MOBILE CLOUD FOR AIDING AND HARD-WEARING HEALTHCARE

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Abstract— **Deploying state-of-the-art technologies is vital and inevitable in assistive healthcare to cope with emerging services such as remote monitoring, collaborative consultation, and electronic health record. Grid computing has succeeded somewhat in enabling the sharing of resources across organizations but has not been deployed widely due to its complex implementation and interface. Cloud computing overcomes this aspect by allowing simple and easy user access, coping with users' dynamic and elastic demands, providing metered usage for its resources and hence is increasingly being adopted by individual users as well as enterprise users. The Cloud may just be the right technology for healthcare infrastructure. However, several serious issues concerning security, data protection and ownership, quality of services, and mobility need to be resolved before Cloud computing can be widely adopted.. This paper proposes Mobile Cloud for Assistive Healthcare (MoCAsH) as an infrastructure for assistive healthcare. Besides inheriting the advantages of Cloud computing, MoCAsH embraces important concepts of mobile sensing, active sensor records, and collaborative planning by deploying intelligent mobile agents, context-aware middleware, and collaborative protocol for efficient resource sharing and planning. MoCAsH addresses security and privacy issues by deploying selective and federated P2P Cloud to protect data, preserve data ownership and strengthen aspects of security. It also addresses various quality-of-service issues concerning critical responses and energy consumption.**

Keywords- mobile computing; context-aware; cloud computing; healthcare; federate cloud

I. INTRODUCTION

The integration of healthcare with the Internet and mobile technologies has led to increased accessibility to healthcare providers, more efficient processes and higher quality of healthcare services [1,2]. With the advance of Information Technology, current healthcare systems are being transformed from traditional scenario that requires manual care and monitoring to more advanced scenario where patients can be automatically monitored and fast emergency response can be provided by deploying latest mobile sensing technologies, wireless sensor networks, and sophisticated back-end emergency processing centres. Our previous research [3,4] concentrated on providing a robust solution for monitoring non-intrusively the health conditions of elder or pregnant women through a collaborative sensor Grid infrastructure with wireless sensor networks, active databases. Our research also reveals some weaknesses with Grid-based infrastructures in dealing with end-users interactively and meeting emerging requirements:

- *Deployment difficulty*. Grid technology [5] "exposes too much detail of the underlying implementation, thus making the application development more complex, difficult interoperability and scaling".
- *Network selection limitation.* It is difficult to switch automatically between networks from when the user moves from one network to another. Services offered by different networks may not be compatible.
- *Power limitation of mobile devices.* Mobile devices have to operate with very limited power supply and yet the quality of care has to be maintained.
- *Context-sensitive data and applications*. Physiological data of the same person varies with different activities, different places and ages. It also varies with different people. For example, when a person is sleeping, eating and moving, the variation of physiological index shows a different frequency comparing to normal state when the person is at rest. Data received from personal body sensors with such short- or long-term variations may trigger as false alarm. Emerging applications must be context-sensitive and must satisfy different behaