the biggest problem facing the health sector currently is the rising incidence of HIV/AIDS, which is placing and will continue to place considerable strain on the public health system in many African countries. To overcome these challenges and to increase the accessibility of healthcare to all in Africa, implementing ICT in healthcare industries is a good strategy. Researchers in [1] proposed that *pervasive healthcare* is one solution to the current crisis in the healthcare industry.

Pervasive healthcare may be defined from two perspectives: i) as the application of pervasive computing technologies for healthcare, and ii) as making healthcare available everywhere, anytime and to anyone [2]. According to Varshney [3], the wide scale deployment of wireless networks 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. Varshney has mentioned that these technologies can support a wide range of applications and services including mobile telemedicine, patient monitoring, location-based medical services, emergency response and management, pervasive access to medical data, personalized monitoring, and lifestyle incentive management.

Wireless technologies can also reduce medical costs and improve quality of service. Wireless LANs and personal area networks make it possible to continually monitor patients almost anywhere and immediately notify healthcare workers, the nearest hospital, or an emergency service of any critical change in status thanks to sensors, actuators, remote connections, and dedicated knowledge bases [4]. Such networks can quickly route biomedical and environmental data from sensors deployed on body area, in a room, or throughout a building to a central computer system for processing.

The concern of this research paper is to design a pervasive healthcare system for remote patient monitoring and personal health management to HIV/AIDS patients. In this system, the patient is equipped with different sensors which are connected to a smart phone using Bluetooth network – forming a Body Area Network (BAN) managed by the phone. These sensors detect different vital signs of the patient including CD4 cell (T-lymphocyte bearing CD4 receptor) count, body weight, body temperature, blood pressure, heartbeat, cough, diarrhea and night sweat and then transmit the data to the smart phone. After collecting vital sign context from sensors, the smart phone performs some preprocessing operations over the raw data to know the medical status of each vital sign and display the status result to the user so that the user may be conscious about his/her health status. Based on the status of vital signs interpreted from the low level context, the smart phone transmits vital signs via Internet to the healthcare unit if there is a difference from the previous value and if it is outside from the normal status. Then the healthcare unit accepts the vital signs as new health context and reasons over this context based on the knowledge base built into the ontology and the rules to trigger some actions in response. For example, it warns or alerts the user and/or the doctor if there are any abnormalities.

1.2. Motivation

HIV has created an enormous challenge worldwide. Since recognition of the disease, HIV has infected close to 71 million people, and more than 30 million have died due to AIDS. With around 68 percent of all people living with HIV residing in sub-Saharan Africa, the region carries the greatest burden of the epidemic[1].

[1] http://www.avert.org/worldstats.htm, retrieved on 11/11/2011.

Currently there is no cure for AIDS. However, there are drugs that can slow down the reproduction rate of HIV and thus slow down the damage to the immune system[2]. These drugs are called antiretrovirals (ARV's) and the treatment is called ART. The goal of ART is to ensure maximum control of the amount of HIV in the body, to restore and protect the immune functioning of the body by allowing white blood cells to increase their number, to reduce HIV-related illnesses and deaths and in the long run to improve the quality of life for people living with HIV. Antiretroviral drugs can also decrease the rate of HIV transmission from mother to child. Thus ART is a fundamental part of the field of HIV care.

With more than 1.3 million plus people living with HIV/AIDS, Ethiopia is one of the countries that are most heavily affected by the epidemic [5]. In addition to morbidity and mortality, the HIV/AIDS pandemic in Ethiopia has harmfully impacted the country's development. HIV/AIDS is affecting the agriculture, education, business and industry, and health sectors. In response, the government of Ethiopia has taken measures to reduce the risk of transmission of HIV and mitigate the impact of the HIV epidemic on society [5]. Recognizing the destructive effect of HIV/AIDS on its population and the positive impact of ART, the Ethiopian government has responded to the epidemic as a national emergency and urgent to scale up the ART program [6]. The Ministry of Health has been working towards the provision of safe, effective, equitable and sustainable ART services to those infected by HIV. In this effort, it has developed an ART Policy and ARV guidelines with support from national and international partners.

Due to these efforts made by the Government of Ethiopia to combat the epidemic, Ethiopia is making progress in the fight against HIV/AIDS. But, still this is not enough due to the large number of people living with HIV and the area and depth of the problem. Still there are a number of people infected with HIV who need ART service. Today, hospitals are overcrowded with AIDS patients, which makes difficult for caregivers to provide quality and fast service to customers. It's common to see patients in governmental hospitals sleeping on corridors due to shortage of nursing rooms. Moreover the ART program is not accessible in rural areas due to lack of healthcare coverage. This motivates the researcher to design a pervasive healthcare

[2] http://www.emedicinehealth.com/hivaids/page9_em.htm, retrieved on July 30,2010 at 09:20:40

system for HIV/AIDS patients to monitor them remotely. This system not only minimizes hospitalization through remote monitoring and ART but also enables patients themselves to be conscious about their health. It helps them to change their behavior by giving continuous feedbacks via their mobile device and develop good habits to care about their health.

1.3. Statement of the Problem

Pervasive healthcare is best solution to the challenges that healthcare industries are facing. A number of researches are made which show how pervasive healthcare can make a difference in the arena of healthcare service. Although, Pervasive healthcare has the potential to avoid these challenges and improve quality of healthcare service, it also faces many technical problems and needs many requirements. For example, transmission of vital signs, frequency of transmission of vital signs, network communication cost, context refinement, and management of large contexts.

In this research work, we designed a pervasive healthcare system for HIV/AIDS patients which detect vital sign contexts from patients and transmit them to the central system after performing preprocessing on the raw context. This preprocessing operation on the patient's mobile device is used to decide when to transmit the vital sign data to the central hospital (i.e. when there is a change from the previous value and if the status is abnormal). It is also used to reduce the task of refining relevant context on the central system, which in turn increases the efficiency of context reasoning, and reduce network communication cost needed for transmitting irrelevant context if it were sent without any preprocessing.

1.4. Objectives of the Thesis

1.4.1. General Objective

The general objective of this research work is to design a pervasive healthcare system for HIV/AIDS patients which can improve their quality of life.

1.4.2. Specific Objectives

The specific objectives of this research include:

- Studying in detail about the implementation of ART in Ethiopia to identify more related problems.
- Studying the state of the art of pervasive healthcare systems specifically related to remote patient monitoring.
- Studying the state of the art of ontology related tools to manage and reason context data.
- Modeling a pervasive healthcare system for HIV/AIDS patients for remote monitoring, and personal health management.
- Developing a prototype of the proposed system
- Testing and evaluating the system

1.5. Scope and Limitation

Our healthcare system considers only some vital signs including CD4 count, body temperature, body weight, blood pressure, heartbeat, cough, diarrhea and night sweat as context of patients. It doesn't include sophisticated contexts such as location, user activity, and the like. On the other hand security and privacy of medical context information while transmitting over communication networks, which is important in real applications, is not studied in this work.

The major limitation of this thesis work is that we didn't find real pervasive smart devices for implementation purposes. This is because of the budget limitation allocated for the work. Therefore, we couldn't buy the smart sensor devices and smart phones that we proposed to use. Simulation is used to test and validate the proposed components in the system.

1.6. Methodology

Data (information) collection: In order to understand the problem in detail and to define the requirements of the system, techniques like document review, on site observation, interview and questionnaires are used.

Context Modeling: Context-awareness is the fundamental characteristics of pervasive computing systems. There are a number of approaches of modeling or representing context information of such systems. However, ontology based modeling is a promising instrument for

modeling context information in pervasive environments due to its high and formal expressiveness and possibilities for applying ontology reasoning techniques. It allows to describe as much context states as possible in an arbitrary detail. Therefore, we use this modeling technique to represent the context information of the system.

Simulation: In this thesis work different body sensor devices which detect health parameters are used. However, we learned that, due to budget limitation, it is not possible to buy these devices. As an alternative solution, though a lot of additional work is involved to study the characteristics of these devices and develop the simulation system, we simulate all these devices in order to demonstrate the work.

1.7. Application of Results

The result of this research work will be useful for:

- The government, specifically to Ministry of Health, to redesign a new ART plan highly supported by ICT.
- Hospitals to improve their quality of service of ART to HIV infected persons.
- HIV infected persons and AIDS patients to pay attention about their health and prevent themselves from different other infections.
- Researchers to investigate more on how to support the current healthcare service by the potential of ICT.

1.8. Organization of the Thesis

This thesis document has a total of six chapters including the current chapter. Chapter two is review of literature that details about definition of pervasive computing in general, its characteristics, and applications in making life simple, with a special focus on its application in the healthcare industry – pervasive healthcare. Chapter three discusses several research works done under the area of pervasive healthcare. In the fourth chapter, we present the proposed pervasive healthcare system for HIV/AIDS patients that we designed in a new and innovative way. It contains the details of each component of the system. The fifth chapter is about the prototype implementation and demonstration of the proposed system. Finally, after presenting

discussions and evaluations on the system, chapter six concludes the work and indicates the future works planned.

Chapter Two: Literature Review

In this chapter, we discuss what pervasive computing technology is, its characteristics and its applications in daily human life and activities. In the application part, we see different general application areas and have a special focus on pervasive healthcare applications.

2.1. Pervasive Computing

2.1.1. Overview

In the history of computer technology, pervasive computing is the third wave of computing technologies to emerge since the existence of computers. Mainframe computing era is the first wave in which one computer is shared by many people, via workstations. The second wave is personal computing era in which one computer is used by one person, requiring a conscious interaction of users assisted by graphical user interface. In this period of computers, users are largely bound to desktop computers. The third wave is pervasive (also called ubiquitous) computing era in which one person uses many computers.

Pervasive computing technology is not something that exist by its own rather it is a new computing trend that emerged out of distributed and mobile computing. Therefore, it is strongly related to both distributed and mobile computing. The idea of distributed systems arose at the intersection of personal computers and local area networks. They are characterized by remote communication, fault tolerance, high availability, remote information access, and security [8]. Mobile computing was born in an effort to tackle problems that arise in building a distributed system with mobile clients. It is characterized by mobile networking, mobile information access, adaptive applications, energy saving and location sensitivity [8]. Pervasive computing shares what is inside in distributed and mobile computing and in addition new problems are introduced which are specific to its nature of pervasiveness.

The current idea of pervasive computing was articulated by Mark Weiser in his vision towards computing technology at the computer science lab of Xerox PARC. In 1991, he said that "the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it'' [9]. Even though Weiser's vision was too far ahead of its time due to hardware technology limitations, now it becomes real because of the exponential growth in electronic device miniaturization technology.

Pervasive computing is an environment which is saturated with computing and communication capability, yet so gracefully integrated with users that it becomes a technology that disappears [8]. To put it simply it is computation that's freely available everywhere, at any time to anyone. Pervasive computing is invisible everywhere computing that is embedded in the objects around us—the floor, the lights, our cars, the washing machine, our cell phones, our clothes, and so on. The idea that technology is moving beyond the personal computer to everyday devices with embedded technology and connectivity as computing devices become progressively smaller and more powerful. Pervasive computing is the result of computer technology advancing at exponential speeds -- a trend toward all man-made and some natural products having hardware and software. Pervasive computing goes beyond the realm of personal computers: it is the idea that almost all devices imbed smart chips to connect the device to an infinite network of other devices.

2.1.2. Characteristics of Pervasive Computing

As described above, some problems and their corresponding solutions in distributed and mobile computing can be directly applied to pervasive computing. Some of the technical problems in pervasive computing are already identified and solved during the evolution of these two computing trends. However, the demands of pervasive computing introduced some other new problems which are not identified before. Among the characteristics of pervasive computing which distinguishes it from distributed and mobile computing are context awareness, invisibility, ad-hoc networks, smart spaces and devices. In the following sections, we will look each characteristic one by one.

Context awareness

Before discussing what context awareness is, first let us define what is mean by context in pervasive computing. It is quite difficult to define the word "context", but many researchers tried to give their own definition. Schilit and Theimer [10] defined context as location, identities of nearby people and objects, and changes to those objects. Brown *et al.* [11] referred context as location, identities of the people around the user, the time of day, season, temperature, etc. In [12], researchers describe context as the user's emotional state, focus of attention, location and orientation, date and time, objects, and people in the user's environment. Dey and Abowd [13] claim that all the above definitions are difficult to apply since they define context by example. They said that when we want to determine whether a type of information not listed in the definition is context or not, it is not clear how we can use the definition to solve the dilemma. Therefore, they proposed the most commonly referenced definition as:

"Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves."

Context awareness is a general concept that refers to the capability of a system to be aware of its physical and logical environment and to intelligently react according to this awareness. It is a pervasive system that captures context information from the environment and user and act accordingly with the changing environment. Here are two definitions that are frequently given in the research:

A system is said to be context-aware if its operations and services can be adapted to the current context without explicit user intervention and thus aims at increasing the usability and effectiveness by taking environmental context into account [14].

A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the extent to which it anticipates users' needs and acts in advance by "understanding" their context [15].

Context aware systems are sometimes referred to as sentient systems due to their capability to "perceive and feel" changes in the environment. They detect changes to their physical (external)

and logical (internal) environment and respond to these changes on behalf of the user without needing user's conscious knowledge or awareness about what is going on. These contexts can be classified as external or internal. External contexts are those that can be measured by sensor devices and include location, light, sound, movement, touch, temperature, air pressure, etc. On the other hand, internal contexts are mostly specified by the user or captured by monitoring the user's interaction and include the user's goals, tasks, work context, business processes, the user's emotional state etc.

In order for context aware systems to function completely, they have to have different requirements which include context capturing, context modeling, aggregation/interpretation, context reasoning, actions and collaboration.

- **Context Capturing**: This is a context subsystem which is responsible for collecting context information from the dynamically changing environment. For detecting and capturing external contexts, smart devices called sensors are used.
- **Context Modelling**: Once context information is gathered, it has to be represented and organized in a systematic way so that it will be easy to be processed by the machine. This process of structuring and storing context data so that it will be suitable for machine processing is called context modeling. There are different approaches for modeling contexts, but ontology based modeling is nowadays becoming more popular. An ontology is a specification of a conceptualization [16] and it formally describes concepts and relationships which can exist between them. It is a data model that represents a domain and is used to reason about the objects in that domain and the relations between them. Ontology languages such as OWL and RDF are used to develop ontologies.
- **Aggregation/Interpretation**: refers to combining context information to generate a higher meaningful context.
- **Context Reasoning**: This step refers to deriving high-level context data from a set of low level context data. It deals with deducing high-level implicit context from low-level explicit context since high-level context can't be directly acquired from sensors rather it is reasoned from sensor-driven, low-level context.

- **Actions:** Taking proactive/reactive actions in response to the changing context without the need for user's intervention.
- **Collaboration:** Pervasive environments consist of a set of smart devices and software agents which need sharing of context information among each other – collaboration.

Invisibility

This is another characteristic of pervasive computing in which the system is expected to disappear from the user's consciousness. Practically, it is impossible to make a system completely disappear from the user rather it refers to achieving a reasonable approximation to this idea i.e. is minimal user distraction.

Ad – hoc Network

The vision of pervasive computing becomes true due to the advancements of wireless networks. However, the potentially irregular coverage of existing infrastructure oriented wireless networks will significantly affect the communication among devices in a pervasive environment. To overcome this communication problem, wireless ad-hoc networks are used instead of infrastructure oriented networks. Wireless ad-hoc networks are not infrastructure based networks, but simply devices are interconnected to each other without any base station requirement. Examples include Bluetooth, ZigBee, MANET (Mobile Ad-hoc NETwork), VANET (Vehicular Ad-hoc NETwork), etc.

Smart Spaces and Devices

One of the things that pervasive computing environment can have is that of "smart" things. Smart spaces are spaces like homes, offices, classrooms, meeting rooms having special computing facilities. What distinguishes these spaces from ordinary spaces is the presence of different electronic sensors deployed on different parts. For example, a smart phone may switch on the TV when user is entering to home. Smart devices are every day devices with powerful computing power due to embedded special chips. They can be interconnected to each other and communicate with other smart devices.

2.1.3. Applications of Pervasive Computing

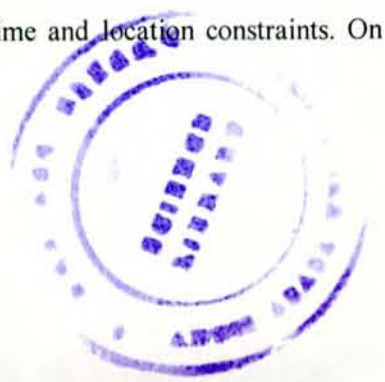
The main goal of pervasive computing is to make life easy. It achieves this by integrating Information and Communications Technology (ICT) into people's lives and environments. It can be said that there is no area of life that pervasive technologies can't be applied. It is possible to make any activity in any discipline to use the potential of this technology to increase the quality of human life. But, just to mention few, healthcare, transport, industry, business, agriculture, military and environmental monitoring are some of the application areas.

2.2. Pervasive Healthcare

2.2.1. Overview

Pervasive healthcare is nothing but the application of pervasive computing technologies in healthcare industry. This can be achieved through two major approaches [2]: 1) pervasive patient monitoring: In this approach, there will be a pervasive sensing subsystem which continuously senses body functions, user's context and environmental parameters. Then the information from sensing subsystem will be delivered to a higher level application. 2) Pervasive Prevention: Motivating people to change their behavior. This is a transformation from managing illness to maintaining wellness. Pervasive technologies are anticipated to not only cure sickness, but also promote wellness throughout all stages of life by promoting people to change their behavior via just in time feedback – coaching.

Advancement in wireless technologies has made it possible the efficient communication among patients, doctors, paramedics, other healthcare workers and family. Nowadays, using wireless network technologies, it is possible to deliver patient information to hospitals being anywhere at any time. The wireless networking examples may include wireless LANs, ad hoc wireless networks, cellular/GSM/3G infrastructure-oriented networks and satellite-based systems. At the same time, advances in electronic devices contributed to the proliferation of wearable intelligent body sensors which can be dressed by a patient or be implanted inside the body. These devices can detect the physiological signs of a patient and can transmit the sensed data to personal computer, smart phones or PDAs and then delivered to the central care center. Therefore it is possible to monitor, diagnose and control patients without time and location constraints. On the



other hand, pervasive computing, together with persuasive technologies and behavioral science, can be applied for disease prevention by motivating people to change their behavior and become conscious about their health. For example, people can be encouraged to do some physical exercises in response to some non critical physiological signs. Technologies that motivate and support healthier lifestyle decisions related to diet, exercise, smoking, sexual behavior, TV and internet use, stress management, and maintaining social relationships could delay or even prevent the onset of a variety of medical problems, and improve the quality of life [17].

2.2.2. Pervasive Healthcare Applications and Requirements

The unique capabilities of current and emerging mobile devices, wireless networks, and middleware technologies can support a wide range of applications and services including mobile telemedicine, patient monitoring, location-based medical services, emergency response and management, pervasive access to medical data, personalized monitoring, and lifestyle incentive management [18].

- **Mobile telemedicine**: The ability to transmit critical information about victims to a hospital before they arrive, or to let specialists diagnose and recommend treatment from a distance.
- **Comprehensive health monitoring services**: Would allow patients to be monitored at anytime in any location. Using his/her medical history and current conditions, one or more actions can be taken including sending an alert message to the nearest ambulance or a healthcare professional.
- **Intelligent Emergency Management System**: This system could be designed using the intelligence of and information from mobile and wireless networks to manage the large call volume received due to a single accident or incident and effectively manages the fleet of emergency vehicles.
- **Health-aware mobile devices:** Would detect certain conditions such as pulse-rate, blood pressure, and level of alcohol by the touch of a user. Many of the portable medical devices can be integrated in the handheld wireless device. With its analysis of known allergies and medical conditions, the device could alert healthcare emergency system.
- **Pervasive access to healthcare information:** Would allow a patient or healthcare provider to access the current and past medical information.

- **Pervasive lifestyle incentive management:** Could involve, for example, giving a small mobile micro-payment to a user device every time the user exercises or eats healthy food.

Varsheny [18] also identified some general requirements of pervasive healthcare. The following are some of the requirements:

- **Security**: Counter measuring threats to healthcare data and abuse of benefits, encryption, authentication, and access control.
- **Privacy**: Personal information being collected, transmitted and stored in greater volume, the opportunities for data interception, theft and 'ubiquitous surveillance' will be sensitive.
- **Usability and reliability of patient's device**: Making patient's device portable or wearable.
- **Reliability and scalability of wireless infrastructure**: Wireless network infrastructure that is accessible, supports prioritized communications, is always on by multi-network or redundancy, and has sufficient network resources for pervasive healthcare

2.2.3. Context Awareness in Pervasive Healthcare

As we have defined above, context is any information that can be used to characterize the situation of an entity, which is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves. The most common context types are location, identity, time, and activity. However, in pervasive healthcare the context types may also include patient's medical history, current vital signs and medications, handicaps, and current environment.

In the design of pervasive healthcare, these contexts of patients must be effectively represented and analyzed. The result of this context analysis will be used by the context aware health monitoring system to react to changes in context. Figure 2.1 shows a typical representation of medical information for individual patients.

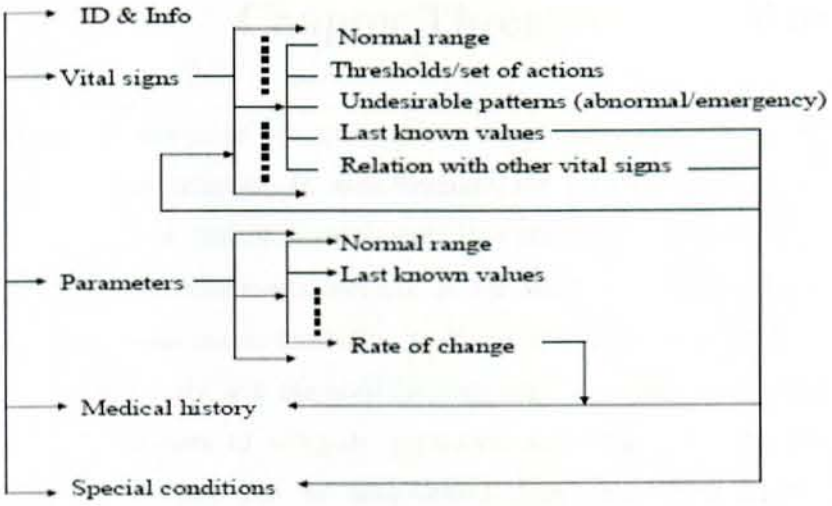


Figure 2.1: Representation of medical information [18]

Chapter Three: Related Works

Healthcare industries are one of the many public service institutions having centralized organizational structure. In such structure, the healthcare service given is professional-centric with very poor patient involvement. However, nowadays, the ageing of the population in developed countries exerts pressure on the healthcare systems in various ways: increasing of chronic diseases and co-morbidity, problems of compliance to medication and lifestyle guidance among the elderly, and the need for long-term care and assistance of elderly people [2]. This forces researchers to integrate pervasive technology into the healthcare services so that healthcare systems can be transformed from centralized professional-centric systems to distributed, networked and patient centric systems. Many research works are done and continued to be done in this area of pervasive healthcare. In this chapter, we present different related research works conducted under the area of pervasive healthcare grouped under different categories: Wireless Networks for Pervasive Healthcare, Mobile Patient Monitoring Systems, Ontology based Context Aware Pervasive Systems, and Persuasive Technologies.

3.1. Wireless Networks for Pervasive Healthcare

In the previous section, we saw that communications networks are one of the components of pervasive computing environments. Advancement and wide scale deployment of intelligent wireless networks is one of the factors which contribute to the paradigm shift of computing trend – from distributed mobile computing to pervasive computing. We have already defined that pervasive healthcare is the application of pervasive technologies in healthcare so that the healthcare services will become easily accessible to everyone, anywhere, any time. Like other pervasive application systems, wireless network technologies play an important role in making healthcare industry pervasive. Different alternative wireless communications networks can be applied in the healthcare so that medical professionals, patients and other caregivers can communicate each other and exchange any medical data/information. These may include wireless LANs, ad-hoc wireless networks, cellular/GSM/3G infrastructure oriented networks, and satellite communications networks.

In this section, we will review some of the works which give witness about how wireless technologies fulfill the vision of pervasive healthcare. Varshney [19] discussed how wireless technologies can be applied in the healthcare environment. In this paper, the author claimed that even though the introduction of telecommunications technologies in the healthcare environment has led to an increased accessibility to healthcare providers, more efficient tasks and processes and higher quality of healthcare services, many challenges still exist in the healthcare industry. These include a significant number of medical errors, considerable stress on healthcare providers, partial coverage of healthcare services in rural and underserved areas, an increasing cost of healthcare services and the exponential increase in the number of seniors and retirees in developed countries which have created several major challenges for policy makers, healthcare providers, hospitals, insurance companies and patients. After identifying and discussing major challenges of healthcare industries, the author anticipated that the current and emerging wireless technologies have potential to overcome all these challenges. They can improve the overall quality of service for patients in both urban and rural areas, can reduce the stress and strain on healthcare providers while enhancing people's productivity, retention and quality of life, and also reduce the overall cost of healthcare services.

In addition, the paper discusses several challenges and open issues that should be overcome before the deployment of wireless technologies in healthcare which include how to best utilize the capabilities of diverse wireless technologies and how to effectively manage the complexity of wireless and mobile networks in healthcare applications.

[18] similarly discusses that with an increasing mobility, the wide scale deployment of mobile and wireless networks can support many healthcare applications. They can make the vision of pervasive healthcare, i.e. healthcare to anyone, anytime, and anywhere, to become true. How infrastructure-oriented wireless LANs, such as versions of IEEE 802.11, can be used to support patient monitoring in diverse environments is presented in [20]. The paper also determines the requirements of patient monitoring and satisfying these requirements using infrastructure-oriented wireless networks. It is clear that using wireless patient monitoring; it is possible to provide better healthcare service for large number of patients with limited medical and human resources. However, the irregular and spotty coverage of infrastructure-oriented wireless

networks affects the quality of service. Ad hoc wireless networks can be formed among mobile and wearable patient-monitoring devices for improving the coverage of patient monitoring when infrastructure-oriented networks are not accessible [21].

3.2. Mobile Patient Monitoring Systems

Nowadays, the ageing of the population in developed countries exerts pressure on the healthcare systems in various ways: increasing of chronic diseases and co-morbidity, problems of compliance to medication and lifestyle guidance among the elderly, and the need for long-term care and assistance of elderly people [2]. Therefore, these days, how to provide better healthcare service for the elderly people and enabling independent living has become an important research problem. In effort to solve this problem, researchers introduced ICT to the healthcare. Early deployments of telemedicine services were using the traditional public switched telephone network, but now, due to the advancement and proliferation of intelligent wireless networks, telecare services are becoming smart enough. As described in the above sub section, patients can be monitored and diagnosed while moving. In this section, we will see some of the works done in mobile patient monitoring systems.

A) A Mobile Care System with Alert Mechanism

The authors of this paper suggested that chronic diseases such as hypertension and arrhythmia can be effectively prevented and controlled if the physiological parameters of the patient are constantly monitored, along with the full support of the health education and professional medical care [22]. They proposed and implemented a role-based intelligent mobile care system with alert mechanism in chronic care environment. The roles in their system include patients, physicians, nurses, and healthcare providers each of which represents a person equipped with a mobile device such as a mobile phone to communicate with the server setup in the care center.

Chronic patients hold commercial mobile phones with Bluetooth communication capability in which physiological signal recognition algorithms were implemented and built-in without affecting their original communication functions. The authors said that it is possible to integrate several biosensor devices with Bluetooth communication capability to extract patients' various

physiological parameters such as blood pressure, pulse, saturation of haemoglobin (SpO2), and electrocardiogram (ECG), to monitor multiple physiological signals. These biosensors, which only deal with signal extraction and wireless transmission without doing any signal processing, will transmit extracted physiological signs to mobile phone via Bluetooth communication. Then the mobile phone is responsible for uploading physiological information to healthcare center for storage and analysis. The system has also an alert management mechanism which has been deployed in back-end healthcare center to initiate automatic emergency alerts.

B) A mobile health monitoring system using RFID ring-type pulse sensor

In this paper, a mobile health management system is presented which integrates a wearable RFID ring-type pulse monitoring sensor with a smart phone [23]. The ring-type sensor is used to measure pulses/temperature from the patient and transmit the physiological data to the RFID reader using wireless RF. The reader, using its Bluetooth connection capability, then passes the data to the smart phone. The smart phone collects/displays the physiological data and also transmits data to the remote medical station using wireless infrastructure networks like GPRS, 3G, WiFi, or WiMax. It has also GPS built in inside so that it can provide the position information of the monitored person based on which the medical personnel can be dispatched to the right location more promptly in an emergency situation. The authors said that it is possible to add additional sensors to measure more other physiological signals, so that the system can be used as an e-coach. Figure 3.1 shows the overall system architecture and the prototype RFID ring sensor.

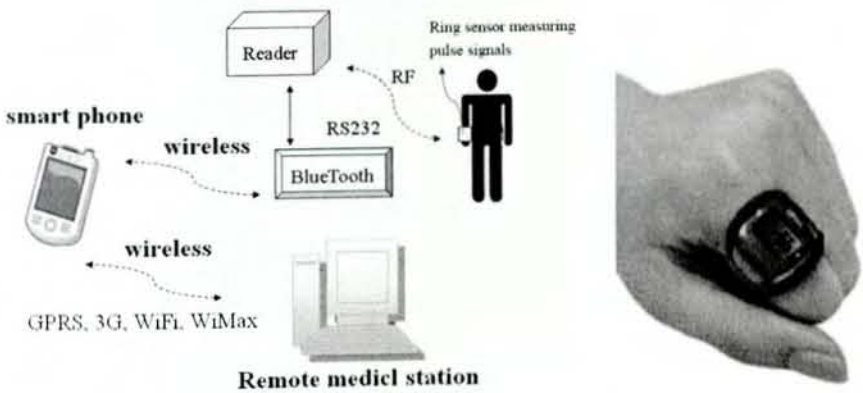


Figure 3.1 System architecture and the RFID ring-sensor of [23]

C) SPA: A Smart Phone Assisted Chronic Illness Self-Management System with Participatory Sensing

The authors of this paper complained that the medical system has not been able to effectively adapt to the dramatic transformation in public health challenges, from acute to chronic and lifestyle-related illnesses [24]. They said that acute illnesses can be treated successfully in an office or hospital, but chronic illnesses comprise the bulk of health care needs and require a very different approach. Active participation of the patient is needed for sustainable and successful chronic disease management. The patient's participation in the health care can be increased by giving regular feed-back of relevant health data to the individual patient. However, still now, there is lack of effective and easily deployed tools that helps patients for self-monitoring and self-care. Therefore, they proposed a smart phone assisted chronic illness self-management system called SPA that can continuously monitor a person's body, behavior, and environment during his or her daily life, and then alert the person to take corrective action when health risks are identified.

The architecture of the SPA system consists of three major parts: body area sensor network to collect biomedical and environmental data, a remote server to store and analyze data, and a group of health care professionals to check records and give health care suggestions as shown in figure 3.2.

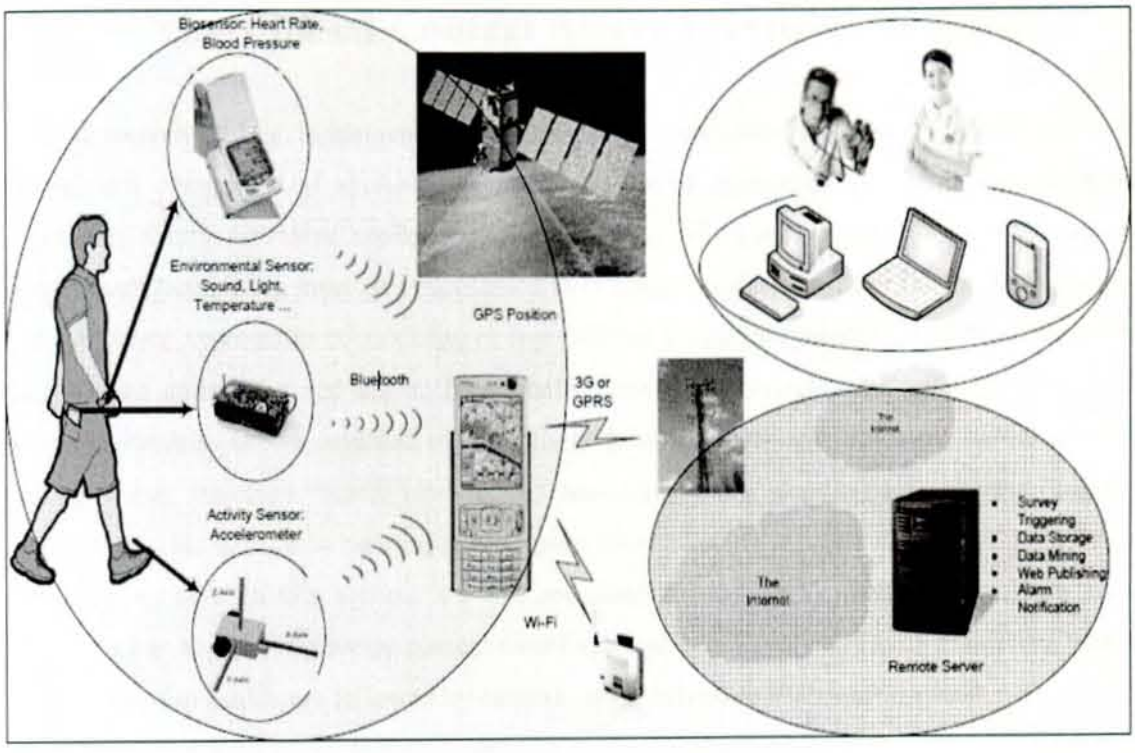


Figure 3.2 The architecture of the SPA system[24]

The body area sensor network again consists of a smart phone, a set of biosensors and a set of environmental sensors. Biosensors are used to detect physiological signs of the patient such as heart rate, blood pressure while environmental sensors are used to capture the environmental conditions like sound, light, temperature, etc. Data collected from both type of sensors will be transmitted to the smart phone via Bluetooth network. The smart phone has built-in GPS service to track the location of the patient. In addition to the biomedical, environmental and location data, the subjective state of the participant is also reported via random or periodical survey questions presented to the patient. Then the smart phone delivers all the sensed data and filled surveys to the remote server. A remote server stores all collected sensor data in a formatted data warehouse and these data will be processed using different data mining algorithms for decision making.

3.3. Ontology based Context Aware Pervasive Systems

Context awareness is a fundamental characteristic of pervasive computing applications. It is through this component of applications that the vision of distraction free computing finds its fulfillment. Every pervasive application has this nature of awareness about what is going on around even though the level of awareness differs based on the application domain. There are many different approaches of modeling or representing context information digitally so that the machine can understand and use it. These include key-value models, markup scheme models, graphical models, object oriented models, logic based models and ontology based models. Among these, ontology based models are becoming more popular to represent context information. This is because ontologies have great potential to express more knowledge in detail than other models. In this section, we will see some related works which use or show how ontologies can be used to develop context aware applications. First, we discuss researches which are not related to healthcare followed by context aware pervasive healthcare systems.

3.3.1. Works not related to Healthcare

A) An Ontology for Context-Aware Pervasive Computing Environments

A system architecture of ontology based context-aware system representing smart spaces, called Context Broker Architecture (CoBrA), is developed in this paper [25]. The fundamental component of this architecture is an intelligent agent called the context broker. The function of the context broker is to maintain ontology based shared model of context for other agents in the architecture and devices in the smart space. In addition to providing common context model, the context broker also protects the privacy of users by enforcing the user-defined policies during information sharing among agents in the space.

The context broker consists of four design components as shown in figure 3.3.

- **Context Knowledge Base**: a persistent storage of the context knowledge.
- **Context Reasoning Engine**: a reactive inference engine that reasons over the stored context knowledge.
- **Context Acquisition Module**: a library of procedures that form a middle-ware abstraction for context acquisition.

- **Policy Management Module**: a set of inference rules that deduce instructions for deciding the right permissions for different computing entities to share a particular piece of contextual information and for selecting the recipients to receive notifications of context changes.

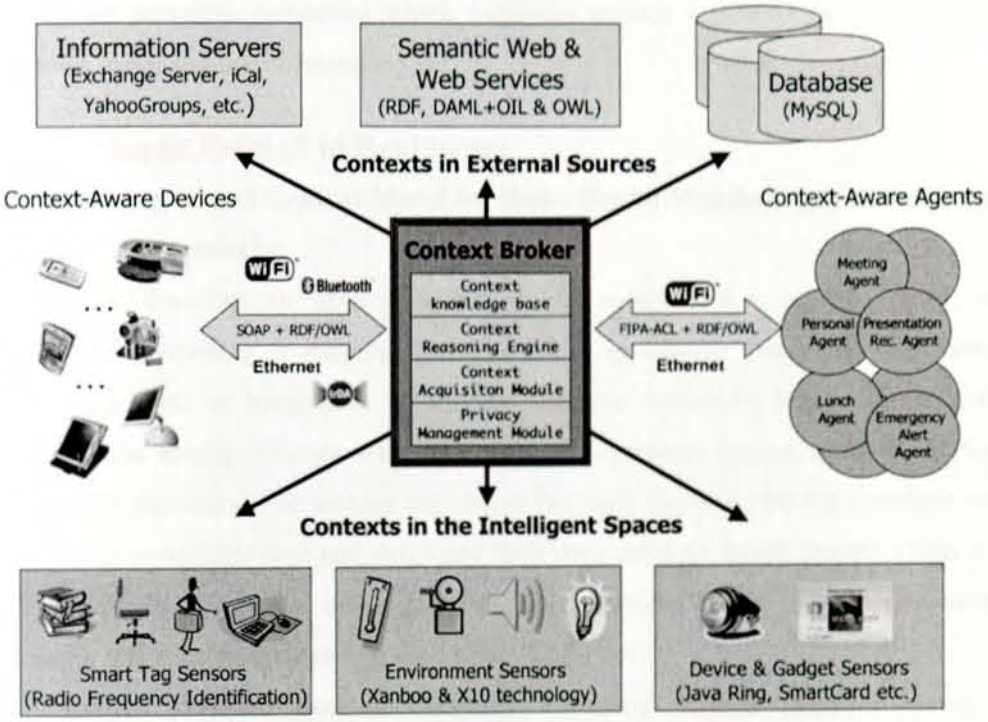


Figure 3.3 Context Broker Architecture [25]

The ontology developed as part of CoBrA is called COBRA-ONT which helps the context broker to share contextual knowledge with other agents and enabling it to reason about context. It is collection of ontologies of different context entities (places, agents, agent's location and agent's activity) written in OWL to represent an intelligent smart meeting room.

B) Ontology Based Context Modeling and Reasoning using OWL

A general context ontology, modeling common high level context entities such as location, user, activity and computational entity, called CONON, is developed in this research work [26]. This

ontology is expressed in OWL ontology language and supports logic based context reasoning (both ontology based and user defined reasoning).

C) An ontology-based approach to context modeling and reasoning in pervasive computing

In this paper, the authors developed an ontology based reusable context model, written using OWL, for pervasive computing which facilitates context reasoning by providing structure for contexts, rules and their semantics [27].

3.3.2. Works Related to Healthcare

i. An Ontology-based Context Model for Home Health Monitoring and Alerting in Chronic Patient Care Networks

This work describes an ontology-based context model and a related context management middleware providing a reusable and extensible application framework for monitoring and assisting patients at home [28]. The model supports continuous home care services based on collaboration among different stakeholders: health operators, patient relatives, as well as social community members. The authors introduced the main requirements for a context aware system for chronic conditions care and developed their own ontology based context model for satisfying these requirements. They developed different ontologies using OWL representing different concepts and relationships among each other. These are:

- **Patient Personal Domain Ontology**: represents relevant patient's context information including physical data (i.e. biomedical parameter values), location and activity.
- **Home Domain Ontology**: represents relevant context data mainly sensed environmental parameters, such as temperature and relative humidity,
- **Alarm Management Ontology**: represents care network members that might be engaged in critical situations handling and thus might have to be notified by the system for intervention.
- **Social Context Ontology**: represents care networks resources coming from different organizations (health teams, social community members, etc.).

ii. Using Ontology to Support Context Awareness In Healthcare

By considering a ubiquitous healthcare environment enabled by RFID technology, the authors designed intelligent hospital architecture [29]. The architecture is comprised of four different layers as shown in figure 3.4.

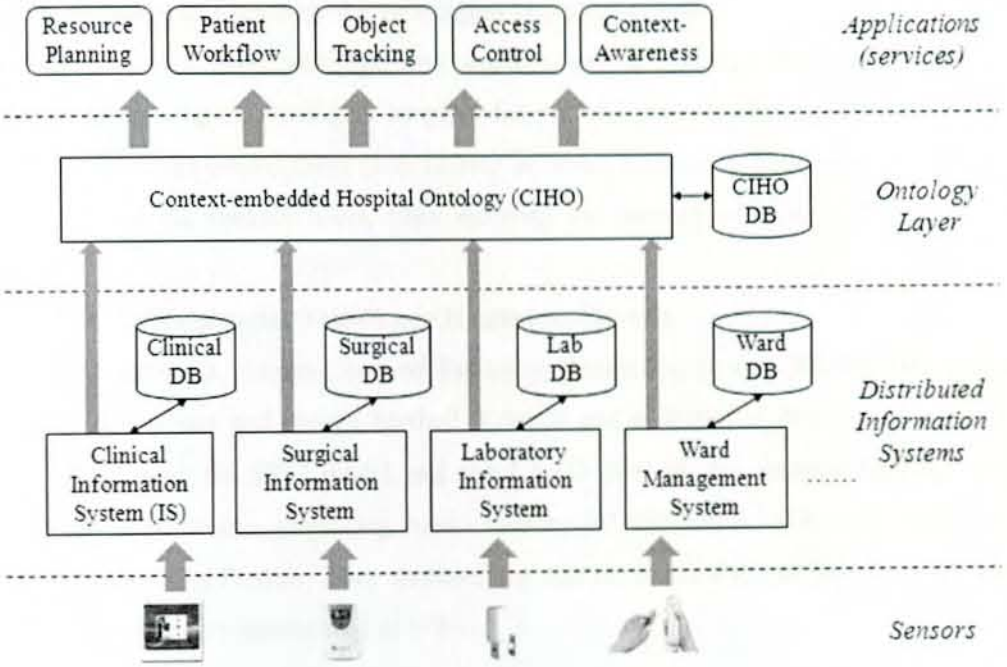


Figure 3.4 Architecture of RFID-enabled Intelligent Hospital Model [29]

- **Sensors:** a variety of sensors that are attached to objects in a hospital such as persons, devices, and rooms (e.g. RFID wristband of patients, environmental sensors, etc.).
- **Distributed Information Systems:** information systems of different departments with separate databases.
- **Ontology Layer:** a shared ontology that integrates heterogeneous information systems and devices, aiming to enable semantic interoperability for supporting a variety of applications and services that need information across different departments.
- **Applications (Services):** services for an intelligent hospital which include resource planning, patient workflow optimization, context-aware services, etc.

The developed ontology, which they called Context-embedded Intelligent Hospital Ontology (CIHO), captures the concepts of an RFID-enabled intelligent hospital and supports knowledge sharing, semantic interoperability and context-aware services (applications). It is developed using OWL-DL and provides a formal description of the healthcare domain and supports logic-based context reasoning.

iii. Implementation of Ontology for Intelligent Hospital Wards

The writers of this paper designed and implemented a Hospital Intelligent Ward Ontology (HIWO), representing an intelligent hospital domain and gives explicit specification of concepts and the relationships behind them [30]. HIWO provides a common understanding of the hospital environment for its domain users, thus enabling the sharing of data and capturing context awareness.

iv. A Pervasive Multimodal Tele-Home Healthcare System

The paper describes a Human-Centered Pervasive Computing System Model (HPC), a Layered Architectural Analysis and Design Method (LAAD) and a Waterfall Prototyping Process Model (WPP) [31]. Using the HPC model and the LAAD method, the authors designed and partly implemented a pervasive computing based multimodal tele-home healthcare system using the Waterfall Prototyping Process. They modeled the context information of the pervasive healthcare system using onologies represented in OWL.

3.4. Persuasive Technologies

From the serpent in the Garden of Eden to our modern mass-media society, persuasive efforts abound in a continuous attempt to influence our attitudes and behaviors, convincing us to spend money on one product rather than another, to vote for a particular political party, to stop smoking, to exercise more, to fight for environmental conservation, animal wellbeing, better schools or to eat an apple [32]. Persuasive technology is the use of technology such as computers and mobile phones to change the attitude or behavior of people. In the area of healthcare, it is possible to change bad behaviors and customs of patients, poor self-care and attention to self health management, etc by persuading people using this technology. Few efforts have been made in this area and we will review some of them in the next paragraphs.

One of the problems found in healthcare industries, actually in developed countries, is the dramatic increase of elderly people in need of life-long care which causes high healthcare costs. One way to potentially reduce or slow spiraling medical costs is to use technology, not only to cure sickness, but also to promote wellness throughout all stages of life, thereby avoiding or deferring expensive medical treatments [33]. The author of [33] suggested that ubiquitous computing technologies and context aware algorithms offer a new healthcare opportunity and a new set of research challenges: exploiting emerging consumer electronic devices to motivate healthy behavior as people age by presenting "just-in-time" information at points of decision and behavior. According to this paper, there are four components to an effective strategy to motivate behavior change using just-in-time information: 1) present a simple, tailored message that is easy to understand, 2) at an appropriate time, 3) at an appropriate place, 4) using a nonirritating strategy. The author also identifies major challenges in developing such systems some of which include achieving subtlety, detecting the right time, motivating the "healthy", and proving efficacy.

Through mobile persuasive technology, researchers in [34] developed an application to combat obesity trends in teenagers. Their aim is to motivate teens to be active in their physical exercise and continue this healthy lifestyle throughout their life. Similarly, authors in [35] developed a Mobile Therapy - just-in-time coaching that is triggered by physiological indicators of stress. This system detects level of stress of the user (measured from moment-to-moment changes in heart rate variability which is an indicator of stress) using biosensors and triggers feedback via mobile phones (mobile therapies) for emotional regulation. It aims to help people pay attention to early signs of stress and modulate reactivity that could potentially damage their health.

3.5. Summary

In this chapter we have seen different research works related to pervasive healthcare and other areas grouped under different categories: Wireless Networks for Pervasive Healthcare, Mobile Patient Monitoring Systems, Ontology based Context Aware Pervasive Systems, and Persuasive Technologies.

All these works show that using ICT in healthcare industry really makes a change. Advances in wireless technologies— such as intelligent mobile devices and wearable networks—have made possible a wide range of efficient and powerful medical applications. Health context aware systems make healthcare services available anywhere, anytime and to anyone. However, there are still problems in pervasive healthcare systems that these works didn't touch. These include frequency of transmission of vital sign data from patients to healthcare centers, network communication cost, refining relevant medical context information and management of bulky medical context data. In an effort to overcome these challenges, in this work, we propose an innovative context aware healthcare system as explained in the next chapter.

In Ethiopia, the trend of using ICT in everyday life activities is very poor which really affects the progress of its development. This trend should be developed and everything should be computerized for better quality of life in the future. Nowadays, it is understood that ICT plays a great role in the development of nations. Especially for developing countries like Ethiopia, ICT is hoped as a great opportunity for facilitating their progress with a rapid rate. Of many sectors which can be supported by ICT, the healthcare industry is the most important sector. It is only when the citizens of a nation are healthy that we can talk about development. The most difficult challenge in making a change in the healthcare service in Ethiopia is the case of HIV/AIDS. In this chapter, we saw that many researchers in the ICT community responded to healthcare industry problems by proposing pervasive healthcare as one solution – actually in developed nations. The main cause of healthcare problems in these nations that the researchers mentioned is the growing number of their aging population and the corresponding cost needed to care them. In Africa, specifically in Ethiopia, the root cause for the healthcare problem is not the aging population rather poverty. However, we can enjoy with ICT based healthcare by applying the same solution, i.e. pervasive healthcare, to our complicated healthcare problems. Therefore, in addition to solving the above technical problems in pervasive healthcare, we developed this healthcare system for putting our own solution to this case of our country and its threat of HIV/AIDS.

Chapter Four: The Proposed System

Africa is on the move, and information and communications technologies (ICT) are powerful tools to boost economic growth and poverty reduction [36]. Implementing ICT in different sectors is the best solution to make governmental services accessible to both urban and rural areas. There is a very wide digital divide between the citizens of African nations and the developed ones, and even among the same citizens of African countries – for example between urban and rural. This makes African countries less competitive in the current era of globalization and internationalization. Realizing this, many African governments are giving their ears to the implementation and deployment of ICT by incorporating it to their developmental and transformation plans. Like other African governments, the government of Ethiopia has also given its attention towards implementing ICT in many sectors including Agriculture, Industry, Commerce, Education, Health, etc [37]. Recently, the government has established the Ministry of Communication and Information Technology (MCIT) with a mission "to develop, deploy and use Communication and Information Technology to improve the livelihood of Ethiopian and optimize its contribution to the development of the country."

However, this effort must be supported by many ICT researches considering the local perspective. Therefore, the ICT community must respond to the plan of the government by tackling various technical problems through continuous research works and case studies. In this research, we contribute our part in this regard by designing an innovative pervasive healthcare system for HIV/AIDS patients.

In addition, we also contribute to the technical world of pervasive healthcare in general by designing a new model for pervasive healthcare system. In the previous chapter, we have studied the works of many researchers which indicate how the healthcare industry can be supported and improved by using the good opportunities made available by the advancement of ICT. They have shown us how advancements in wireless technologies— such as intelligent mobile devices and wearable networks can make a change in the healthcare industry. We have also seen how the ontology based context aware pervasive systems can be applied to the field of healthcare service

industry to fulfill the visions of pervasive healthcare – healthcare anywhere, anytime, and to anyone. In this work, we designed a Context Aware Pervasive Healthcare System for HIV/AIDS patients – which we call CAPHS. In the proposed system, patients will be equipped with different smart sensor devices which detect their respective vital sign data. These sensors are connected to the smart mobile phone of the patient via Bluetooth communication network. The smart phone has a responsibility of fetching vital sign data from each sensor, preprocess each data for simple status interpretation, displaying this status interpretation to the user and send some statuses which are above or below the normal range to the central hospital system via Internet. The central system will reason over this context and give warnings or alerts both to doctors and patients. What is new in our system is the preprocessing (first level context interpretation) ability that is performed inside the mobile phone itself before sending the collected context. We will elaborate more on this concept in the next sections.

4.1. Overview of the System

The proposed system, CAPHS, has three main subsystems as shown in figure 3.1. These are the patient unit, the healthcare unit and the doctor/nurse unit. The patient is equipped with different body sensors and a smart mobile phone which controls the sensors by communicating with them via Bluetooth network. The doctor/nurse also holds a smart phone. The smart phones of the patient as well as the doctor/nurse will communicate with the healthcare unit through Internet/SMS. In the next sections, we will discuss each unit one by one.

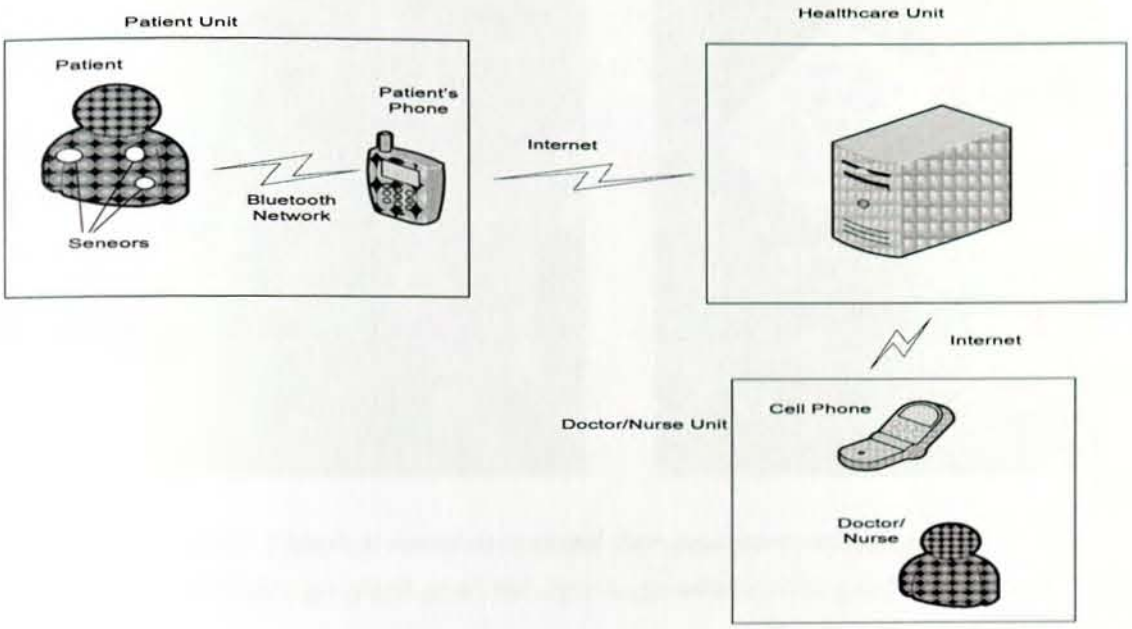


Figure 4.1 Overview of CAPHS

4.1.1. The Patient Unit

As medical contexts of an HIV/AIDS patient, we have identified about eight vital signs to be continuously detected from the patient. These are CD4 count, body weight, body temperature, blood pressure, heartbeat, night sweet, diarrhea, and cough. The patient is equipped with sensor devices used for detecting these medical contexts as shown in figure 3.2. Some of these devices are wearable so that the patient can wear them and move freely. These include the CD4 cell counter, which is actually the smart phone itself, the temperature sensor, the galvanic skin sensor, heartbeat sensor, and cough sensor (microphone) which detect CD4 count, body temperature, skin sweat, heartbeat, and coughing respectively. While other sensor devices like wireless weight scale and RFID sensors, which are used to detect body weight and the presence of diarrhea respectively, will be placed in specific rooms of the home of the patient. For example, the wireless weight scale can be placed (embedded) in the bed of the patient and RFID in the toilet room.

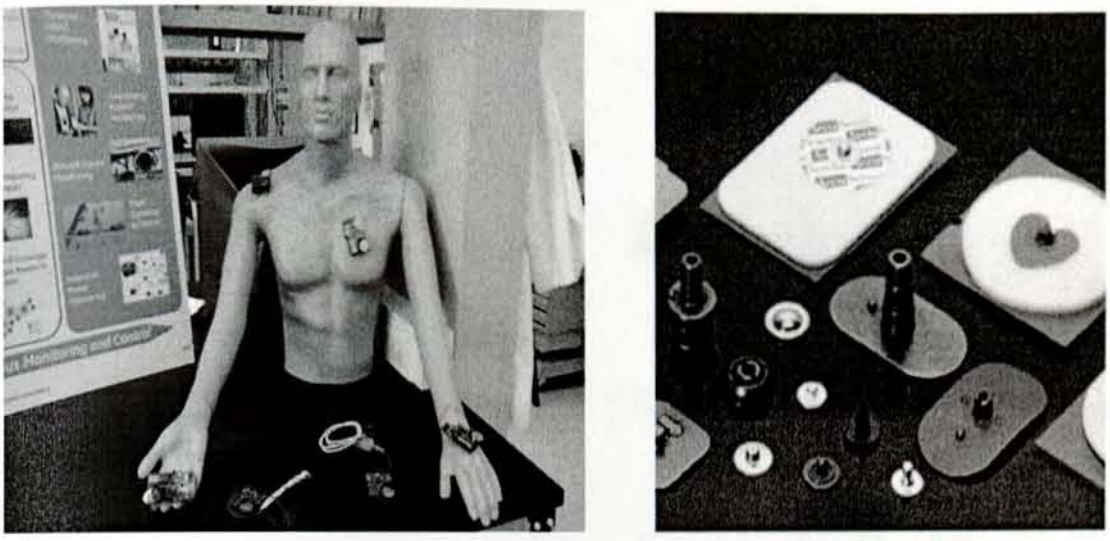


Figure 4.2 Medical sensor devices and their deployment on human body
(Source: http://www.gereports.com/vital-signs-to-go-wireless-with-ges-body-sensors/)

Each sensor is connected to the smart phone of the patient through Bluetooth in a master/slave piconet configuration fashion – sensors as slaves and the smart phone acting as a master (see figure 4.3). The smart phone periodically fetches medical data from each sensor. After collecting vital sign medical context from the sensors, the smart phone starts carrying out its first level context data interpretation task to determine the status of each vital sign data – whether it is normal, below or above the threshold. Then it will display the status result to the patient on a display screen so that the patient may know his/her current heath status. This makes the patient to be conscious about his/her health condition which actually enables our system patient – centric (patient participatory) health care system. When the vital signs data deviates from the normal medical threshold value, the smart phone sends the status of the signs to the central healthcare unit using the already existing Internet network infrastructure.

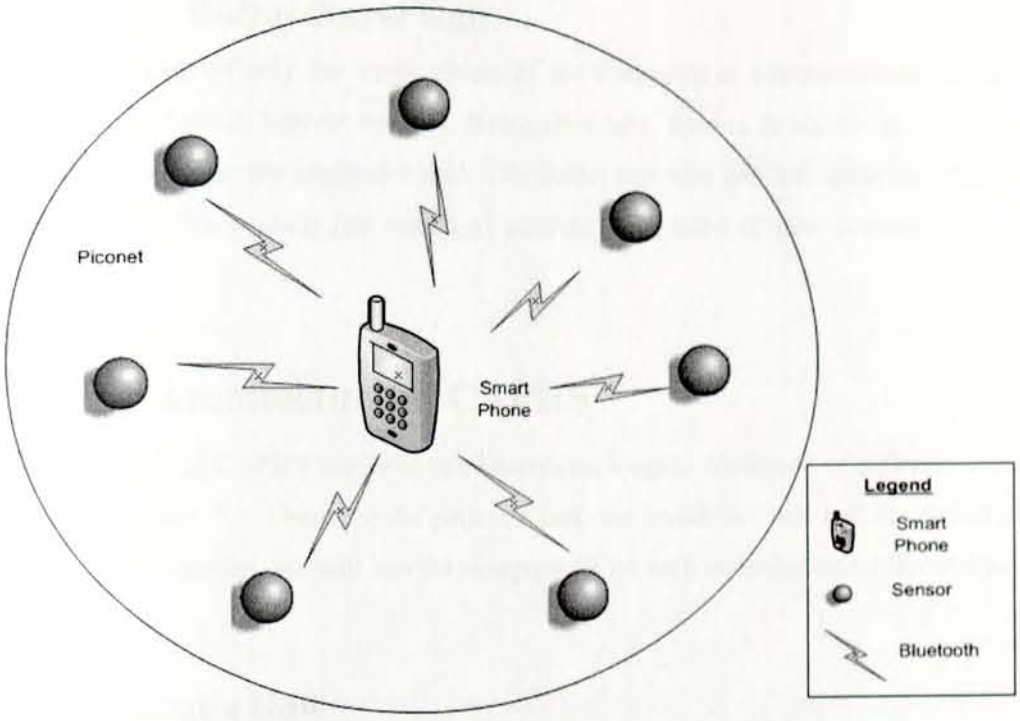


Figure 4.3 Bluetooth Communication of sensors with the smart phone

4.1.2. The Healthcare Unit

The healthcare subsystem is located in the healthcare center. It consists of a web server for containing servlets which communicate to the mobile of the patient and the doctor/nurse. It also contains an HIV/AIDS – ART related hospital ontology which represents the concepts in the service of ART. There is also a user defined Jena rule to be used with the ontology applied on the observed medical context of the patient for reasoning. This unit accepts the medical context of patients from smart phones of patients. It also accepts different patient information like medical test results of patients and record of new coming patients from the doctor's phone provided by the doctor. Then, it uses this medical context information, the developed ART ontology and Jena rule to perform reasoning using Jena reasoners. Based on the results obtained from the reasoners, actions will be triggered to be invoked in response to the new context. For example, the patient or the doctor or both may receive message containing warnings or recommendations based on the criticality of the case.

4.1.3. The Doctor/Nurse Unit

This unit consists of only the smart phone of the doctor/nurse communicating to the central healthcare unit through Internet network. Being anywhere, doctors or nurses can see their patient information found on the healthcare unit. The doctor can also provide different information of his/her patients like medical test results of patients and record of new coming patients to the center.

4.2. The Architecture of CAPHS

The architecture of CAPHS has three constituents each again composed of different components as shown in figure 3.4. These are the patient's unit, the healthcare unit and the doctor's/nurse's unit. In this subsection, we will see the components of each constituents of the architecture in detail.

4.2.1. Patient's Unit

This unit consists of the patient wearing/having different sensor devices and a smart phone – in which different components are deployed. It contains different components namely medical Sensors, Context Data Acquisition component, Context Preprocessor and Provider component, and context aware Services (applications) component –which includes services: Reminder Service, Status Display Service, Coaching Service, and Message Listener Service. The details of these components are presented in the next subsections.

4.2.1.1. Sensors

One of the characteristics of pervasive computing services is the presence of smart devices or smart things. These devices are found in many different forms and sizes, from handheld units (similar to mobile phones) to near-invisible devices set into everyday objects (like furniture and clothing). Today such devices are being commercialized having Bluetooth or ZigBee wireless network standards and TinyOS – an operating system environment for tiny devices. This will enable them to communicate wirelessly with each other and act intelligently. Depending on the type of application of pervasive systems, different smart devices may be deployed to achieve the goal of the application. For example, in pervasive healthcare systems the smart devices used are

devices that can detect the vital signs of patients. Most of these devices have Bluetooth communication capability to communicate with other devices.

In the proposed system we have used a number of sensor devices that are used to detect different vital signs of HIV/AIDS patients. Before discussing these devices, let's say something about what these vital signs are.

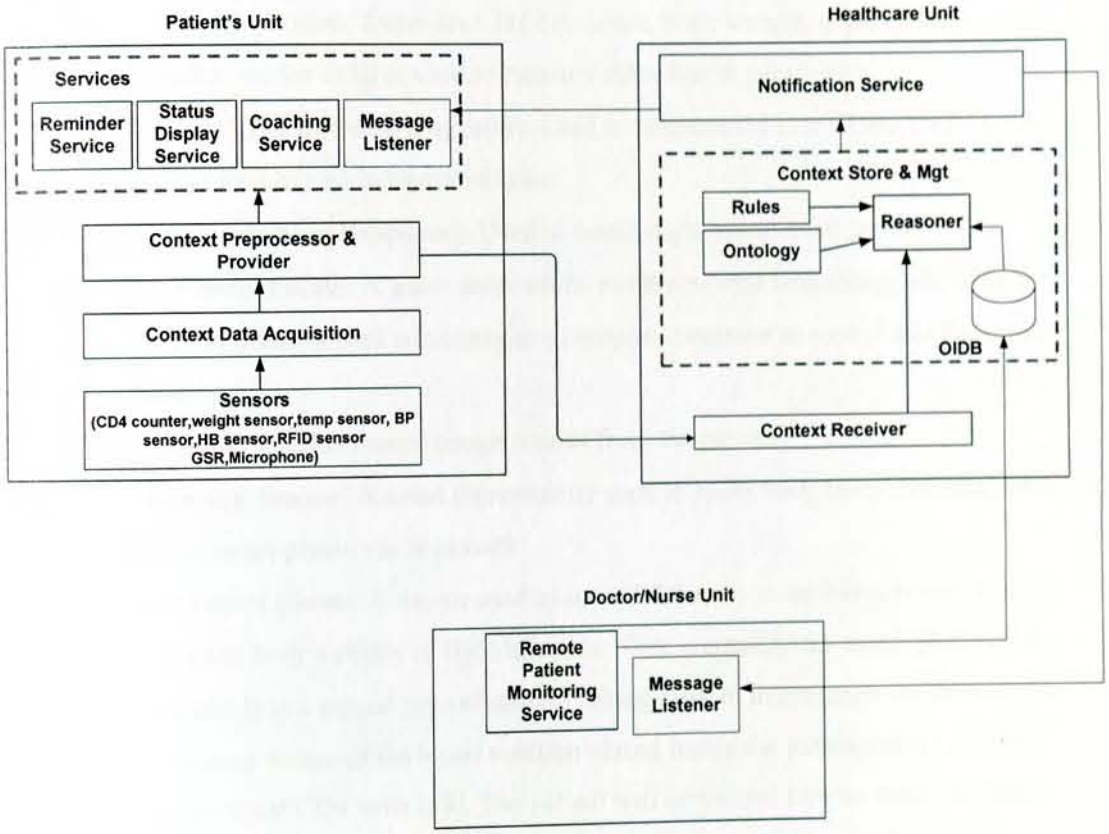


Figure 4.4 The Architecture of CAPHS

Vital signs are the most basic parameters that can be measured from patients. They indicate their physical condition and wellness. When the measurements tend to move away from normal, an abnormality in the physical status can be inferred. Most medical conditions can be diagnosed through vital signs and confirmed with the help of other tests. The following vital signs are some of the standard parameters in most medical settings:

- Pulse/heart rate
- Respiratory rate
- Blood pressure
- Temperature

These vital signs of an individual can help in determining various problems within the body and hence can be used for primary diagnosis. However, in our system we included other parameters specific to HIV/AIDS patients. These are CD4 cell count, body weight, night sweat, coughing, and diarrhea. Below are the devices used to measure these health parameters.

- **Wireless ECG (Electrocardiograph)**: Used to measure the rate of heartbeat (heartbeat variability) which is an indicator of stress.
- **GSR (Galvanic Skin Response)**: Used to detect night sweat from patients' skin.
- **Wireless weight scale**: A smart scale which has the newest technology allowing the capability to transmit data wirelessly to a personal computer to record weight trends overtime.
- **Microphone**: Used to record cough sounds from the patient.
- **Temperature Sensor**: A smart thermometer used to sense body temperature and transmit the data to smart phone via Bluetooth.
- **LUCAS Smart phone**: A device used to count CD4 cells in the bloodstream and determine the body's ability to fight infection. This is actually the smart phone of the patient itself. It is a special type of mobile having built in microscope inside which is used to take an image of the blood solution placed inside the phone and a LUCAS platform to count CD4 cells [38]. The patient will be trained how to insert his/blood solution into the phone. The mobile phone takes the image of the solution and can transmit it to the healthcare unit for further diagnosis as shown in figure 4.5.

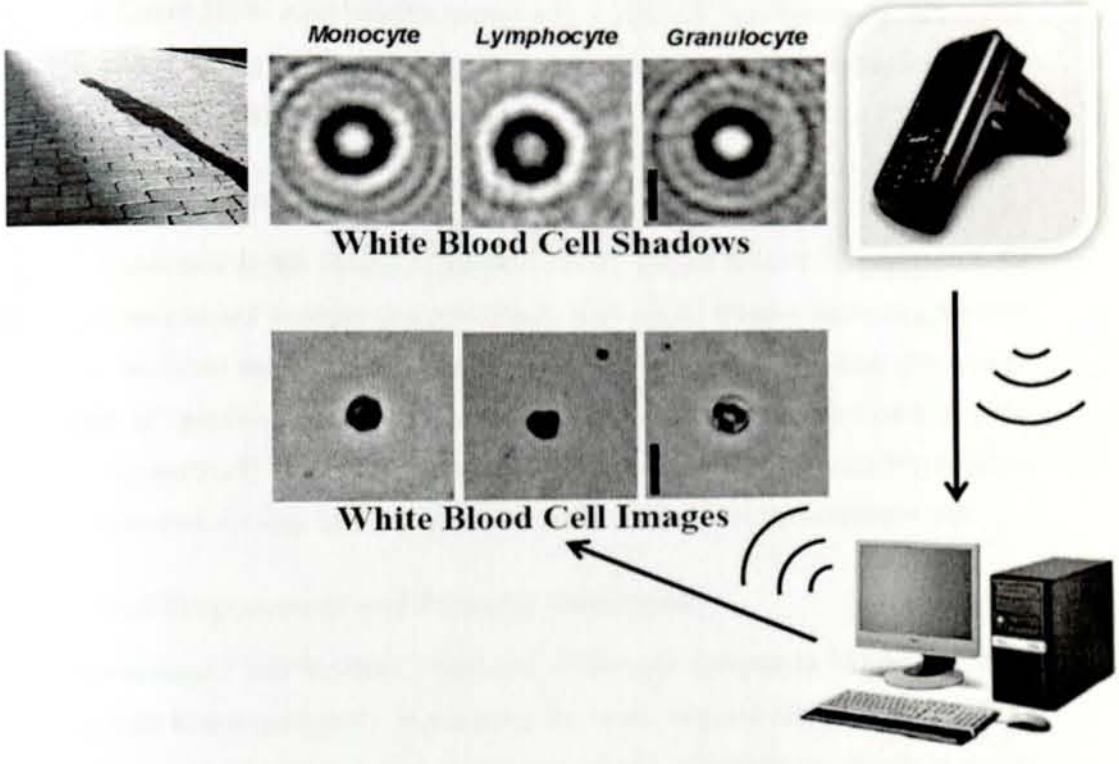


Figure 4.5 LUCAS Mobile Phone transmitting its image to a PC [38]

- **Pressure sensor**: Wireless pressure sensor device used to measure the blood pressure of the patient and transmits it wirelessly to a mobile phone or a PC.
- **RFID**: RFID reader placed on the toilet room to detect the frequency of toilet use of the patient per day. The patient will have an RFID tag in order to be identified by the RFID reader. In the medical world if a person uses toilet more than three times per day, it is considered that he/she might have diarrhea.

All these sensor devices are under the control of the LUCAS[3] mobile phone owned by the patient. Using different J2ME APIs (Mobile sensor API – JSR 256, and Bluetooth API – JSR 86), the mobile phone will be configured with components which are used to manage these tiny devices and fetch data from them wirelessly.

4.2.1.2. Context Data Acquisition component

Context Data Acquisition is the second component on the patient unit. It is responsible for managing sensor devices and fetching data periodically from them. When it wants to get sensor data, typically it performs the following operations with a sensor: sensor detection (discovery), sensor activation, (Connection, Monitoring), and Data capture (Fetching). After collecting the necessary data, automatically it provides the data to the next component, Context Preprocessor and Provider component, for first level interpretation and transmission to the healthcare unit.

4.2.1.3. Context Preprocessor and Provider component

The Context Preprocessor and Provider component is the core component having two main responsibilities. The first responsibility is accepting the newly detected medical contexts from Context Data Acquisition component and performing context preprocessing operation before sending it to the healthcare unit. The second responsibility is comparing the new context information with previous value and then sending the information to the healthcare unit if there is any change.

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[3] **The prototype of this cell phone has been constructed in 2008 in the lab of UCLA that is capable of monitoring the condition of HIV and malaria patients, as well as testing water quality in undeveloped areas or disaster sites. The innovative imaging technology was invented by Professor Aydogan Ozcan, a member of the California NanoSystems Institute at UCLA. The imaging platform, known as LUCAS (Lensless Ultra-wide-field Cell monitoring Array platform based on Shadow imaging), has been successfully installed in both a cell phone and a webcam. Both devices acquire an image in the same way, using a short wavelength blue light to illuminate a blood, saliva or other fluid sample. LUCAS captures an image of the micro particles in the solution using a sensor array. Because red blood cells and other micro particles have a distinct diffraction pattern, or shadow image, they can be identified and counted instantaneously by LUCAS using a custom-developed "decision algorithm" that compares the captured shadow images to a library of training images. Data collected by LUCAS can then be sent to a hospital for analysis and diagnosis using the cell phone.**

Context preprocessing is one of the important steps of context data management. Most context data obtained directly from sensors may be less meaningful to work with. It needs some preprocessing activity to bear more meaningful information. What the Context Preprocessor and Provider component does over the vital sign data obtained from sensors, through Context Data Acquisition component, is that it transforms it to some more meaningful medical context information after some preprocessing operations. This is just to determine the status of each vital sign value based on predefined medical threshold values. The status of each vital sign measurement used in the medical world (some specific only to HIV/AIDS patients) is presented on the following tables.

Table 4.1 CD4 value status

HIV-associated Immunodeficiency (Status)	CD4 Values for Adults
None	> 500
Mild	350–499
Advanced	200–349
Severe	<200

Source: Revised WHO clinical staging and immunological classification of HIV and case definition of HIV for surveillance. 2006.

Table 4.2 Body weight loss status

Status	Weight loss
Moderate unexplained weight loss	under 10% of presumed or measured body weight
Unexplained severe weight loss	over 10% of presumed or measured body weight

Source: Revised WHO clinical staging and immunological classification of HIV and case definition of HIV for surveillance. 2006.

Table 4.3 Body Temperature value status

Status	Value (°C)
Hypothermia	< 35.6
Normal	36.1 – 37.8
Fever	> 37.8

Source: http://medical-dictionary.thefreedictionary.com/temperature.

Table 4.4 Blood Pressure value status

Status	Systolic (mmHg)	Diastolic (mmHg)
Hypotension	< 90	< 60
Normal	90 – 120	60 – 80
Prehypertension	121 – 139	or 81 – 89
Stage 1 Hypertension	140 – 159	or 90 – 99
Stage 2 Hypertension	>= 160	or = 100

Source: http://www.cvphysiology.com/BloodPressure.

Table 4.5 Heart rate value status

Status	Heart Rate Value (bpm)
Low Rate	Less than or equal to 60
Normal Rate	Between 60 and 70 (including 70)
High Rate	Greater than 70

Source: http://www.buzzle.com/articles/.

The diarrhea vital sign is detected by sensing how many times the patient uses the toilet per day using RFID sensors. In the medical world, if a person uses a toilet more than three times per day, it can be considered that the person might have diarrhea. Table 4.6 shows this information.

Table 4.6 diarrhea vital sign status

Status	Number of usage of toilet per day
Normal	Less than or equal to 3
Medium	Between 3 and 6 (including 6)
Chronic	Greater than 6

The preprocessing operation is carried out based on this status information. Then the status information will be provided for the Status Display Service component to be displayed for the user. Performing such a preprocessing operation on the raw context data has two advantages. The first advantage is that it reduces the burden of the healthcare unit by sharing the task of context interpretation. The healthcare unit on the healthcare is crowded with patients' information and the large ART ontology data. Therefore, making the patient's smart phone to share the data processing task increases healthcare unit's speed and efficiency. The second advantage is if the context data were to be transmitted to the healthcare unit without any preprocessing, the status information to be displayed to the user must be sent back to patient's mobile which increases unnecessary network communication cost.

The next task of the Context Preprocessor and Provider component is sending the preprocessed context information to the server. Always when it gets new context, this component preprocesses and stores it to the persistent storage facility provided by J2ME platform. The frequency of sending context information depends on the status of each vital sign parameter. That means sending takes place only when a certain parameter status becomes abnormal (below or above the normal status) and, in addition, when there is a change from the previous value. By doing this, only relevant contexts will be sent to the server. Again this technique has two main advantages to the overall performance of the system. The first advantage is the reduction of network communication cost as everything obtained from sensors will not be sent. Only the critical contexts will be sent. The second advantage is a refinement of context data for only relevant (critical) contexts which can make a change on the decision of the reasoning system will be sent. This avoids the context refinement task of the healthcare unit.

4.2.1.4. Services/Applications

The last component on the patient side is the Services component which includes different context aware services provided to the user.

- **The Reminder Service:** the Riminder Service is first service which reminds the patient about different scheduled tasks based on time context information. Especially, this service is important for taking medications on time as HIV/AIDS patients take many complex combinations of medicines. They may also use this service to be alarmed on their appointment with their doctor.
- **The Status Display Service:** the Status Display Service is the second service which is triggered when a vital sign context is obtained from sensors. It displays the status of each vital sign parameter on a display screen so that the patient may be aware of his/her health status. This helps him/her to be conscious about his/her condition and makes him/her active participant on the self healthcare.
- **The Coaching Service**: the Coaching Service is the third service which always looks for the body weight status of the user and gives some feedbacks/advices to be taken as a measure. Mostly, HIV/AIDS patients suffer from continuous weight loss. This periodical coaching service encourages them to do some tasks as their habit for weight gain.
- **The Message Listener Service:** the Message Listener Service is the last service given to the user which is responsible for continuous listening of messages coming from the healthcare unit and displays it to the user on a display screen. These messages are generated as a result of context reasoning by the healthcare unit based on the vital sign contexts sent from the user.

4.2.2. The Healthcare Unit

The healthcare unit is composed of different components. These include the Context Receiver component, the Schema Ontology component, the OIDB (Ontology Instance Database) component, the Jena Rules component, the Reasoner component, and finally the Notification Service component. In the next sections, we will see details of all these components.

4.2.2.1. The Context Receiver component

The first component of the healthcare unit is the Context Receiver component. Its primary task is to continuously listen the incoming vital sign contexts from patient's mobile and delivering it to the next component (the Reasoner). In addition to accepting vital sign context information from the patient, it also prepares the received context in a format suitable for consumption by the reasoner.

4.2.2.2. The Ontology component

As described in the previous chapter, ontology in computer science is a specification of concepts found in a given domain. It explicitly defines different concepts in a domain, properties of these concepts, and relationships between themselves. This explicit definition of terms or concepts is represented in a machine understandable format so that machines can use this knowledge for different applications. In this thesis, we have developed a hospital ontology representing concepts specific to HIV/AIDS treatment service – ART.

Treating HIV/AIDS is the most difficult and complex task in the field of medicine. This is mainly because of the dynamically evolving science of HIV. New concepts and recommendations emerged each time through different research works. The other problem is the effect of the virus on the body of victims. It attacks the human immune system, the body's natural defense mechanism, and then opens a room for other opportunistic diseases. An HIV victim is more vulnerable to be infected by any other diseases than an HIV negative person. Any disease, starting from simple common cold to other very complex ones, can attack a person simply because he/she is an HIV victim. Till now, no medication to cure the disease has been discovered. However, if HIV is diagnosed before it becomes AIDS, medicines given through ART service can slow or stop the damage to the immune system. Through our ontology, we developed a very huge knowledge representing these complex concepts, needed to give this treatment service using pervasive healthcare application. Even though our ontology is very much specific to HIV/AIDS treatment service only, it can also be expanded to other treatment services for other diseases found in a hospital if it is necessary. Below are the main concepts/classes specified in the domain. Complete list of ontology classes are presented in figure 4.6. [Graphical representation of the hierarchy of classes is presented in figure 4.7.]

- **Person**: This concept represents any person working in a hospital or customers of that hospital who come as patients. It has two subclasses, Hospital Personnel and Patient, which are classified and described further in subclasses.
- **HospitalPersonnel**: Any person working in a hospital as a medical professional staff and has a close relation with patients by treating them. It has two subclasses, Doctor and Nurse.
- **Doctor**: A hospital personnel who is a medical doctor and treats patients
- **Nurse**: A hospital personnel who is a nurse and follows up patients
- **Patient**: Any person who is a victim of a particular disease and come to hospital to receive treatment. The Patient class may have many subclasses specified based on disease types. We specified three subclasses with three disease types, HBVPatient, HIVAIDSPatient and TBPatient. We include HBV and TB patients in our ontology, because these diseases need special treatment when they appear on the HIV/AIDS patients.
- **HBVPatient**: a patient having HBV disease
- **HIVAIDSPatient**: an HIV/AIDS patient
- **TBPatient**: A TB patient
- **Treatment**: this is a service given to patients to cure their illness. Different treatment types may be defined as necessary, but in our case we defined only ART (treatment for HIV/AIDS) and TB treatment. This is because the type of HIV/AIDS treatment given for HIV patients who are also co-infected with TB depends on the type of medication given to them to cure their TB.
- **ART**: Treatment given specifically to HIV/AIDS patients. It has three subclasses, each differ from each other based on the type of medication and complexity of the disease. These are FirstLineART, SecondLineART and ThridLineArt.

- **FirstLineART**: Treatment given to HIV/AIDS patients when they start ART for the first time.
- **SecondLineART**: Treatment given to HIV/AIDS patients when their first line ART fails.
- **ThridLineArt**: Treatment given to HIV/AIDS patients when their second line ART fails.
- **TBTreatment**: Treatment given specifically to TB patients.
- **WHOHIVDiseaseStage**: Represents the disease stage of HIV/AIDS patients based on WHO disease stage classification, see at Appendix A. It has only four instances distinguished from each other based on the associated symptoms. These are namely, Stage1, Stage2, Stage3 and Stage4.
- **Symptom**: Represents signs of a specific disease or diseases grouped under common catagory. For our case, we define only HIVSymptom but it is possible to define other symptom types of a diseases or group of diseases, like TBSymptom, etc, according to the need.
- **HIVSymptom**: Symptoms of HIV/AIDS appeared based on HIV disease stage.
- **PhysiologicalParameter**: This represents vital signs of HIV/AIDS patients that we proposed to be detected from them via medical sensors. These are BloodPressure, BodyTemprature, BodyWeight, CD4Count, Cough, Diarrhea, HeartBeat, and NightSweat.
- **Medicine**: Represents drugs used to treat a specific disease(s). This class may be classified into different drug categories according to the need like Anticancer Drugs, HIV drugs, etc. In our case, we need to define only HIV drugs (ARVs).
- **ARV**: Represents drugs for HIV. This class has three main subclasses classified depending on the type of action they have on HIV and the type of ART line in which they are used. These are NNRTI, NRTI, and PI.
- **NRTI**: a type of ARV representing Nucleoside Reverse Transcriptase Inhibitors which mimic the normal building blocks of HIV DNA.

- **NNRTI**: a type of ARV representing Non- Nucleoside Reverse Transcriptase Inhibitors which directly inhibit reverse transcriptase.
- **PI**: a type of ARV representing Protease inhibitors which inhibit late stages of HIV replication.
- **Device**: An electronic device in our pervasive healthcare environment owned by persons. It has three subclasses: MobilePhone, PC, and Sensor.
- **MobilePhone**: Represents smart phone owned by patients, doctors and nurses.
- **PC**: A personal computer on the healthcare center
- **Sensor**: A medical sensor owned by HIV/AIDS patient for detecting physiological parameters.

The namespace CAPHC represents:

```
CAPHC="http://www.owl-ontologies.com/CAPHC_Ontology.owl#"
```

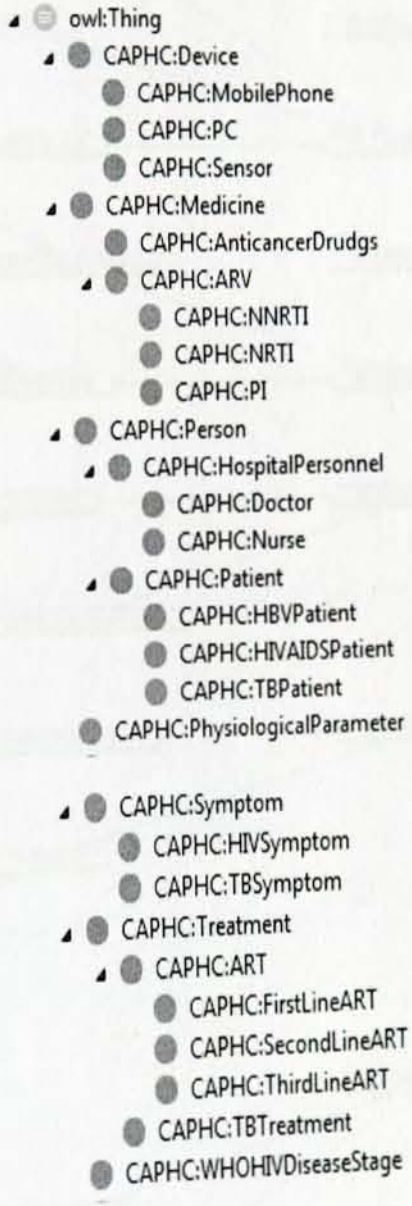

Figure 4.6 Ontology classes in CAPHS and their hierarchy

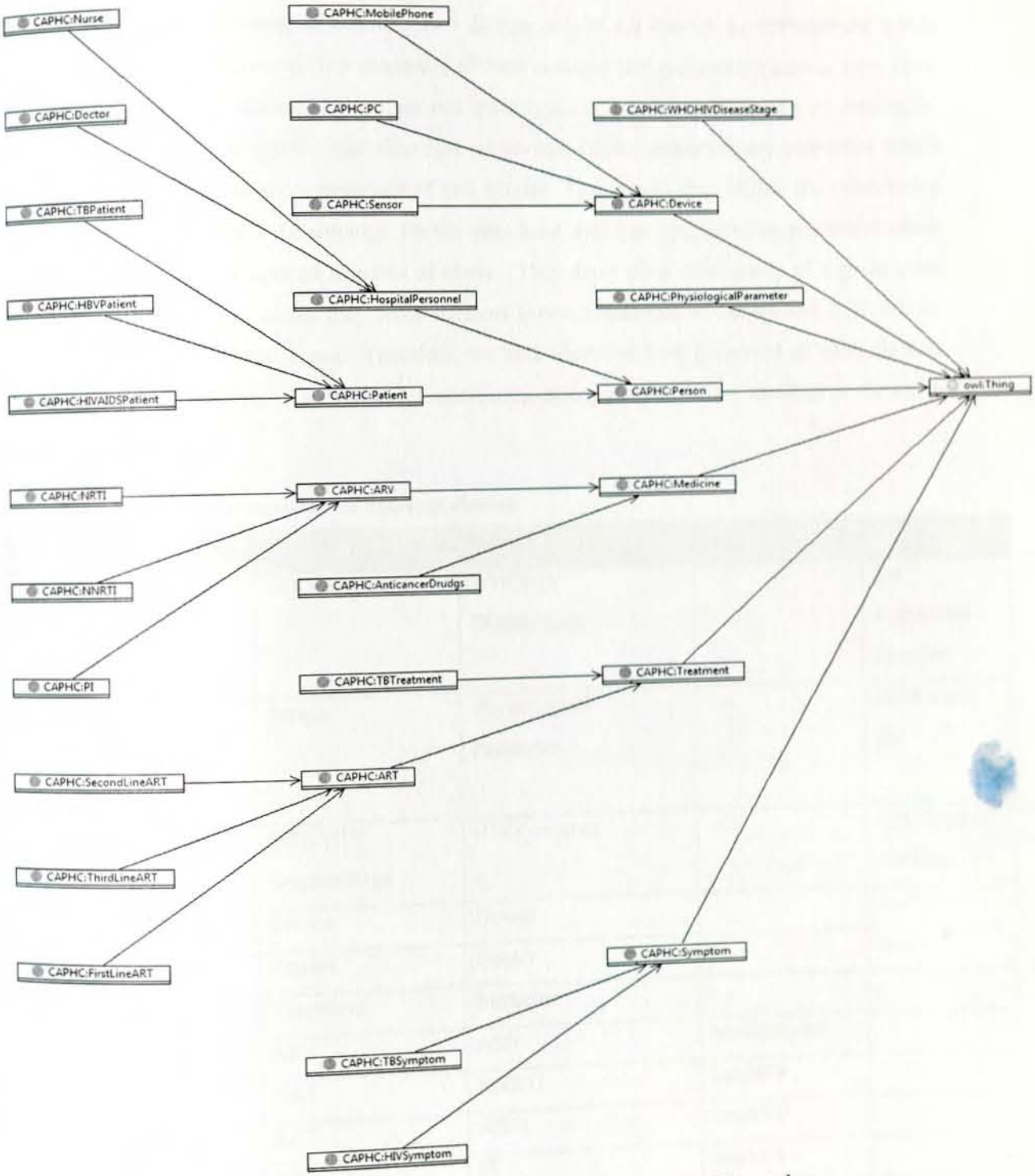

Figure 4.7 Graphical representation of class hierarchy of CAPHS ontology

Defining Relationships between Ontology Classes

Identifying and defining all concepts in a domain only is not enough to represent the whole knowledge of that domain. The properties of these concepts and relationship among them must also be identified. Basically, there are two main types of properties of classes of ontologies. These are *object properties* and *data type properties*. Object properties are properties which describe relations between instances of two classes. That means they define the relationship between two classes in the ontology. On the other hand, data type properties are properties which simply describe the internal structure of classes. They don't show relationship of a given class with any other class; rather they show relations between instances of classes and RDF literals and XML Schema data types. Therefore, we have identified both properties of each class as listed in tables 4.7 and 4.8. Similarly, relationship among classes of our ontology is shown in figures 4.8 – 4.12.

Table 4.7 Object Properties of ontology classes

No	Property Name	Domain	Range	subPropertyOf	inverseOf
1	Appeared AtStage	HIVSymptom	WHOHIV DiseaseStage	-	has Associated Symtom
2	Detect Physiological Parameter	Sensor	Physiological Parameter	-	isDetected By
3	hasAssociated Symptom	WHOHIV DiseaseStage	HIVSymptom	-	Appeared AtStage
4	hasDevice	Person	Device	-	hasOwner
5	hasDoctor	Patient	Doctor	-	treats
6	hasMedicine	Treatment	Medicine	-	-
7	hasARV	ART	ARV	hasMedicine	
8	hasNNRTI	ART	NNRTI	hasARV	
9	hasNRTI	ART	NRTI	hasARV	
10	hasPI	ART	PI	hasARV	
11	hasNurse	Patient	Nurse	-	followsUp

12	hasOwner	Device	Person	-	hasDevice
13	hasPhysiological Parameter	Patient	Physiological Parameter	-	-
14	hasSymptom	Patient	Symptom	-	
15	hasHIVSymptom	HIVAIDSPatient	HIVSymptom	hasSymptom	
16	hasWHO DiseaseStage	HIVAIDSPatient	WHOHIV DiseaseStage	-	-
17	isDetectedBy	Physiological Parameter	Sensor	-	detect Physiological Parameter
18	readsPhysiological Parameter	MobilePhone	PhysiologicalParameter	-	-
19	recievesTreatment	Patient	Treatment	-	-
20	recievesARTLine	HIVAIDSPatient	ART	receives Treatment	-
21	Suggested Substitute	ARV	ARV	-	-
22	Treats	Doctor	Patient	-	hasDoctor
23	followsUp	Nurse	Patient	-	hasNurse

Table 4.8 Data type Properties of ontology classes

No	Property Name	Domain	Range	Description
1	ARTMustBeInitiated	WHOHIVDiseaseStage	boolean	Determines whether ART has to be initiated or not for the stage
2	clinicalDiagnosis	HIVSymptom	string	Clinical diagnosis of a symptom
3	commonAssociatedToxicity	ARV	string	Associated toxicity of ARV drugs
4	definitiveDiagnosis	HIVSymptom	string	Definitive diagnosis of a

				symptom
5	diseaseName	Patient	string	Name of the disease that the patient has
6	enzymeInhibited	ARV	string	Name of HIV enzyme that an ARV drug inhibits
7	hasAbbrevation	Medicine	string	Abbreviated name of a drug
8	hasAdultDose	Medicine	string	Recommended dose of a drug for adults
9	hasAge	Patient	integer	Age of a patient
10	hasCPUSpeed	Device	string	CPU processor speed of a device
11	hasBMI	Patient	float	Body mass index of a patient
12	hasDepartment	HospitalPersonnel	string	Department of a Hospital Personnel
13	hasDeviceName	Device	string	Name of a device
14	hasE-mailAddress	Person	string	E-mail address of a person
15	hasFirstName	Person	string	First name of a person
16	hasFullName	Person	string	Full name of a person
17	hasGenericName	Medicine	string	Generic name of a drug
18	hasHIVType	HIVAIDSPatient	string	HIV type of an HIV/AIDS patient (HIV1 or HIV2)
19	hasMessageToSent	MobilePhone	string	Message generated by the reasoned to sent to the owner of that mobile
20	hasParameterName	PhysiologicalParameter	string	Name of a Physiological Parameter
21	hasSpecialCase	HIVAIDSPatient	string	Special condition of HIV/AIDS patient to be considered before recommending ART drugs

				(e.g. pregnancy, psychiatric illness, etc)
22	hasStartedART	HIVAIDSPatient	string	Determines whether an HIV/AIDS patient has started ART or not
23	hasStatus	PhysiologicalParameter	string	The status of a Physiological Parameter of a patient
24	hasSymptomName	Symptom	string	Name of a disease symptom
25	hasTimeStamp	MobilePhone	string	The time that a Mobile Phone has when it sends medical contexts to the server
26	hasTradeName	Medicine	string	The trade name of a drug
27	hasValue	PhysiologicalParameter		The value of a Physiological Parameter
28	isAsymptotic	HIVAIDSPatient	Boolean	Determines whether an HIV/AIDS Patient any symptoms of HIV or not
29	specificAction	ARV	string	Specific action of an ARV drug on HIV
29	stageName	WHOHIVDiseaseStage	string	Name of WHO HIV Disease Stage
30	targetPopulation	ART	string	Target population for which an ART option is recommended

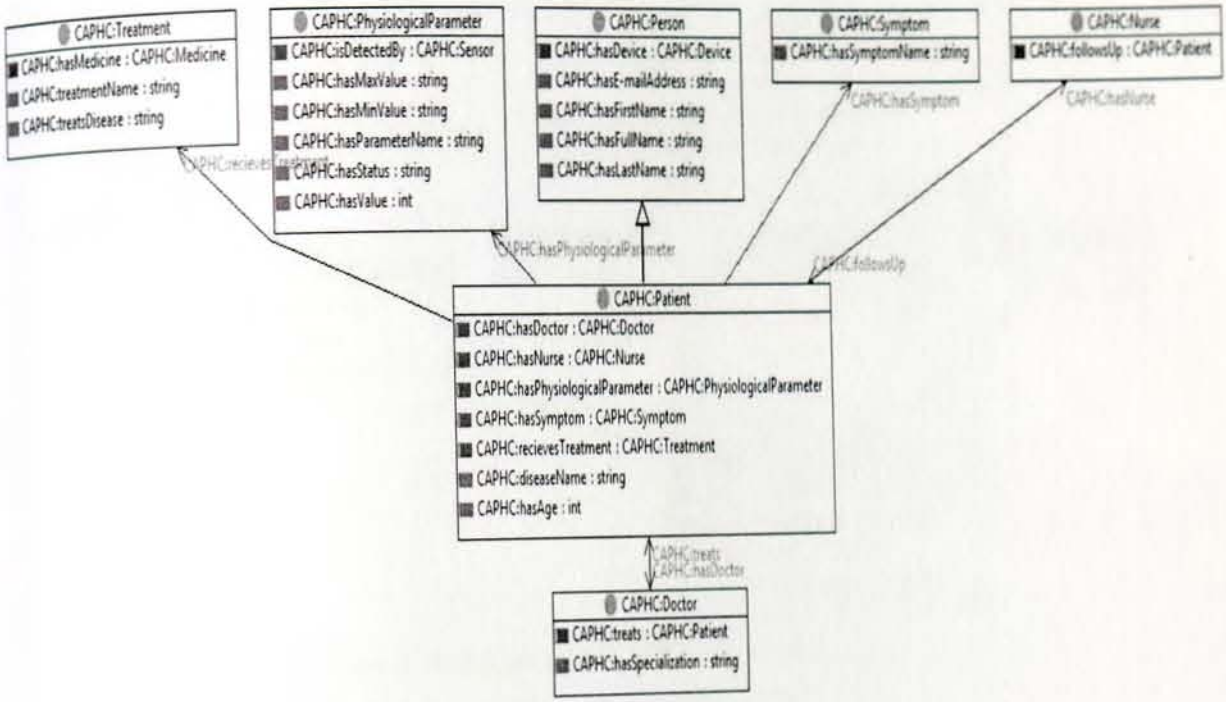

Figure 4.8 Relationship of Patient class with others

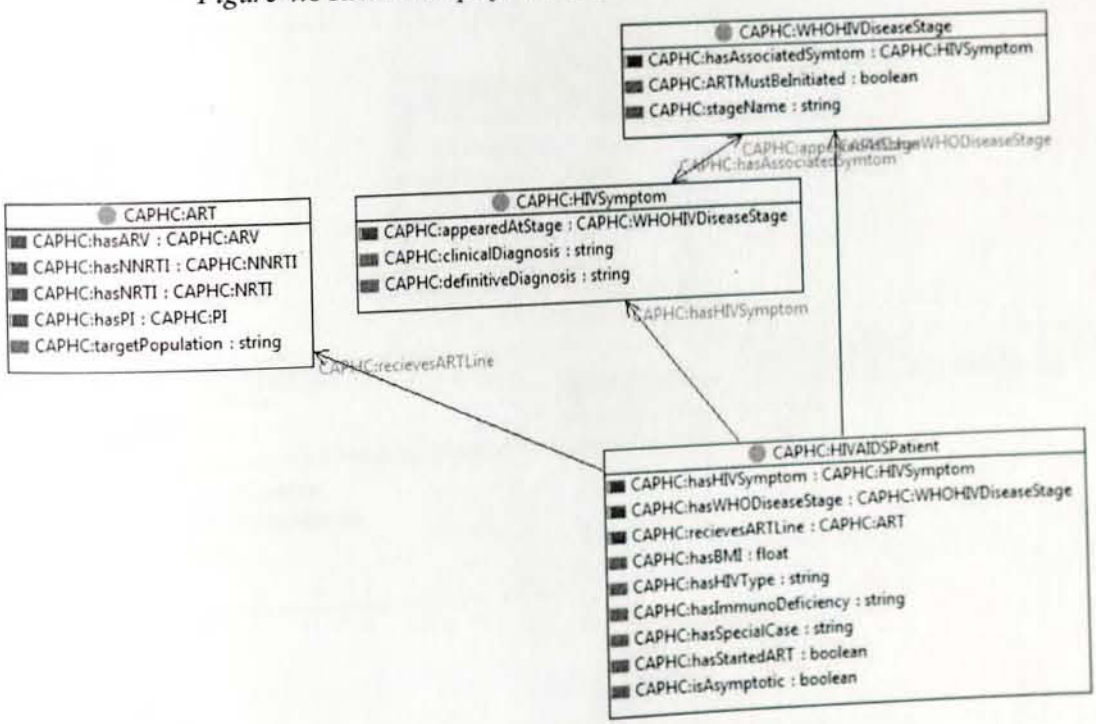

Figure 4.9 Relationship of HIVAIDSPaient class with others

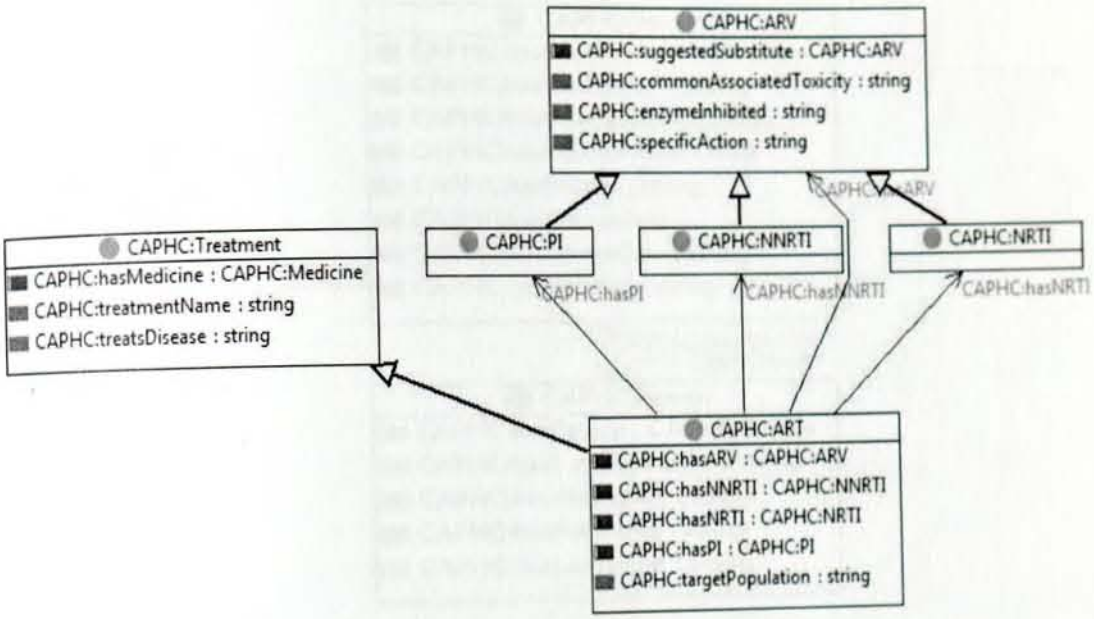

Figure 4.10 Relationship of ART class with others

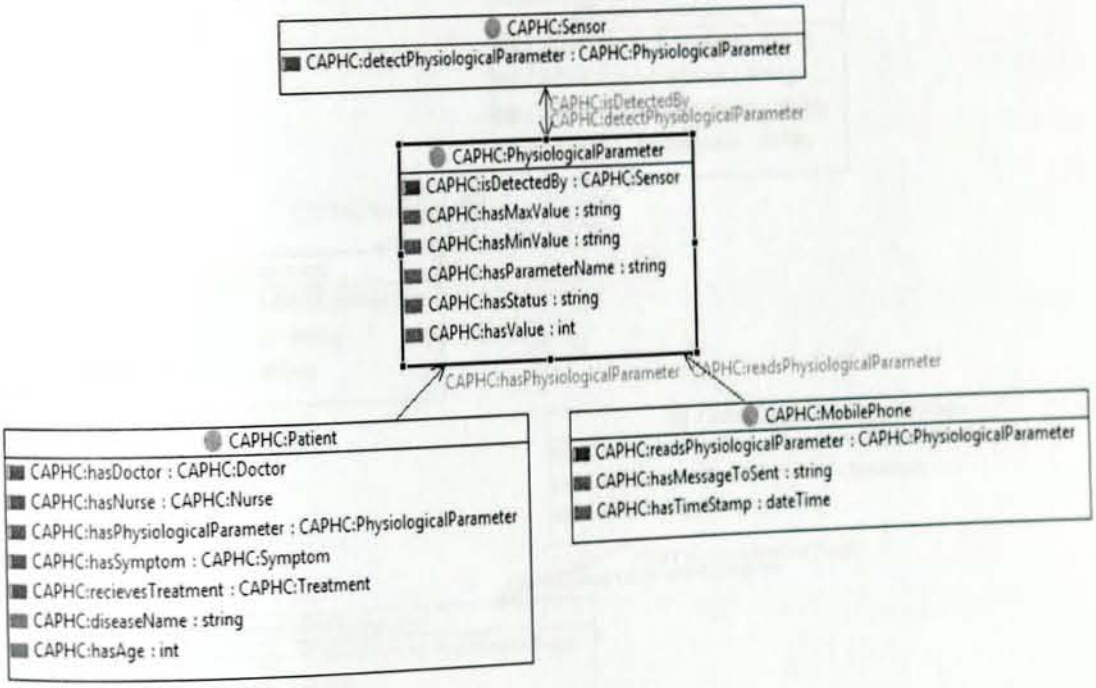

Figure 4.11 Relationship of PhysiologicalParameter class with others

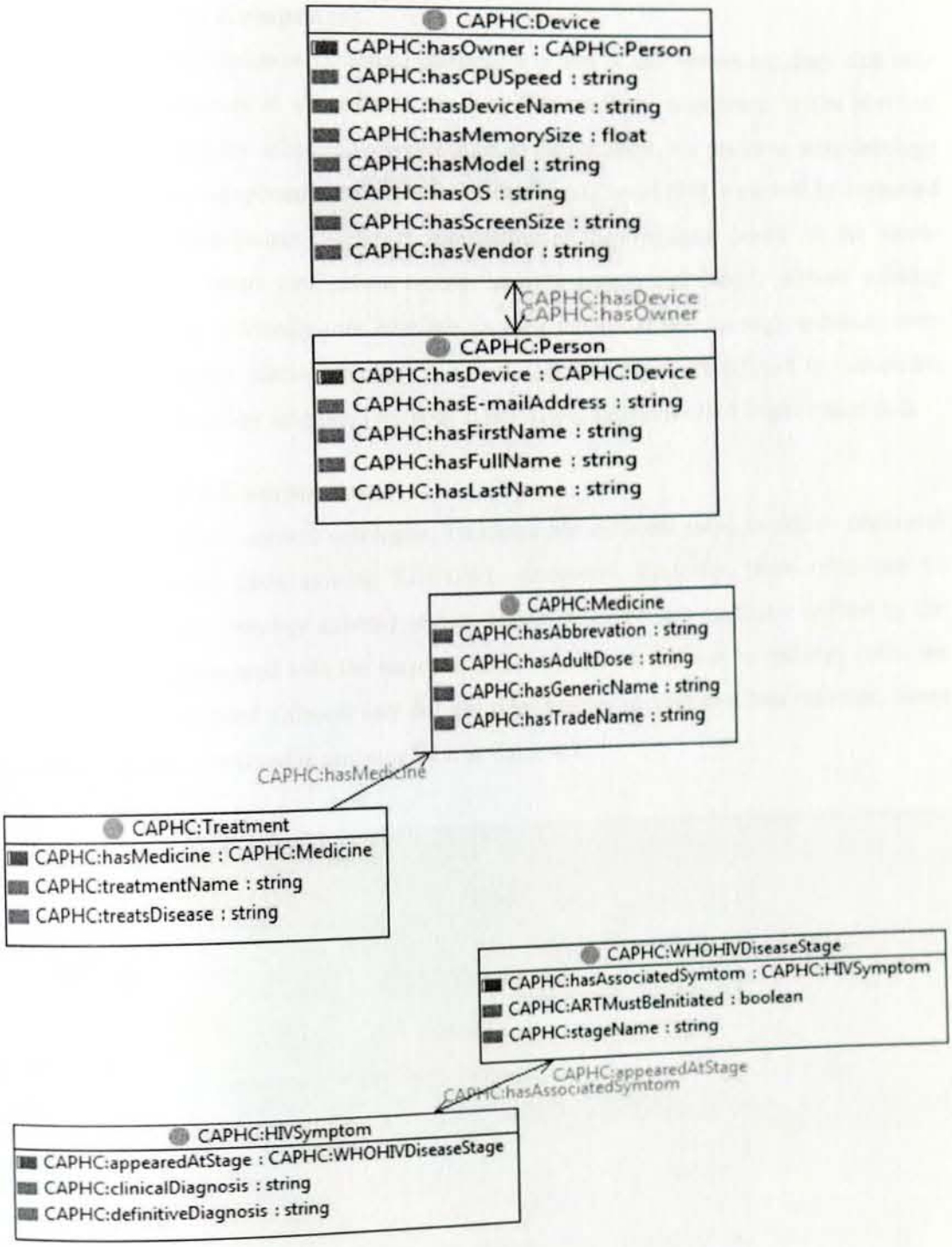

Figure 4.12 Relationships of the remaining classes

4.2.2.3. The OIDB Component

The OIDB (Ontology Instance Database) component is part of our system ontology that only stores ontology instances in an ordinary database. The ontology component in the previous section simply defines the schematic representation of the ontology. We prefer to store ontology instances in separate component for better context data management [39]. As it will be explained later, doctors can manipulate the health information of their patients stored on the server remotely. They can insert new patient records into the system and modify already existing patient records using a friendly user interface via their mobile. If the ontology instances were stored together with the schema ontology in an ontology file, it will be difficult to manipulate patient records as ontology languages are poor in processing and retrieval of large context data.

4.2.2.4. The Rules Component

During reasoning over context ontologies, reasoners use different rules to derive additional knowledge assertions from existing RDF/OWL statements. Basically, these rules can be ontology rules (from ontology axioms) or user defined rules that are explicitly defined by the programmer and associated with the reasoner. In our system, in addition to ontology rules, we have developed and used different user defined rules associated with our Jena reasoner. Some important rules are presented in sentence form in figure 4.13.

Ontology Rules

Inverse Rules:

1. *If a device d has an owner p, then p has a device d.*
2. *If a patient p has a doctor d, then d treats p.*
3. *If a patient p has a nurse n, then n up follows p.*
4. *If a given WHO HIV disease stage s has an associated symptom sympt , then sympt appears at disease stage s.*

Transitive Rules:

If HIVAIDSPatient is subclass of Patient and Patient is subclass of Person, then HIVAIDSPatient is subclass of Person (subclass Property).

Disjoint Classes:

If X is a person, it can't be a member of other classes like a Device, Medicine, Treatment, Symptom, PhysiologicalParameter, and WHODiseasesStage (disjointWith property).

FunctionalProperty:

A person p has a unique device d.

.....

.....

.....

User defined rules:

1. *If a given mobile device m has a Physiological Parameter reading p and m has an owner o who is an HIV/AIDS Patient, then o has Physiological Parameter p.*

   Example of rule representation using generic rule syntax:

   [VitalSign_Rule: (?phone CAPHC:readsPhysiologicalParameter ?param)
   (?phone CAPHC:hasOwner ?patient)
   (?patient rdf:type CAPHC:HIVAIDSPatient)
   ->(?patient CAPHC:hasPhysiologicalParameter ?param)]

2. *If an HIV/AIDS Patient p has also been co-infected with HBV or TB and he/she still didn't start ART, then inform the doctor of p with a message saying: "p has HIV-HBV or HIV-TB co-infection and didn't start ART yet. Please initiate ART as soon as possible."*
3. *If the CD4 cell count c of an HIV/AIDS Patient p becomes less than or equal to 350* cells/mm^3 and he/she still didn't start ART, then inform the doctor of p with a message saying: "The CD4 count of p has been detected as c, and didn't start ART yet. Please initiate ART as soon as possible." At the same time inform the situation to the patient also and warn him/her to meet his/her doctor as soon as possible.*
4. *If the WHO disease stage of an HIV/AIDS patent becomes stage three or stage four and he/she didn't start ART because his/her CD4 count is normal, then inform the doctor of the patient to initiate ART irrespective of his/her CD4 cell count.*
5. *If the status of weight physiological parameter of an HIV/AIDS patent is found to be "Moderate Loss", then the patient has an HIV/AIDS symptom called "moderate weight loss." On the other hand, if it has a status of "Sever Loss", then the patient has one of the*

HIV/AIDS symptoms called "Sever weight loss."

6. *If the status of the temperature physiological parameter of an HIV/AIDS patent is found to be "Fever", then the patient has one of the HIV/AIDS symptoms called "Persistent fever."*
7. *If an HIV/AIDS patient pregnant woman is in the first trimester pregnancy period and becomes eligible to start ART, then inform her doctor to avoid any use of EFV and rather to use NVP instead.*

.....

*** Note that in Ethiopia, the current CD4 count value to start ART is 200cells/mm^3 which is WHO's 2006 recommendation. However, in the 2010 recommendation it is increased to 350. Therefore we have used the latest recommendation as countries must move towards adapting to the new recommendation.**

Figure 4.13 Sample Rules

4.2.2.5. The Reasoner Component

This is the central component in the healthcare subsystem that reasons over the schema ontology, ontology instance data, and context information using ontology and user defined rules. When the Context Receiver component obtains new contexts from the patient's mobile, it prepares the context in a RDF/OWL triple format and delivers it to this component. The reasoner component then, having the newly accepted context, it loads all the information sources (i.e. schema ontology, ontology instance data, and user defined rules) from the file system and entails other additional ontology assertions as shown in figure 4.14. When loading the instance database, it loads only the necessary records by screening them out from the large database using database queries instead of loading the whole database.

Of these additional entailments, if there are any statements which are necessary for the Notification Service component, it extracts them through the SPARQL query and then provides this newly obtained information to the Notification Service component, after preparing the information to make it ready to be directly consumed by the Notification Service component. Actually, this information needed by the Notification Service component is any message to be forwarded to the users of the system (i.e. patients or doctors).

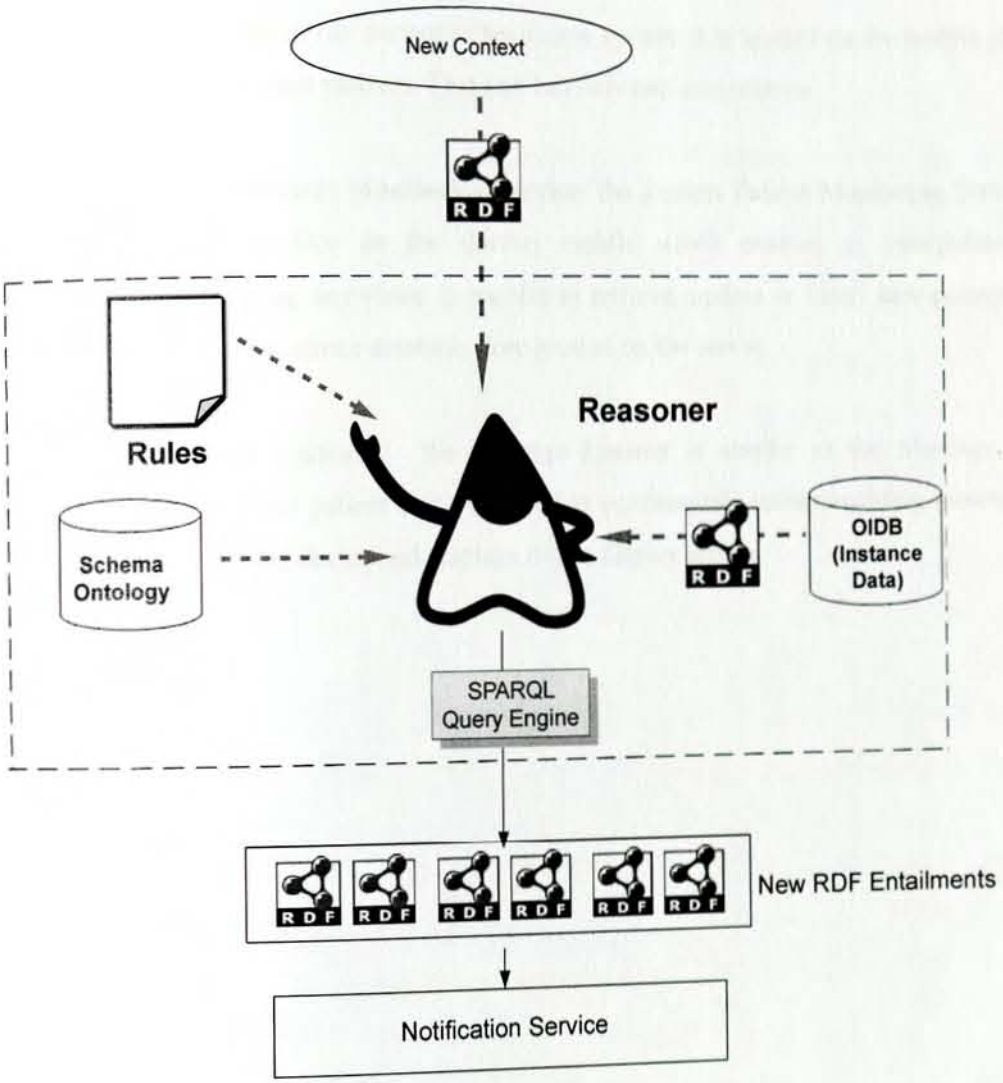

Figure 4.14 The Reasoner Component

4.2.2.6. The Notification Service Component

This component is the final component in the healthcare center subsystem. It subscribes for messages generated by the reasoner component to send them to the respective person. The reasoner component provides this component a generated message plus to whom this message should be sent. The Notification Service accepts this information and delivers the message to the right user.

4.2.3. The Doctor/Nurse Unit

This is the smallest unit of our pervasive healthcare system. It is located on the mobile phones of doctors or nurses who treat patients. This unit has only two components:

- **The Remote Patient Monitoring Service**: the Remote Patient Monitoring Service is an application interface on the doctors mobile which enables to manipulate patient information being anywhere. It enables to retrieve, update or insert new patient records on the patients instance database store located on the server.

- **The Message Listener**: the Message Listener is similar to the Message Listener component of the patient unit. It is used to continuously listen incoming messages from the server for the doctor and displays it on a display screen.

4.3. Summary

In this chapter, we have seen the detail of the components of our proposed pervasive healthcare system. The system has three main constituents: the Patient Unit, the Healthcare Unit and the Doctor/Nurse Unit. Again each constituent consists of multiple components. The Patient Unit contains different components namely the Sensors, the Context Data Acquisition, the Context Preprocessor and Provider, and a number of Services/Applications. Sensors are medical devices used for detecting vital signs from patients. Context Data Acquisition collects the values of these signs periodically from sensors. Context Preprocessor and Provider accepts vital sign context data and preprocess it to interpret into vital sign status information stores it in record store facility of J2ME. Then, if there is any abnormal condition which is different from the previous value, it sends the vital sign information to the Healthcare Unit for further processing.

The Healthcare Unit consists of a number of components including the Context Receiver, the Ontology, the Rules, the OIDB, the Reasoner, and the Notification Service. The Context Receiver as its name indicates receives context from Patent Unit, prepares it into an RDF/OWL format and provides for the Reasoner component. The Ontology component contains all concepts and their relationships in the domain of ART. The OIDB is an extension of the Ontology component containing only the instances of the Ontology. The Rule component contains multiple ontology and user defined Jena rules. The Reasoner component is a cascade of Jena Reasoners consuming RDF triples from the above sources to generate additional new knowledge. The last component, the Notification Service uses this new knowledge to notify users about abnormal situations.

The last unit of the architecture is the Doctor/Nurse Unit. This is the lighter unit in the architecture containing only two components. These are the Remote Patient Monitoring Service which is used by the doctor/nurse to manipulate patient records remotely using a phone, and the Message Listener which accepts messages coming from the Healthcare Unit and display them to the doctor/nurse.

Chapter Five: Prototype Implementation

In the previous chapter, we have seen in detail the architecture of CAPHS that we proposed in this thesis. In this chapter, we will see the prototype implementation and demonstration of the system to see practically the concepts we discussed in the previous chapter. First we will present all the tools and technologies that we have used to prepare our prototype implementation and demonstration. Then, to give the reader an idea of how CAPHS works, a scenario of different patient cases will be presented. After this formulated scenario of patients, the implementation of the components of the designed system will be presented. Finally, we will demonstrate our prototype implementation using practical screen shots of the implementation.

5.1. Tools and Technologies used for the Prototype

For the preparation of the prototype of the system, we have used lots of programming languages, network communication technologies, and hardware devices. All of them are listed as follows:

- J2ME SDK 3.0 platform with CLDC configuration and MIDP profile – for the implementation of components of the patient and the doctor/nurse mobile units, [40] and [41].
- Eclipse SDK version 3.3.1.1 – to develop the components of the server side.
- Apache Tomcat version 6.0 – is used as a web container for Java Servlets of the server.
- TopBraid Composer Maestro Edition- 2.4.2 – for developing the ontology of the system
- Jena Semantic Web framework version 2.6.4 – used to develop the Reasoner component of the server. It is also used to load the schema ontology and the ontology instance database in to Jena models and to associate user defined Jena rules to the generic Jena ontology reasoner.
- SPARQL – to query over RDF triples
- MY SQL database server version 5.0.22 – is used for persistent ontology instance data storage and management on the server.
- Different body sensor devices[4] are used to detect vital signs of patients

[4] Due to budget and local market limitations the sensor devices are implemented by simulation.

- LUCAS[5] mobile phone is used as smart mobile for patients
- Bluetooth wireless communication network is used for communication of body sensors with the smart phone.
- Internet communication network is used for communication between the server and mobile phones.

5.2. Scenario of Patients

Before presenting the scenario of patients, based on which we prepared our demonstration, first it is necessary to see some ART service guide lines recommended by WHO which we have used in our scenario and hence on our demo. These include recommendations on when to start ART, what drugs to start, specific populations - when and what to start, when to switch ART, and the like. It is impossible to present all of these recommendations here, but we put some key recommendations here and for further elaboration we request the reader to refer to the full document of WHO recommendations for a public health approach [7].

- *It is recommended to treat all patients with CD4 counts of ≤350 cells/mm^3 irrespective of the WHO clinical stage.*
- *It is recommended that all patients with WHO clinical stage 1 and 2 should have access to CD4 testing to decide when to initiate treatment.*
- *It is recommended to treat all patients with WHO clinical stage 3 and 4 irrespective of CD4 count.*
- *Start one of the following regimens (combination of different ARVs) in ART-naive individuals eligible for treatment.*
  - *AZT (zidovudine) + 3TC(lamivudine) + EFV(efavirenz)*
  - *AZT + 3TC + NVP(nevirapine)*
  - *TDF(tenfovir disoproxil fumarate) + 3TC (or FTC(emtricitabine)) + EFV*
  - *TDF + 3TC (or FTC) + NVP*
- *Start ART in all pregnant women with HIV and a CD4 count of ≤350 cells/mm^3, irrespective of clinical symptoms.*

[5] Due to budget and local market limitations the smart mobile is implemented by emulation.

- *CD4 testing is required to determine if pregnant women with HIV and WHO clinical stage1 or 2 disease need to start ARV treatment or ARV prophylaxis for PMTCT (prevention of mother-to-child transmission HIV).*
- *Start ART in all pregnant women with HIV and WHO clinical stage 3 or 4, irrespective of CD4 count.*
- *Start one of the following regimens ((combination of different ARVs)) in ART-naive pregnant women eligible for treatment:*
  - *AZT + 3TC + EFV*
  - *AZT + 3TC + NVP*
  - *TDF+ 3TC (or FTC) + EFV*
  - *TDF + 3TC (or FTC) + NVP.*
- *Do not initiate EFV during the first trimester of pregnancy, or if there is a potential for pregnancy unless taking effective contraceptives.*
- *Start ART in all HIV/HBV co-infected individuals who require treatment for their HBV infection, (chronic active hepatitis), irrespective of the CD4 cell count or the WHO clinical stage.*
- *Start TDF and 3TC (or FTC)-containing antiretroviral regimens in all HIV/HBV co-infected individuals needing treatment.*
- *Start ART in all HIV-infected individuals with active TB, irrespective of the CD4 cell count.*
- *Start TB treatment first, followed by ART as soon as possible afterwards (and within the first eight weeks).*
- *Use efavirenz (EFV) as the preferred NNRTI in patients starting ART while on TB treatment.*
- *Where available, use viral load (VL) to confirm treatment failure.*
- *Where routinely available, use VL every 6 months to detect viral replication.*
- *A persistent VL of >5000 copies/ml confirms treatment failure.*
- *When VL is not available, use immunological criteria to confirm clinical failure.*

For the demonstration of our prototype, we formulated the following scenario of three HIV/AIDS patients all of them are under the treatment of a particular doctor. We have chosen a

scenario of three patients in order to consider different cases which may not appear on a single patient. These scenarios will be used in subsequent sections.

1. *Ashebir is an HIV carrier. He is receiving the pre – ART follow up service at Black Lion Hospital until he becomes eligible to start ART. The reason that currently he doesn't take any ART medication is that his CD4 cell count is normal and he doesn't have any HIV/AIDS disease symptoms. However, after three months, the smart mobile phone of Ashebir reported to the healthcare unit that certain abnormal health conditions have appeared even though his CD4 cell count is still in a normal condition. From the report obtained from the mobile, the healthcare unit found that certain HIV/AIDS symptoms started to appear. These include persistent fever, sever weight loss, and chronic diarrhea. Then the healthcare unit deduced that Ashebir reach to the third stage of HIV/AIDS disease. Immediately, the healthcare unit warned Dr. Abebe, Ashebir's doctor, that his patient Ashebir is currently suffering from many HIV symptoms of stage three and therefore he has reached disease stage three, and he must start ART irrespective of his CD4 status. The system also informed patient Ashebir to meet his doctor as soon as possible. Then Dr. Abebe decided to give ART to Ashebir and other treatments to other opportunistic diseases. Now Ashebir received a bulk of drugs that needs careful interaction. However, the reminder service on his mobile phone assisted him to take all his medicines timely and orderly. Now Ashebir is in a good and healthy state, but his body weight couldn't recover faster. The coaching service on his mobile phone helps him to give attention to his weight gain by displaying his weight status regularly and recommending important advices to follow cheap and balanced diet system.*

2. *W/ro Almaz and her spouse wanted to have a child in the near future. However, before pregnancy they decided to check for HIV for the sake of the child to be born. Sorrowfully, after the test, they are found to be HIV positive. Their doctor recorded their profile into the HIV/AIDS patients' record database including the special case of w/ro Almaz that she has potential for pregnancy. After two months, the mobile phone of w/ro Almaz reported her CD4 cell count to be 304cells/mm^3 even though she feels no pain. The healthcare unit concluded that her CD4 count is below 350cells/mm^3 and therefore she must start ART irrespective of her disease stage. Then the healthcare unit warned her doctor about the situation and recommended to initiate ART for her. Moreover, the system reminded the doctor that w/ro*

Almaz has a great potential of pregnancy and hence must avoid the use of EFV drug and use NVP instead. The system also recommended w/ro Almaz that she must meet her doctor as soon as possible.

3. *Kebede goes to hospital to fix his problem of continuous cough for more than two weeks. After conducting the necessary laboratory test, it has been found that Kebede is infected with TB. After recording his profile into the patients' database as a TB patient, the TB doctor prescribed him the required medications and ordered him to check for HIV in the HIV/AIDS department of the hospital as it is necessary for any TB patient to check for HIV and vice versa. Sadly, HIV has been found in his blood solution. However, his CD4 cell count is normal even though approaching the ART starting threshold value. Then, Kebede was registered in the department so that he can get the ART and follow up service. Immediately after registration, the healthcare unit of CAPHS recommended to the HIV doctor to initiate ART and provides information on which drugs are given for his TB infection, after reasoning from the patients' database and finding both TB and HIV co – infection. The doctor then acted accordingly and made him to start ART. Kebede was also given a pervasive life assistant with some orientation and made to go home. He continues taking all the drugs given for both TB and HIV infections through the help of the reminding service on his smart phone. He becomes better from time to time from his cough and the like, but from the report from his phone his CD4 cell count continues to decline. After receiving the CD4 cell count report remotely, the healthcare unit deduced that the first line ART regimen given to Kebede might have failed to help his body defense mechanism to recover. Therefore, the system strongly recommended Kebede to meet his doctor as soon as possible. At the same time, it also informed the doctor that the ART medication given to Kebede might have failed; therefore, plasma viral load measurement is required (if affordable) and the second line regiment has to be initiated.*

5.2.1. Implementation

The prototype implementation of CAPHS is based on its three main constituent units. Below is the implementation architecture of the system (figure 5.1). The subsequent sections describe the details of implementation of each component.

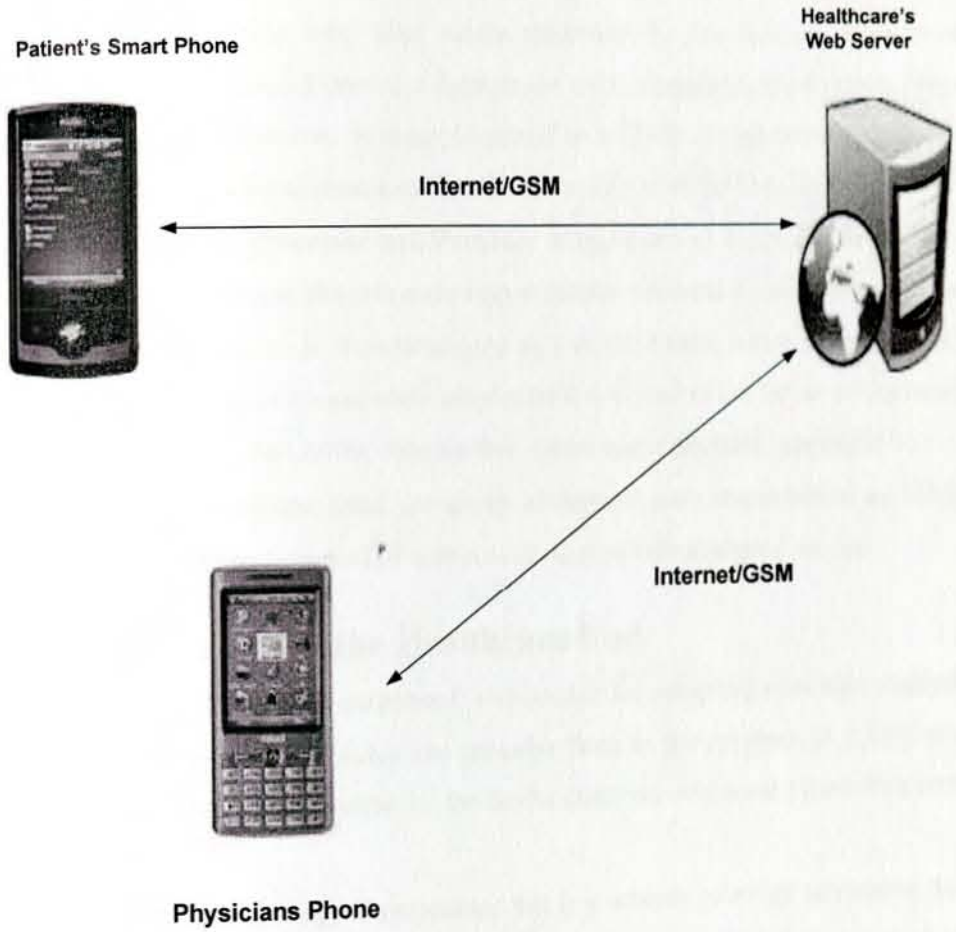

Figure 5.1 Implementation diagram of the system

5.2.2. Components on the Patient Unit

- **The Sensors Component:** this module is implemented as a J2ME thread which periodically generates valid body sensor values of each vital sign parameters. By doing this, this component simulates the real operation of medical sensor devices. Since it is a java thread class, it runs continuously once it has been started.
- **The Context Data Acquisition Component:** this component is responsible for periodically fetching vital sign values generated by the Sensors component. After collecting the values, it provides them to the next component, the Context Preprocessor and Provider component. It is implemented as a J2ME thread consumes the generated values with a producer/consumer thread relationship with the Sensors thread.
- **The Context Preprocessor and Provider component:** as explained in chapter three in detail, this component has two main responsibilities: context preprocessing and sending it to the remote server. It is implemented as a J2ME thread which accepts the vital sign values from the above component preprocess it and send to the server as explained during the design phase. Part of the code for this component is found in Appendix B.
- **Services/Applications:** these are group of services each implemented as J2ME midlet classes with the necessary GUI components to give their designed service.

5.2.3. Components on the Healthcare Unit

- **The Context Receiver component:** responsible for accepting vital sign medical context values from patients' mobiles and provides them to the reasoner. It is implemented as Java Servlet which is invoked by the Sevlet container whenever connection comes from patients.
- **The (Schema) Ontology Component:** this is a schema ontology containing the domain specific schema data. It is developed using OWL ontology language and stored as OWL/RDF file.
- **The Rules:** this is a collection of user defined Jena rules which are associated with the reasoner. It is developed using a simple text editor and stored as a RULES file. We have presented it in Appendix C.

- **The OIDB:** this is part of the ART ontology, but only contains the low level part of the ontology which stores instance data in a separate database file for the sake of better data management.
- **The Reasoner:** this is the most important component which gives intermediate and final reasonings based on data from the data sources. It is implemented as Java class which intensively uses the Jena APIs. Part of the implementation code for this component is found in Appendix D.
- **The Notification Service:** this component is implemented as Java Servlet which communicates with mobile phones of users to deliver important notification messages.

5.2.4. Components on the Doctor Unit

This unit only contains two components. The first is the Remote Patient Monitoring Service which is implemented as a J2ME midlet application with interactive GUI capabilities. It enables the doctor to remotely manipulate the records of his/her patients stored in OIDB. The second is Message Listener having a similar function with the same component found in patient's unit. It is used to listen the incoming message from the server. It is implemented as always running J2ME thread, and if it gets a message from remote it displays to the user with the necessary GUI.

5.3. Demonstration

In this section, we will demonstrate the implementation of the prototype. The demonstration is prepared based on the above patient scenario. Therefore, we demonstrate the cases of each patient in the scenario one by one as follows.

Scenario I

For the first scenario, i.e. Ashebir, context on the following medical parameters was sent to the server from the mobile. Note that the mobile phone of the patient only sends the preprocessed context. That means the status value of parameters having abnormal status will be sent.

Parameter	Status
Temperature	Fever
Body Weight	Sever Loss
Diarrhea	Chronic

Then the healthcare unit sever accepts this context information, prepares it to make suitable for consumption as shown in figure 5.2, and interprets it to intermediate context by reasoning over it using the rules shown in figure 5.3.

```
.....

<CAPHC:PhysiologicalParameter rdf:about = "http://www.owl-
ontologies.com/CAPHC_Ontology.owl#BodyTemprature">
<CAPHC:hasStatus
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Fever</CA
PHC:hasStatus></CAPHC:PhysiologicalParameter>

<CAPHC:PhysiologicalParameter rdf:about = "http://www.owl-
ontologies.com/CAPHC_Ontology.owl#BodyWeight">

<CAPHC:hasStatus
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Sever
Loss</CAPHC:hasStatus></CAPHC:PhysiologicalParameter>

<CAPHC:PhysiologicalParameter rdf:about = "http://www.owl-
ontologies.com/CAPHC_Ontology.owl#Diaherria

<CAPHC:hasStatus
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Chronic</
CAPHC:hasStatus></CAPHC:PhysiologicalParameter>

.....
```

Figure 5.2 Prepared Context of Scenario I

```
[ VitalSign_Rule: (?phone CAPHC:readsPhysiologicalParameter ?param)
                  (?phone CAPHC:hasOwner ?patient)
                  (?patient rdf:type CAPHC:HIVAIDSPatient)
                 ->(?patient CAPHC:hasPhysiologicalParameter ?param)]
[ BodyWeight_Rule2: (?p rdf:type CAPHC:HIVAIDSPatient)
                    (?p CAPHC:hasPhysiologicalParameter CAPHC:BodyWeight)
                    (CAPHC:BodyWeight CAPHC:hasStatus "Sever Loss"^^xsd:string)
                   ->(?p CAPHC:hasHIVSymptom CAPHC:Severe_weight_loss)]
[BodyTemperature_Rule:  (?p rdf:type CAPHC:HIVAIDSPatient)
                        (?p CAPHC:hasPhysiologicalParameter CAPHC:BodyTemprature)
                        (CAPHC:BodyTemprature CAPHC:hasStatus "Fever"^^xsd:string)
                        ->(?p CAPHC:hasHIVSymptom CAPHC:Persistent_fever)]
 [ Diarrhea_Rule:  (?p rdf:type CAPHC:HIVAIDSPatient)
                  (?p CAPHC:hasPhysiologicalParameter CAPHC:Diarrhea)
                  (CAPHC:Diarrhea CAPHC:hasStatus "Chronic"^^xsd:string)
                    ->(?p CAPHC:hasHIVSymptom CAPHC:Unexplained_Chronic_diarrhoea)]
[WHODiseaseStage_3: (?p rdf:type CAPHC:HIVAIDSPatient)
                    (?p CAPHC:hasHIVSymptom ?s)
                    (?s CAPHC:appearedAtStage CAPHC:Stage_3)
                    ->(?p CAPHC:hasWHODiseaseStage CAPHC:Stage_3)]
[ ARTInitiation_Rule2: (?p rdf:type CAPHC:HIVAIDSPatient)
                       (?p CAPHC:hasStartedART "false"^^xsd:boolean)
                       (?p CAPHC:hasWHODiseaseStage CAPHC:Stage_3)
                       (?p CAPHC:hasDoctor ?d)
                       (?d CAPHC:hasDevice ?phone)
                       (?p CAPHC:hasDevice ?pd)
                       (?p CAPHC:hasFullName ?pname)
                       (?d CAPHC:hasFullName ?dname)
                       strConcat("Hello Dr.",?dname,", ",?pname," has WHO disease
                       stage stage 3, please initiate ART irrespective of
```

```
CD4 count",?msgToDoctor)
strConcat("Hello",?pname,",", "You have reached disease stage
three. Please meet your doctor as soon as possible",?msgToPatient)

->(?phone CAPHC:hasMessageToSent ?msgToDoctor)
(?pd CAPHC:hasMessageToSent ?msgToPatient)]
```

Figure 5.3 Rules used for the first scenario

According to VitalSign_Rule and our ontology (in which the device and person relationship is maintained – hasOwner is inverse of hasDevice), any physiological parameter read by a mobile phone is automatically interpreted to be the physiological parameter of the owner of that mobile. The status of each vital sign in the context will then be interpreted to other high level intermediate context using rules BodyWeight_Rule2, BodyTemperature_Rule, and Diarrhea_Rule as shown in table 5.1. As a result, each vital sign status is interpreted to symptoms of HIV that appeared during the third stage of the disease (see Appendix A). According WHODiseaseStage_3 rule, if one or more HIV symptoms of stage three appear, then it is concluded that the patient has reached stage three. From this, another information is generated which is preparing warning messages for both Ashebir and Dr.Abebe as shown in table 5.1. Finally, these messages are sent to the corresponding user. Figure 5.4 shows the message display sent for Ashebir and Dr. Abebe through their mobiles.

Table 5.1 Context Processing for the scenario I

Parameter	Status Context	Intermediate Context1 (HIV Symptom)	Intermediate Context2	Final Context	Action
Temperature	Fever	Persistent_fever	Disease stage three	Ashebir and Dr.Abebe have message to send	Send the right message to the right user
Body Weight	Sever Loss	Severe_weight_loss			
Diarrhea	Chronic	Unexplained_Chronic_diarrhoea			

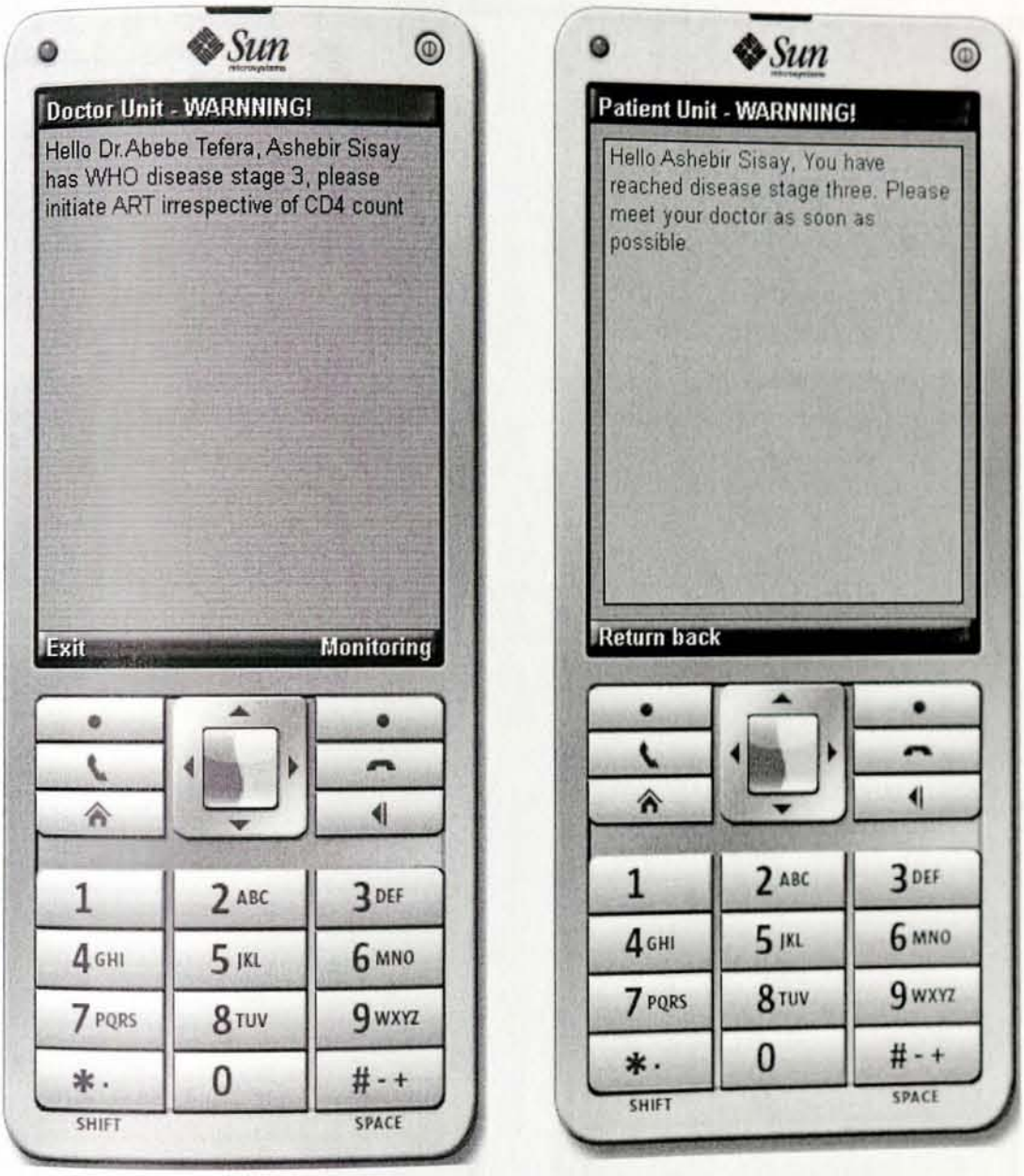

Figure 5.4 Messages sent to Dr. Abebe and his patient Ashebir

As explained in the scenario, Dr. Abebe prescribed to Ashebir to start ART and other medicines, may be after he made extra tests. The reminder service in Ashebir's mobile helps him to take his medicine on time if he sets the service to remind him (figures 5.5). In addition, another service,

the coaching service, displays his weight status periodically and gives some advices to take care of his weight gain (figures 5.6).

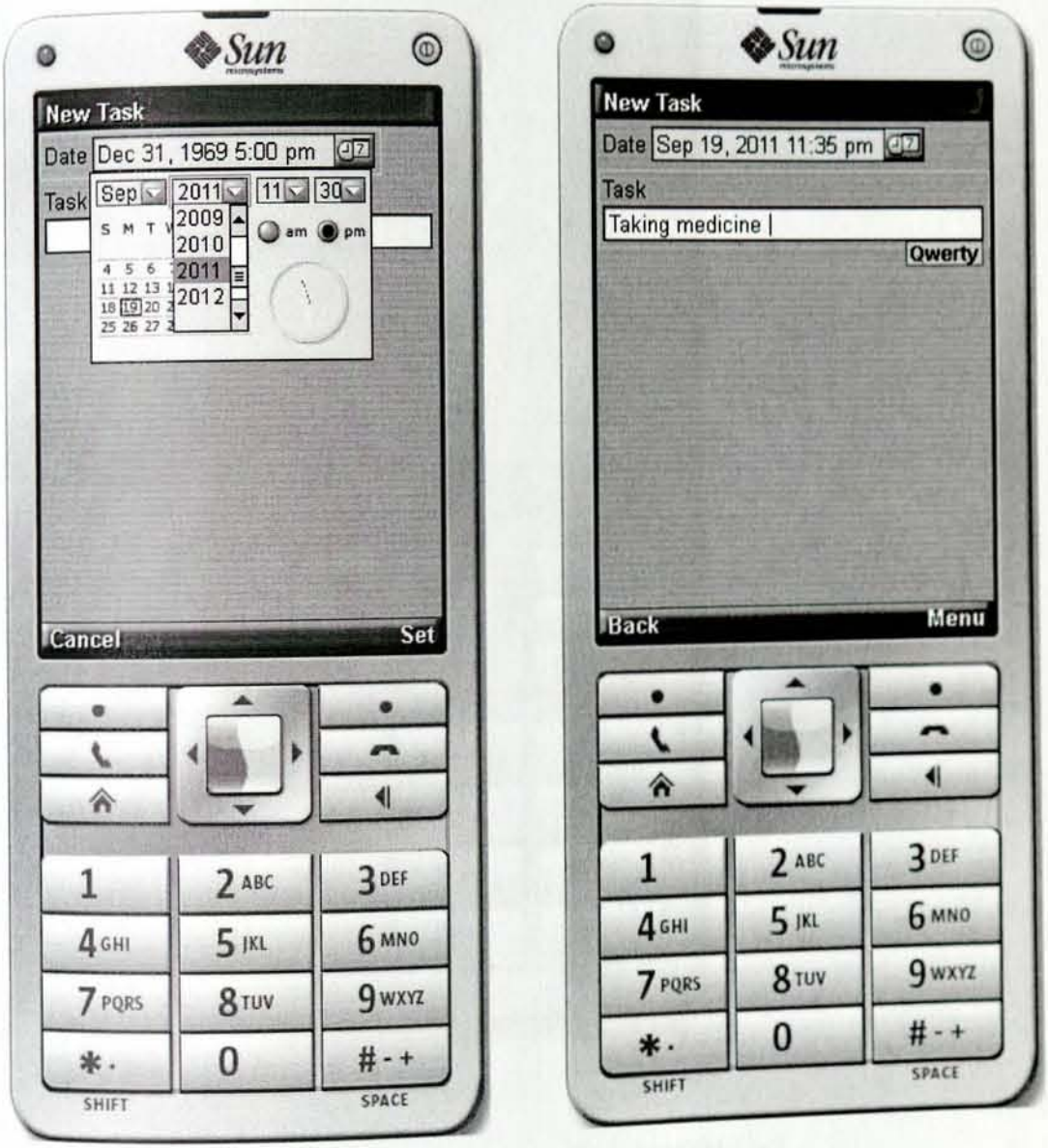

Figure 5.5 Scheduling a task to be reminded

Figure 5.6 Weight status display and feedback

Scenario II

For the second scenario, the system recognizes when the CD4 cell count of w/ro Almaz becomes less than or equal to 350cells/mm^3 and sends messages both to w/ro Almaz and her doctor Dr.Abebe as shown in table 5.2 and figure 5.8.

Table 5.2 Context processing for scenario II

Parameter	Status Context	Final Context	Action
CD4 cell count	CD4 < 350 cells/mm^3	W/ro Almaz and Dr.Abebe have message to send	Send the right message to the right user

From her profile information it also finds that w/ro Almaz has a special condition to be considered when giving any medication to her. Therefore, it reminds the doctor that she has a potential for pregnancy. This is shown in figure 5.9. The Jena rules used for this scenario are also shown in figure 5.7.

```
.....
[ARTInitiation_Rule1:
        (?p rdf:type CAPHC:HIVAIDSPatient)
        (?p CAPHC:hasStartedART "false"^^xsd:boolean)
        (?p CAPHC:hasPhysiologicalParameter ?param)
        (?param CAPHC:hasParameterName "CD4 Count"^^xsd:string)
        (?param CAPHC:hasValue ?cd4Val)
         le(?cd4Val,350)
         (?d CAPHC:treats ?p)
         (?d CAPHC:hasDevice ?phone)
         (?p CAPHC:hasDevice ?pd)
          (?p CAPHC:hasFullName ?pname)
          (?d CAPHC:hasFullName ?dname)
           strConcat("Hello Dr.",?dname,", The CD4 count of ",?pname," has been detected
```

```
        as ", ?cd4Val, ",and didn't start ART yet. Please initiate ART as soon
        as possible.",?msgToDoctor)
        strConcat("Your CD4 value is currently ",?cd4Val,". Please meet your doctor as
        soon as possible.",?msgToPatient)
       ->(?phone CAPHC:hasMessageToSent ?msgToDoctor)
        (?pd CAPHC:hasMessageToSent ?msgToPatient)]
[ Potential_Pregnancy_Rule: (?p rdf:type CAPHC:HIVAIDSPatient)
                            (?p CAPHC:hasSpecialCase "potential for pregnancy"^^xsd:string)
                            (?p CAPHC:hasStartedART "false"^^xsd:boolean)
                            (?p CAPHC:hasDoctor ?d)
                            (?d CAPHC:hasDevice ?phone)
                            (?p CAPHC:hasFullName ?pname)
                            (?d CAPHC:hasFullName ?dname)
                            strConcat("Hello Dr.",?dname,", ",?pname," has a potential
                            for Pregnancy, please avoid any use of EFV. You can use
                            NVP instead.", ?msg)
                           ->(?phone CAPHC:hasMessageToSent ?msg)]
```

Figure 5.7 Rules for the second scenario

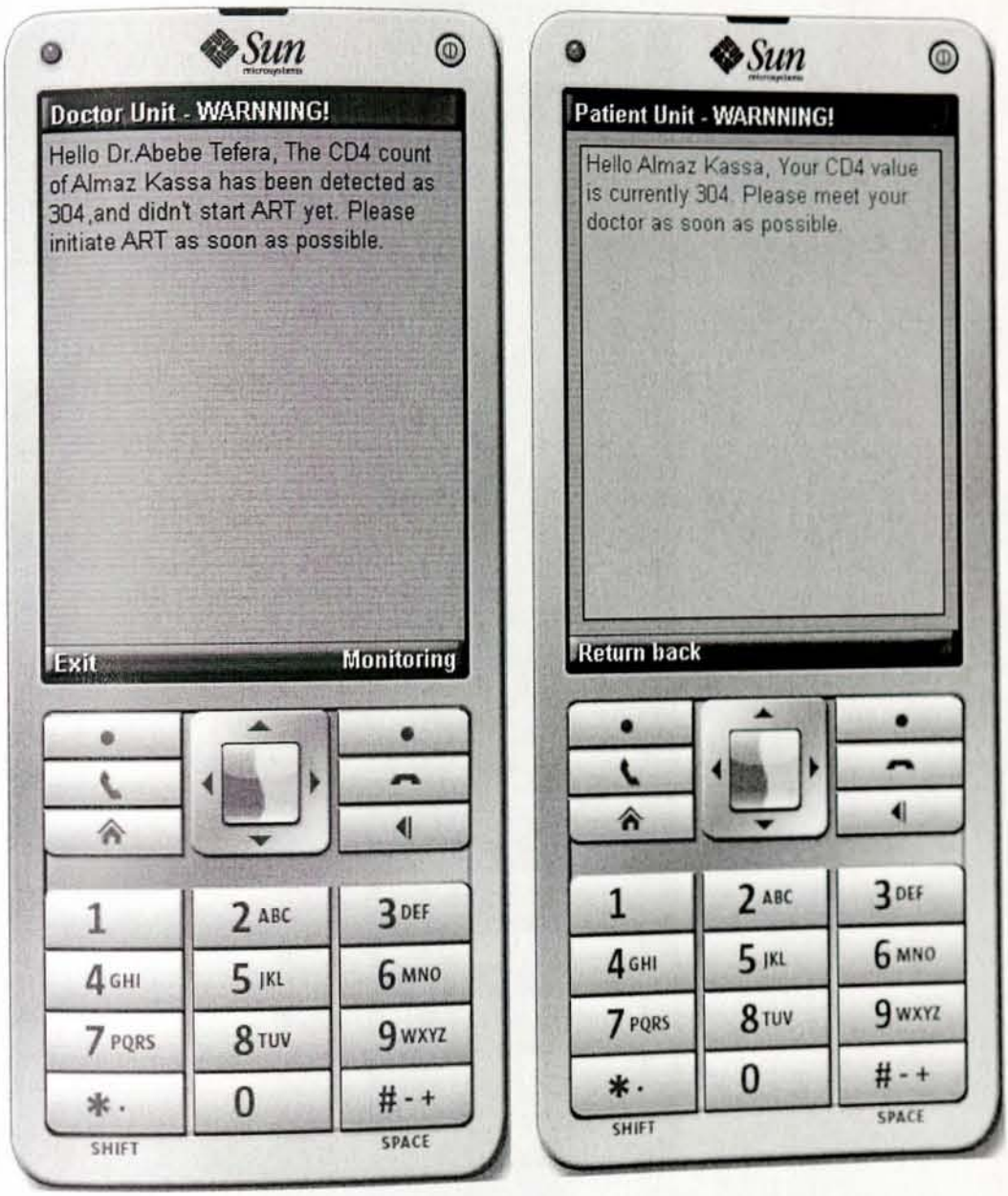

Figure 5.8 Messages to Dr.Abebe and w/ro Almaz about her CD4

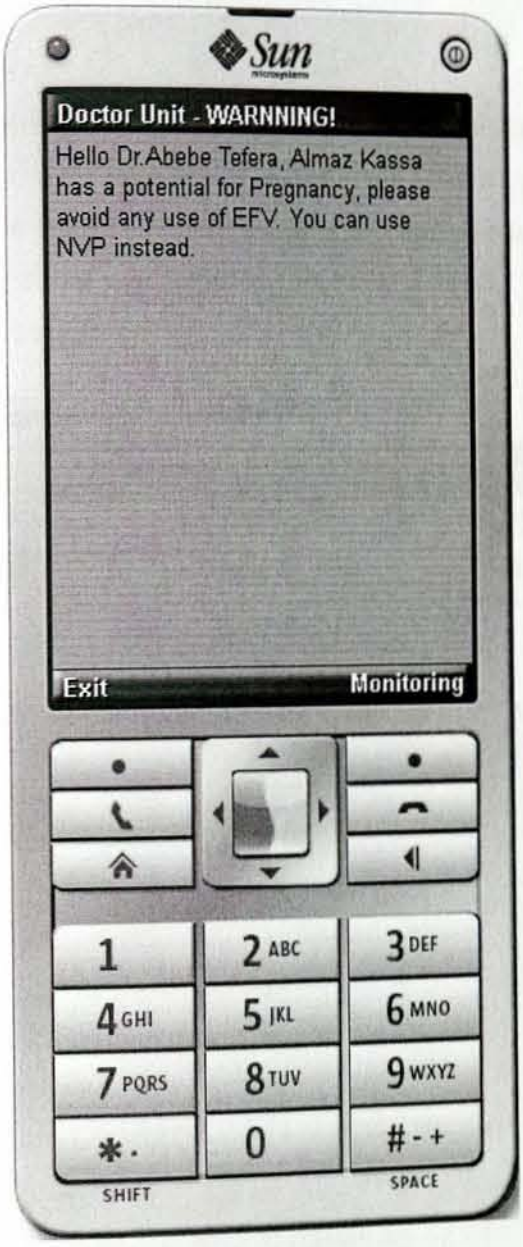

Figure 5.9 Messages to Dr.Abebe reminding the special case of w/ro Almaz

Scenario III

Similarly in the scenario of Kebede, third scenario, the system generates messages to be sent to the doctor since there is co – infection of both HIV and TB as shown in table 5.3. In addition, by the time that the CD4 count of Kebede becomes less than or equal to 350cells/mm^3, it sends a message both to the doctor and Kebede as shown in figure 5.11 and 5.12. The rules for this scenario are presented in figure 5.10.

Table 5.3 Context Processing for scenario III

Context	Final Context	Action
HIV – TB co - infection	Kebede and Dr.Abebe have message to send	Send the right message to the right user
CD4 <= 350cells/mm^3		

```
[ Coinfection_Rule2: (?p rdf:type CAPHC:HIVAIDSPatient)
        (?p rdf:type CAPHC:TBPatient)
        (?p CAPHC:hasStartedART "false"^^xsd:boolean)
        (?d CAPHC:treats ?p)
        (?d CAPHC:hasDevice ?phone)
        (?p CAPHC:hasFullName ?pname)
        (?d CAPHC:hasFullName ?dname)
        strConcat("Hello Dr.",?dname,", ",?pname," has HIV-TB coinfection and
        didn't start ART yet, please initiate ART as soon as possible.",?msg)
        ->(?phone CAPHC:hasMessageToSent ?msg)]

[ ART_Failure_Rule:
    (?p rdf:type CAPHC:HIVAIDSPatient)
    (?p CAPHC:hasStartedART "true"^^xsd:boolean)
    (?p CAPHC:hasPhysiologicalParameter ?param)
    (?param CAPHC:hasParameterName "CD4 Count"^^xsd:string)
```

```
(?param CAPHC:hasValue ?cd4Val)
 le(?cd4Val,350)
 (?d CAPHC:treats ?p)
 (?d CAPHC:hasDevice ?phone)
 (?p CAPHC:hasDevice ?pd)
 (?p CAPHC:hasFullName ?pname)
 (?d CAPHC:hasFullName ?dname)
 strConcat("Hello Dr.",?dname,", The CD4 count of ",?pname," has been detected
 as ",?cd4Val, ",This indicates that the ART medication given might have
  failed; therefore, plasma viral load measurement is required (if affordable) and
  the second line regiment has to be initiated. ",?msgToDoctor)
  strConcat("Your CD4 value is currently ",?cd4Val,". Please meet your doctor as soon
 as possible.",?msgToPatient)

 ->(?phone CAPHC:hasMessageToSent ?msgToDoctor)
 (?pd CAPHC:hasMessageToSent ?msgToPatient)]
```

Figure 5.10 Rules of the third scenario

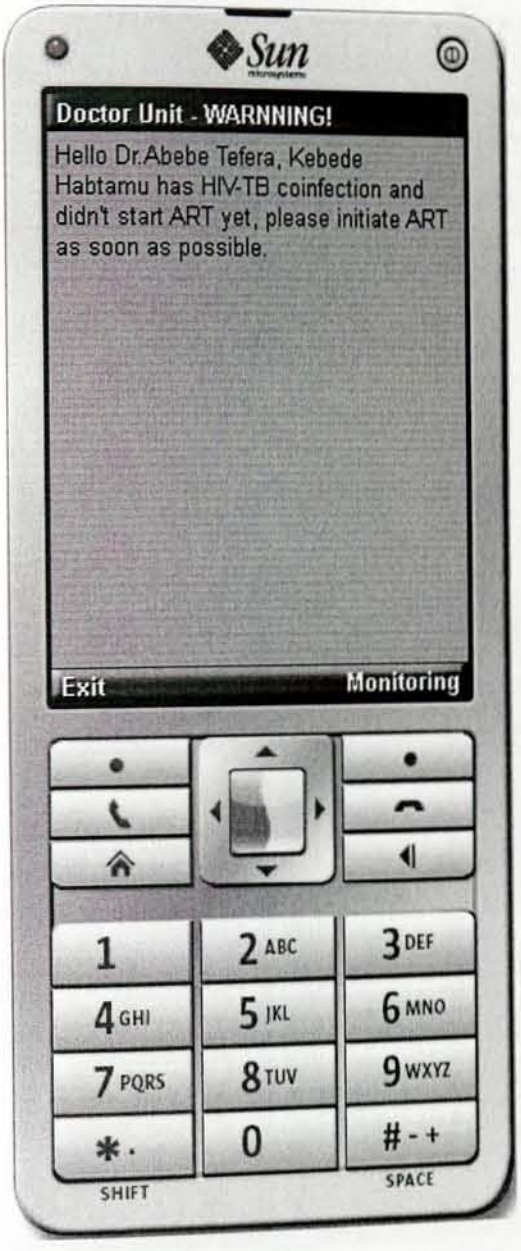

Figure 5.11 Message to the doctor about HIV-TB co – infection of Kebede

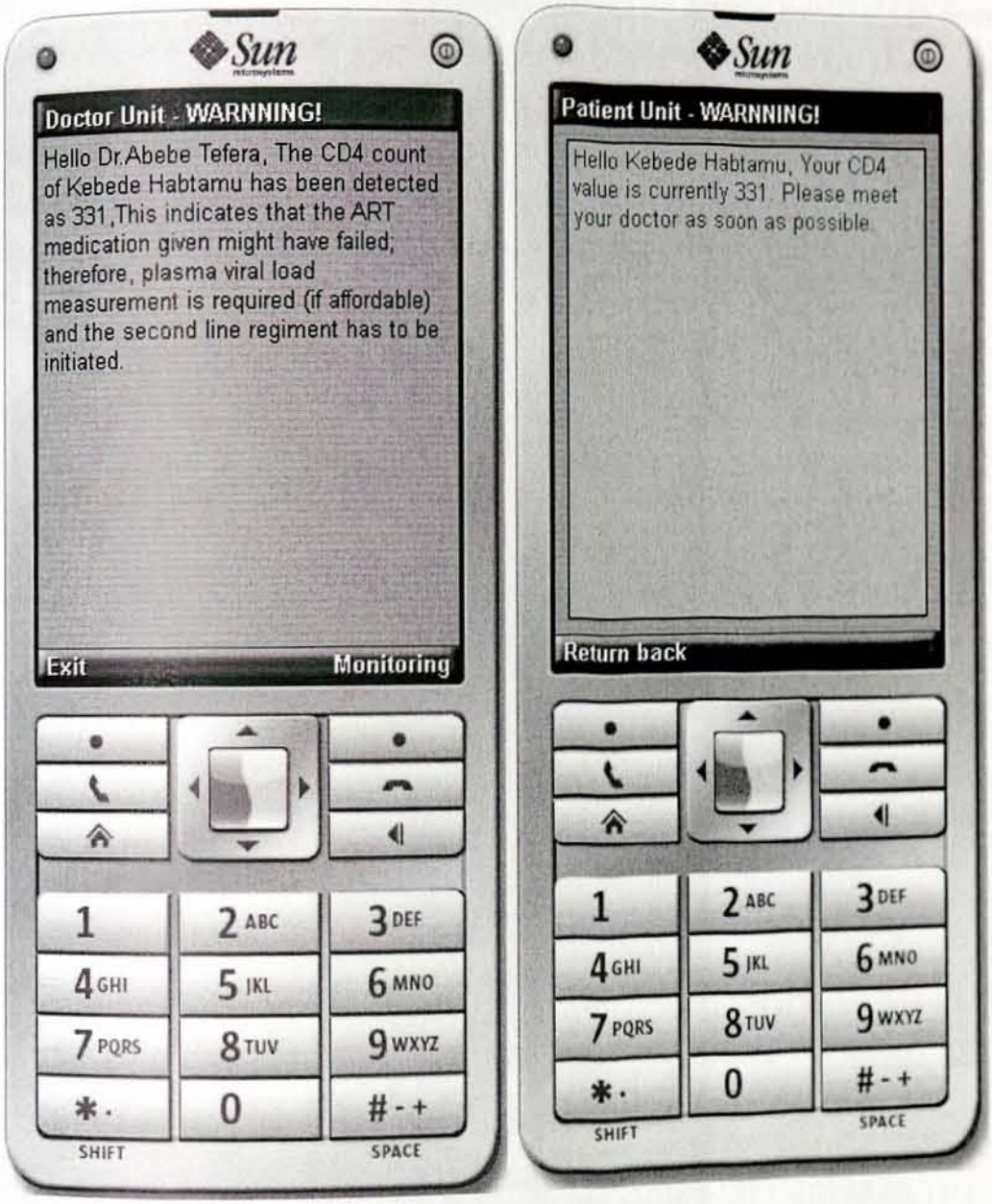

Figure 5.12 Message to the doctor and Kebede about Kebede's CD4 after ART

In addition to these, the system also displays to patients the status of each vital sign parameter periodically via their mobile phone. This service is handled by the Status Display Service component and commonly given to all patients. This makes patients to be conscious about their health status and helps them for better personal self health management. A sample display of status for a given patient is shown in figure 5.13.

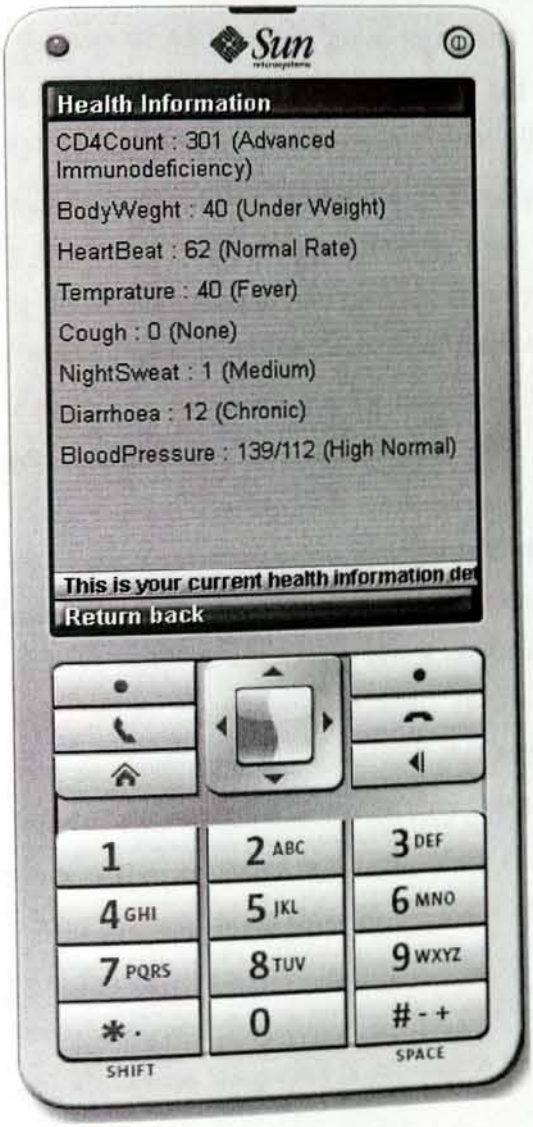

Figure 5.13 Vital Signs Status Display

Chapter Six: Discussion and Conclusion

In the first chapter, when we discuss about our methodology, we have said that we did an observation of ART service delivery mechanism in one hospital – the Black Lion Hospital. We visited the Black Lion hospital in order to observe their service regarding to ART. We were there together with doctors and nurses working on the HIV/AIDS department of the hospital for about 5 days to observe the overall ART service given to victims. We preferred the Black Lion Hospital for it is the largest referral hospital in the country and is part of AAU (Addis Ababa University). We have also prepared a questionnaire to HIV/AIDS professionals and collected detailed information. The questionnaire is attached in this paper as Appendix E. From our observation and the feedback through the questionnaire given by professionals, we have got better understanding about the existing ART service delivery system. Following the same principle, we used medical professionals in the same hospital and evaluated our proposed pervasive healthcare system by comparing it to the existing ART service delivery system. This chapter will also report on the result of the evaluation.

Before going directly to the comparison of the two systems, let's discuss some points that we have obtained from our observation and questionnaire about the existing ART service delivery mechanism in Black Lion Hospital – assuming that a similar approach might be practiced in other hospitals and healthcare centers in the country. In the hospital, patients come to the HIV/AIDS department to check their blood for HIV that may be recommended from other departments of the hospital for example from the TB department. If HIV is found in the blood of these patients, then they will be registered in the department as HIV carrier so that they can get the pre – ART and ART services. From the CD4 cell count and other medical information of patients, the doctors in the department decide to start ART or not. If the CD4 cell count of a patient is below 200cells/mm^3, or if there is HIV – TB or HIV – HBV co – infection they initiate ART for such patients. Otherwise, the patient is not eligible to start ART and will be given the pre – ART follow up service.

For the first case, once the patient has started ART, he/she will be given ARV drugs to be taken for three months. When the patient finishes his/her medicine after three months, then he/she will come again and take the medicine for another three month, which they call ***refilling***. This way the patient will continue taking the drugs from the hospital periodically. In addition, their body weight will be measured each three month. The other important appointment given to such patient is the appointment to check for the CD4 cell count and present to the doctor ***every six month***. In addition, the patient will be strongly advised to come and report to the department if there are any HIV symptoms and pain feelings at any time without any appointment. Based on the CD4 cell count and other pain information reported, the doctor will analyze whether there is ART failure or any drug side effect complexity.

For the second case, i.e. for patients currently not eligible for ART, they will be instructed to come and check their CD4 cell count ***every six month***. Similarly, these patients are also strongly advised to come and report to the department if there are any HIV symptoms and pain complexities at any time. From this information, the doctor decides whether to initiate ART or not based on eligibility criterion to start ART.

6.1. Evaluation

Having this much information about the existing system, let's evaluate the importance of our proposed system over the former. Again for our evaluation work, we have used the scenario of the three patients formulated in the previous chapter. For the case of Ashebir, the system influences him to decide to go to the hospital when some HIV symptoms appear – in this case persistent fever, chronic diarrhea and severe weight loss. In addition, since messages are sent both to Ashebir and his doctor, the doctor may enforce Ashebir to come soon in case he delays. The vital sign status display and the body weight coaching services also makes Ashebir to know about his health condition which helps him to be more alert and active participant for his healthcare than the existing system.

In the second scenario, the system helps the doctor for early ART initiation. In the existing system, persons who are currently not eligible for ART will be requested to come and check for their CD4 cell count every six month. However, in this scenario, we see that the CD4 cell count

of w/ro Almaz reaches to the ART starting value four months before her appointment of CD4 check up. Using our system, the CD4 cell count check up time interval can be scheduled according to the need, for example every 2 weeks or every month based on the patient type. Therefore, by reducing the long time required to get CD4 cell count information (six months) of patients it can improve the quality of the ART service. Another important thing that we can see in this scenario is the reduction of possible medical errors. We have seen that the system reminds Dr.Abebe about the special case of w/ro Almaz that she has a potential for pregnancy. In the ART recommendation presented in the previous chapter, we saw that EFV drug must not be given for women in the first trimester of pregnancy or having a potential for pregnancy. The doctor may forget this condition of Almaz since he recorded this truth two months ago. This way our system can avoid many similar medical errors happening since the ART medication is very complex and specific to a target patient.

In the last scenario (scenario of Kebede), we see the system helping the doctor to identify the criteria for starting ART and early detection of ART failure. It tells the doctor that Kebede has a TB co–infection and must start ART irrespective of his CD4 cell count. It also gives information about what drugs were given to cure his TB infection. This information is very important for the doctor because it is utilized to decide which ART drug option to initiate as this drug option depends on the type of drug given for the TB infection. After initiating ART for Kebede, the doctor detects ART failure via CD4 cell count measurements. According to the existing system, CD4 information is available only each six month which may lead late ART failure detection. However, our system gives CD4 information every time according to the needed schedule. This helps the doctor to recognize any ART failure very early and take the necessary decisions.

We also evaluated the proposed pervasive healthcare system based on the validity of its decision in case of critical conditions. Table 6.1 presents the validity of the decision by comparing it to what doctors will decide with similar information. In this table, we listed around 14 simple critical cases for simplicity. In order to compare the decision of the system with the real decision of doctors, we have prepared a questionnaire and gave to a doctor working on HIV/AIDS department in Black Lion hospital to provide his decision when certain patient conditions appear. We have included the filled questionnaire in Appendix F.

Table 6.1 Evaluating the quality of system's decision

No.	Context (Information)	System's Decision	Doctor's Decision
1	CD4 <= 350cells/mm^3	Must start ART irrespective of disease stage	Must start ART irrespective of disease stage
2	Over 10% of presumed or measured body weight loss	Sever weight loss, and must start ART	Follow the patient and if not because of known problem start ART
3	under 10% of presumed or measured body weight loss	Moderate weight loss, informs the both the patient and the doctor	Follow the patient, see causes for that and investigate further for ART initiation.
4	HIV – TB co – infection	Must start ART irrespective of disease stage and CD4 cell count	Treat TB and initiate ART irrespective of disease stage and CD4 cell count
5	HIV – HBV co – infection	Must start ART irrespective of disease stage and CD4 cell count	Initiate ART irrespective of disease stage and CD4 cell count, good for selection of specific ART
6	Appearance of one or more HIV symptoms of stage three	Must start ART irrespective of CD4 cell count	ART initiation according to WHO if no CD4 cell count awakes
7	Appearance of one or more HIV symptoms of stage four	Must start ART irrespective of CD4 cell count	ART initiation after treating the opportunistic infection
8	CD4 < =350cells/mm^3 after starting ART	Suspect that there may be ART failure	Consider treatment failure, Adherence, then accordingly decide either change, or work on adherence
9	Disease stage three	Must start ART irrespective	Must start ART irrespective of

		of CD4 cell count	CD4 cell count
10	Disease stage four	Must start ART irrespective of CD4 cell count	Must start ART irrespective of CD4 cell count
11	If the patient is in the first trimester of pregnancy and must start ART	Recommend not to initiate EFV	ART must not be EFV based regiment
12	If the patient has a potential for pregnancy and must start ART	Recommend not to initiate EFV	ART must not be EFV based regiment
13	If the patient has a psychiatric illness and must start ART	Recommend not to initiate EFV	Better if ART is not EFV based regiment
14	Appearance of PPE*	Notify the doctor to decide whether to initiate ART or not	Will take his/her own decision whether to initiate ART or not

*** Most physicians would recommend the initiation of ART in the presence of PPEs**

6.2. Conclusion and Future Work

In pervasive computing environments in general, context management is an important key issue of concern. For pervasive healthcare systems specifically, context management needs much more concern because medical context is very sensitive and needs much more care than other contexts for it is about saving life. Therefore, these systems need an excellent context management platform for solving technical healthcare problems in transmission of vital signs, frequency of transmission of vital signs, network communication cost, context refinement, and management of large contexts. In this thesis work, we have proposed our own innovative pervasive healthcare system architecture in response to the above problems. Our contributions regarding these issues through this new proposed architecture are summarized as follows:

- We have identified which vital sign data to transmit to the healthcare unit for HIV/AIDS patients. These include CD4 count, body weight loss, presence of diarrhea, body temperature, blood pressure, coughing, heartbeat and night sweet. Of these vital signs CD4 count and body weight loss have strong impact on the healthcare of HIV/AIDS.
- We preprocess vital signs context data obtained from medical sensors inside the mobile phone of the patient before sending the context data to the healthcare unit to determine the status of each vital sign. Then the mobile phone will only send vital sign data having abnormal status. Therefore, the frequency of transmission of vital signs depends on the status of their value. This shifting of some task of context processing to the mobile side also helps to minimize the communication cost for transmitting vital signs data. In addition, it increases the efficiency of the server in the healthcare unit in context management for it may be crowded with very large volume of patient data.
- We developed a very large hospital ontology which represents very specific concepts in ART service. Even though it is very specific to a particular domain, it is structured from general to specific domains so that one can extend it to include all types of medical services (departments) in a hospital.
- For better context management, we separated the high level schema ontology and the ontology instances as different components. The schema ontology is stored in an OWL/RDF format and the instance data in an ordinary relational database. We used this hybrid context management technique because ontology languages are better to represent and manipulate context knowledge, but very poor to handle retrieval and management of large record data. Inversely, ordinary database management systems are very good in management of large record data, but poor to represent knowledge of all concepts and their relationships in a domain.
- Most of all, we developed a generic architecture for pervasive medical systems that can be applied for other disease types with minor modification. All it needs is to extend the domain ontology and add relevant rules.

In order to prove the concepts that we raised in our system, we have developed a prototype implementation of the system. For demonstration purpose, we have prepared scenarios of three patients representing different patient cases. We have implemented a major number of components that we designed in our pervasive healthcare system. Finally, we presented discussions and evaluations on the system by showing how it really improves the healthcare industry by comparing it to the existing manual healthcare system.

Even though we have designed a promising pervasive healthcare system, we believe that still our system can be enhanced in different aspects. For example, in addition to the vital sign contexts, other contexts can be added to make the system more pervasive like the activity of the patient (doctor), the location of the patient, the educational status of the patient, etc. Such contexts can determine how and when to deliver messages to patients. The other open issue is the privacy and security of patients during transmitting their vital sign information. Finally, due to budget constraints we didn't implement all of the system using real medical sensor devices and deploy it on a smart phone. Therefore, our system can be implemented and deployed using these real devices with minor effort to make it a real and usable system instead of a simulation.

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Appendices

Appendix A: WHO Clinical Staging of HIV Disease in Adults and Adolescents

Clinical stage 1

Asymptomatic

Persistent generalized lymphadenopathy

Clinical stage 2

Moderate unexplained weight loss (under 10% of presumed or measured body weight)

Recurrent respiratory tract infections (sinusitis, tonsillitis, otitis media, pharyngitis)

Herpes zoster

Angular cheilitis

Recurrent oral ulcerations

Papular pruritic eruptions

Seborrhoeic dermatitis

Fungal nail infections

Clinical stage 3

Unexplained severe weight loss (over 10% of presumed or measured body weight)

Unexplained chronic diarrhoea for longer than 1 month

Unexplained persistent fever (intermittent or constant for longer than 1 month)

Persistent oral candidiasis

Oral hairy leukoplakia

Pulmonary tuberculosis

Severe bacterial infections (e.g. pneumonia, empyema, meningitis, pyomyositis, bone or

joint infection, bacteraemia, severe pelvic inflammatory disease)

Acute necrotizing ulcerative stomatitis, gingivitis or periodontitis

Unexplained anaemia (below 8 g/dl), neutropenia (below 0.5 x 109/l) and/or chronic thrombocytopenia (below 50 x 109/l)

Clinical stage 4

HIV wasting syndrome

Pneumocystis jiroveci pneumonia

Recurrent severe bacterial pneumonia

Chronic herpes simplex infection (orolabial, genital or anorectal of more than 1 month's duration or visceral at any site)

Oesophageal candidiasis (or candidiasis of trachea, bronchi or lungs)

Extrapulmonary tuberculosis

Kaposi sarcoma

Cytomegalovirus disease (retinitis or infection of other organs, excluding liver, spleen and lymph nodes)

Central nervous system toxoplasmosis

HIV encephalopathy

Extrapulmonary cryptococcosis including meningitis

Disseminated nontuberculous mycobacteria infection

Progressive multifocal leukoencephalopathy

Chronic cryptosporidiosis

Chronic isosporiasis

Disseminated mycosis (histoplasmosis, coccidiomycosis)

Recurrent septicaemia (including nontyphoidal *Salmonella*)

Lymphoma (cerebral or B cell non-Hodgkin)

Invasive cervical carcinoma

Atypical disseminated leishmaniasis

Symptomatic HIV-associated nephropathy or HIV-associated cardiomyopathy

Appendix B: Part of the code for ContextPreprocessorAndProvider Component

```
public class ContextPreprocessorAndProvider extends TimerTask{

    public final void run(){
        int contextArray [] = receiveContext();
        storeContext(contextArray);
        sendContext();
    }
  public int [] receiveContext(){
    int parameters[];
    parameters = new int[9];
    parameters[0] =  context.cd4Count;
    parameters[1] =  context.bodyWeght;
    parameters[2] =  context.heartBeat;
    parameters[3] =  context.bogyTemprature;
    parameters[4] =  context.cough;
    parameters[5] =  context.nightSweet;
    parameters[6] =  context.diarrhoea;
    parameters[7] =  context.maxBloodPressure;
    parameters[8] =  context.minBloodPressure;
    return  parameters;
  }//end of receiveContext method
public void sendContext(){
    String url = "http://localhost:8080/HealthcareCenter/ContextReceiver";
    HttpConnection httpConn = null;
```

```
DataOutputStream  dos = null;
int rc;
try {
   httpConn = (HttpConnection)Connector.open(url);
   // Set the request method and headers
   httpConn.setRequestMethod(HttpConnection.POST);
   httpConn.setRequestProperty("User-Agent", System.
   getProperty ("microedition.profiles"));
   httpConn.setRequestProperty("Content-Language", "en-US");
   // Getting the output stream may flush the headers
   dos = httpConn.openDataOutputStream();
   //send contexts from contextStore to the server
   //RecordEnumeration re = contextStore.enumerateRecords(null, null, false);
   for(int i = 1; i <= 8; i++){
    String param = new String(contextStore.getRecord(i));
      dos.writeUTF(param);
      //os.flush();          // Optional, getResponseCode will flush
   }
   // Getting the response code will open the connection,
   // send the request, and read the HTTP response headers.
   // The headers are stored until requested.
   rc = httpConn.getResponseCode();
   if (rc != HttpConnection.HTTP_OK) {
      throw new IOException("HTTP response code: " + rc);
   }
```

```
}
catch (ClassCastException e) {
  throw new IllegalArgumentException("Not an HTTP URL");
}
catch (IOException ex) {
 ex.printStackTrace();
}
catch (RecordStoreNotOpenException rsnoe) {
rsnoe.printStackTrace();
}
catch (RecordStoreException rse) {
rse.printStackTrace();
}
finally {
   if (dos != null){
     try {
           dos.close();
   }
     catch (IOException ex) {
       ex.printStackTrace();
       }
   }
   if (httpConn != null){
      try {
           httpConn.close();
```

```
        }
          catch (IOException ex) {
            ex.printStackTrace();
            }
        }
      }
   }//end of method send context
public void storeContext(int []context){
  // code for context preprocess and store
 }
}
```

Appendix C: User defined Rules

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>.
@prefix CAPHC: <http://www.owl-ontologies.com/CAPHC_Ontology.owl#>.
@prefix xsd: <http://www.w3.org/2001/XMLSchema#>.
@include <RDFS>.
@include <OWL>.
[ VitalSign_Rule: (?phone CAPHC:readsPhysiologicalParameter ?param)
                  (?phone CAPHC:hasOwner ?patient)
                  (?patient rdf:type CAPHC:HIVAIDSPatient)

                 ->(?patient CAPHC:hasPhysiologicalParameter ?param)]

[ Coinfection_Rule1: (?p rdf:type CAPHC:HIVAIDSPatient)
                     (?p rdf:type CAPHC:HBVPatient)
                     (?p CAPHC:hasStartedART "false"^^xsd:boolean)
                     (?p CAPHC:hasFullName ?pname)
                     (?d CAPHC:treats ?p)
```

```
                (?d CAPHC:hasDevice ?phone)
                (?d CAPHC:hasFullName ?dname)
                strConcat("Hello Dr.",?dname,", ",?pname," has HIV-HBV coinfection
                and didn't start ART yet. Please initiate ART as soon as possible.",?msg)

                ->(?phone CAPHC:hasMessageToSent ?msg)]

[ Coinfection_Rule2: (?p rdf:type CAPHC:HIVAIDSPatient)
                (?p rdf:type CAPHC:TBPatient)
                (?p CAPHC:hasStartedART "false"^^xsd:boolean)
                (?d CAPHC:treats ?p)
                (?d CAPHC:hasDevice ?phone)
                (?p CAPHC:hasFullName ?pname)
                (?d CAPHC:hasFullName ?dname)
                strConcat("Hello Dr.",?dname,", ",?pname," has HIV-TB coinfection
                and didn't start ART yet, please initiate ART as soon as possible.",?msg)

                ->(?phone CAPHC:hasMessageToSent ?msg)]

[ ARTInitiation_Rule1: (?p rdf:type CAPHC:HIVAIDSPatient)
                (?p CAPHC:hasStartedART "false"^^xsd:boolean)
                (?p CAPHC:hasPhysiologicalParameter ?param)
                (?param CAPHC:hasParameterName "CD4 Count"^^xsd:string)
                (?param CAPHC:hasValue ?cd4Val)
                le(?cd4Val,350)
                (?d CAPHC:treats ?p)
                (?d CAPHC:hasDevice ?phone)
                (?p CAPHC:hasDevice ?pd)
                (?p CAPHC:hasFullName ?pname)
                (?d CAPHC:hasFullName ?dname)
                strConcat("Hello Dr.",?dname,", The CD4 count of ",?pname," has
```

```
                    been detected as ",?cd4Val, ",and didn't start ART yet. Please
                    initiate  ART as soon as possible.",?msgToDoctor)
                    strConcat("Your CD4 value is currently ",?cd4Val,". Please meet
                    your doctor as soon as possible.",?msgToPatient)

                    ->(?phone CAPHC:hasMessageToSent ?msgToDoctor)
                    (?pd CAPHC:hasMessageToSent ?msgToPatient)]

[ ARTInitiation_Rule2: (?p rdf:type CAPHC:HIVAIDSPatient)
            (?p CAPHC:hasStartedART "false"^^xsd:boolean)
            (?p CAPHC:hasWHODiseaseStage CAPHC:Stage_3)
            (?p CAPHC:hasDoctor ?d)
            (?d CAPHC:hasDevice ?phone)
            (?p CAPHC:hasDevice ?pd)
            (?p CAPHC:hasFullName ?pname)
            (?d CAPHC:hasFullName ?dname)
            strConcat("Hello Dr.",?dname,", ",?pname," has WHO disease stage 3,
            please initiate ART irrespective of CD4 count",?msgToDoctor)
            strConcat("Hello",?pname,",", "You have reached disease stage three. Please
            meet your doctor as soon as possible",?msgToPatient)

            ->(?phone CAPHC:hasMessageToSent ?msgToDoctor)
             (?pd CAPHC:hasMessageToSent ?msgToPatient)]

[ ARTInitiation_Rule3: (?p rdf:type CAPHC:HIVAIDSPatient)
            (?p CAPHC:hasStartedART "false"^^xsd:boolean)
            (?p CAPHC:hasWHODiseaseStage CAPHC:Stage_4)
            (?p CAPHC:hasDoctor ?d)
            (?d CAPHC:hasDevice ?phone)
            (?p CAPHC:hasDevice ?pd)
            (?p CAPHC:hasFullName ?pname)
```

```
(?d CAPHC:hasFullName ?dname)
strConcat("Hello Dr.",?dname,", ",?pname," has WHO disease stage four,
please  initiate ART irrespective of CD4 count",?msgToDoctor)
strConcat("Hello",?pname,",", "You have reached disease stage four. Please
meet your doctor as soon as possible",?msgToPatient)

->(?phone CAPHC:hasMessageToSent ?msgToDoctor)
 (?pd CAPHC:hasMessageToSent ?msgToPatient)]

[ BodyWeight_Rule1: (?p rdf:type CAPHC:HIVAIDSPatient)
                    (?p CAPHC:hasPhysiologicalParameter CAPHC:BodyWeight)
                    (CAPHC:BodyWeight CAPHC:hasStatus "Moderate Loss"^^xsd:string)

                    ->(?p CAPHC:hasHIVSymptom CAPHC:Moderate_weight_loss)]

[ BodyWeight_Rule2: (?p rdf:type CAPHC:HIVAIDSPatient)
                    (?p CAPHC:hasPhysiologicalParameter CAPHC:BodyWeight)
                    (CAPHC:BodyWeight CAPHC:hasStatus "Under Weight"^^xsd:string)

                    ->(?p CAPHC:hasHIVSymptom CAPHC:Severe_weight_loss)]

[ BodyTemperature:  (?p rdf:type CAPHC:HIVAIDSPatient)
                    (?p CAPHC:hasPhysiologicalParameter CAPHC:BodyTemprature)
                    (CAPHC:BodyTemprature CAPHC:hasStatus "Fever"^^xsd:string)

                    ->(?p CAPHC:hasHIVSymptom CAPHC:Persistent_fever)]


[ Cough_Rule: (?p rdf:type CAPHC:HIVAIDSPatient)
              (?p CAPHC:hasPhysiologicalParameter CAPHC:Cough)
              (CAPHC:Cough CAPHC:hasStatus "High"^^xsd:string)
```

```
        ->(?p CAPHC:hasHIVSymptom CAPHC:Recurrent_
        bacterial_upper_respiratory_tract_infections)]

[ Diarrhea_Rule:
        (?p rdf:type CAPHC:HIVAIDSPatient)
        (?p CAPHC:hasPhysiologicalParameter CAPHC:Diarrhea)
        (CAPHC:Diarrhea CAPHC:hasStatus "Chronic"^^xsd:string)
        ->(?p CAPHC:hasHIVSymptom CAPHC:Unexplained_Chronic_diarrhoea)]

 [ Pregnancy_Rule:
        (?p rdf:type CAPHC:HIVAIDSPatient)
        (?p CAPHC:hasSpecialCase "First Trimester Pregnant"^^xsd:string)
        (?p CAPHC:hasStartedART "false"^^xsd:boolean)
        (?p CAPHC:hasDoctor ?d)
        (?d CAPHC:hasDevice ?phone)
        (?p CAPHC:hasFullName ?pname)
        (?d CAPHC:hasFullName ?dname)
        strConcat("Hello Dr.",?dname,", ",?pname," is in First Trimester Pregnancy,
        please avoid any use of EFV", ?msg)
        ->(?phone CAPHC:hasMessageToSent ?msg)]

[ Potential_Pregnancy_Rule:
        (?p rdf:type CAPHC:HIVAIDSPatient)
        (?p CAPHC:hasSpecialCase "potential for pregnancy"^^xsd:string)
        (?p CAPHC:hasStartedART "false"^^xsd:boolean)
        (?p CAPHC:hasDoctor ?d)
        (?d CAPHC:hasDevice ?phone)
        (?p CAPHC:hasFullName ?pname)
        (?d CAPHC:hasFullName ?dname)
        strConcat("Hello Dr.",?dname,", ",?pname," has a potential for
```

```
        Pregnancy, please avoid any use of EFV. You can use NVP instead.", ?msg)
        ->(?phone CAPHC:hasMessageToSent ?msg)]

[ Psychiatric_Rule:
        (?p rdf:type CAPHC:HIVAIDSPatient)
        (?p CAPHC:hasSpecialCase "Severe Psychatric illness"^^xsd:string)
        (?p CAPHC:hasStartedART "false"^^xsd:boolean)
        (?p CAPHC:hasDoctor ?d)
        (?d CAPHC:hasDevice ?phone)
        (?p CAPHC:hasFullName ?pname)
        (?d CAPHC:hasFullName ?dname)
        strConcat("Hello Dr.",?dname,", ",?pname," has Severe Psychatric illness,
        please avoid any use of EFV", ?msg)

        ->(?phone CAPHC:hasMessageToSent ?msg)]

[PPE_Rule:
    (?p rdf:type CAPHC:HIVAIDSPatient)
    (?p CAPHC:hasWHODiseaseStage CAPHC:Stage_2)
    (?p CAPHC:hasHIVSymptom CAPHC:PPE)
    (?p CAPHC:hasDoctor ?d)
    (?d CAPHC:hasDevice ?phone)
    (?p CAPHC:hasFullName ?pname)
    (?d CAPHC:hasFullName ?dname)
    strConcat("Hello Dr.",?dname,", ",?pname," has PPE illness, please take your
    own decision whether to initiate ART or not", ?msg)

    ->(?phone CAPHC:hasMessageToSent ?msg)]
```

```
[WHODiseaseStage_1: (?p rdf:type CAPHC:HIVAIDSPatient)
                    (?p CAPHC:hasHIVSymptom CAPHC:PGL)
                    ->(?p CAPHC:hasWHODiseaseStage CAPHC:Stage_1) ]

[WHODiseaseStage_2: (?p rdf:type CAPHC:HIVAIDSPatient)
                    (?p CAPHC:hasHIVSymptom ?s)
                    (?s CAPHC:appearedAtStage CAPHC:Stage_2)
                    ->(?p CAPHC:hasWHODiseaseStage CAPHC:Stage_2)]

[WHODiseaseStage_3: (?p rdf:type CAPHC:HIVAIDSPatient)
                    (?p CAPHC:hasHIVSymptom ?s)
                    (?s CAPHC:appearedAtStage CAPHC:Stage_3)
                    ->(?p CAPHC:hasWHODiseaseStage CAPHC:Stage_3)]

[WHODiseaseStage_4: (?p rdf:type CAPHC:HIVAIDSPatient)
                    (?p CAPHC:hasHIVSymptom ?s)
                    (?s CAPHC:appearedAtStage CAPHC:Stage_4)
                    ->(?p CAPHC:hasWHODiseaseStage CAPHC:Stage_4)]

[ ART_Failure_Rule:
    (?p rdf:type CAPHC:HIVAIDSPatient)
    (?p CAPHC:hasStartedART "true"^^xsd:boolean)
    (?p CAPHC:hasPhysiologicalParameter ?param)
    (?param CAPHC:hasParameterName "CD4 Count"^^xsd:string)
    (?param CAPHC:hasValue ?cd4Val)
    le(?cd4Val,350)
    (?d CAPHC:treats ?p)
    (?d CAPHC:hasDevice ?phone)
    (?p CAPHC:hasDevice ?pd)
    (?p CAPHC:hasFullName ?pname)
```

```
(?d CAPHC:hasFullName ?dname)
strConcat("Hello Dr.",?dname,", The CD4 count of ",?pname," has been detected
as ",?cd4Val, ",This indicates that the ART medication given might have failed;
therefore, plasma viral load measurement is required (if affordable) and the second
line regiment has to be initiated. ",?msgToDoctor)
strConcat("Your CD4 value is currently ",?cd4Val,". Please meet your doctor as soon
as possible.",?msgToPatient)

->(?phone CAPHC:hasMessageToSent ?msgToDoctor)
(?pd CAPHC:hasMessageToSent ?msgToPatient)]
```

Appendix D: Part of the Implementation of the Reasoner Component

```
public class MyReasoner extends Thread{
    public MyReasoner(){
      }
   public void run(){

    ......

    ......

    ......
   // create owl Reasoner
   OntModel schema =  ModelFactory.createOntologyModel
  (OntModelSpec.OWL_MEM_MICRO_RULE_INF, FileManager.get().loadModel
  ("D:\\workspace\\HealthcareCenter\\Ohhh\\CAPHC_Ontology.owl"));

   Model data = FileManager.get().loadModel
   ("D:\\workspace\\HealthcareCenter\\src\\rdfData.txt","RDF/XML");
```

```
Reasoner owlReasoner = ReasonerRegistry.getOWLReasoner();
InfModel owlInfModel  = ModelFactory.createInfModel
(owlReasoner, schema, data);

//Cascading Reasoners
List  rules = Rule.rulesFromURL
("D:\\workspace\\HealthcareCenter\\src\\caphcRules.rules");
GenericRuleReasoner reasoner = new GenericRuleReasoner(rules);
InfModel infModel = ModelFactory.createInfModel(reasoner, owlInfModel);

String queryString = "PREFIX CAPHC:<http:
//www.owl- ontologies.com/CAPHC_Ontology.owl#>"+
                "SELECT ?phone ?message WHERE
                {?phone  CAPHC:hasMessageToSent ?message ." +
                                "}";

Query myQry = QueryFactory.create(queryString) ;
QueryExecution qexec = QueryExecutionFactory.create(myQry,infModel);
ResultSet results = (ResultSet)qexec.execSelect() ;

for ( ; results.hasNext() ; )
    {
    QuerySolution res = results.nextSolution() ;
    RDFNode phone = res.get("phone");
    Resource phoneName = phone.asResource();
    String phoneNo = phoneName.getLocalName();
    String message = res.get("message").toString();
    String msgComb = "/,"+ phoneNo+ "?"+ message;
    .....
    .....
```

.....

}

.....

.....

.....

}//end of MyReasoner

Appendix E: Questionnaire to HIV/AIDS Professionals

1. Can you tell me your responsibility in the hospital?

_____

_____

_____

2. Assume that somebody comes to you to check his/her blood for HIV and sorrowfully, he/she is HIV positive. What do you do next to help this person?

_____

_____

_____

3. Assume that this person is currently not eligible to start HIV medicine. How do you monitor this person whether criteria for staring ART are developed in him/her or not?

_____

_____

_____

4. How do you decide when to start ART and what to start for HIV plus people?

_____

_____

_____

5. What are the common symptoms of HIV/AIDS that you practically experience?

_____

_____

_____

6. How do you follow up a person who has started ART so that you can determine whether there is treatment failure or not?

_____

_____

_____

7. From your practical experience, what are the most common opportunistic infections that frequently affect the health of HIV/AIDS patients?

_____

_____

_____

8. What are the important laboratory tests that you conduct in the process of ART?

_____

_____

_____

9. Do you have enough resources in the hospital to perform the recommended laboratory tests such as CD4 count, CD4 percentage, viral-load, etc for effective treatment?

_____

_____

_____

10. How do you decide, for example on when to start ART, what to start, ART switching and the like, if there is lack of resources to carry out the above laboratory tests?

_____

_____

_____

11. Do you think that the HIV/AIDS patient to professional proportionality is faire? How many patients will be assigned to one professional (doctor, nurse or councilor)?

_____

_____

_____

12. What about the proportionality between number of patients and patients rooms in case of need of hospitalization?

13. Are there any risky behaviors such as alcohol, unsafe sex, chat, illegal drugs, etc. practiced by patients that create problems in ART and facilitate death?

14. How do you council HIV plus people and AIDS patients? How do you contact them? Are you effective?

15. Do you have different professionals, doctors, nurses and psychologists?

Appendix F: Questionnaire to Doctors to know their decision on certain patient conditions

What do you decide during the following conditions of patients

1. When the CD4 cell count of a patient becomes less than or equal to 200cells/mm^3?
   - St. Start on ART
2. If you know that the patient has over 10% of presumed or measured body weight loss?
   - follow the patient and if not b/c of known problem
   - B. Start on ART
3. If you know that the patient has under 10% of presumed or measured body weight loss?
   - follow pt. see causes for that and investigate further for ART initiation
4. When there is HIV – TB co – infection?
   - Treat TB and soon to start ART if eligible
5. When there is HIV – HBV co – infection?
   - good for selection of specific ART (TDF based regimen is 1st line)
   - watch for hepatotoxicity
6. When HIV symptoms of disease stage three start to Appear?
   - ART initiation actually to switch if no CD4 count available
7. When HIV symptoms of disease stage four start to Appear?
   - ART initiation after ready of ART
8. When the CD4 cell count of a patient becomes less than or equal to 200cells/mm^3 after starting ART?
   - Consider treatment failure, Adherence, then accordingly decide either change, or work on Adherence
9. When the disease stage of the patient becomes stage three?
   - Start ART

1

10. When the disease stage of the patient becomes stage four?

ART initiation.

11. What special ART drug is not initiated if the patient is in the following conditions and must start ART?

- First trimester of pregnancy Not EFV based
- Has a potential for pregnancy Not EFV based regimen
- Has a psychiatric illness better if not EFV based regimen
- Appearance of PPE NVP may confuse with NVP toxicity preferred if not there.

Declaration

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in any other university, and that all source of materials used for the thesis have been duly acknowledged.

Declared by:

Name: Alemitu Mequanint

Signature: AM

Date: 18/11/2011

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Name: Dejene Ejigu (PhD)

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Place and date of submission: Addis Ababa, November, 2011.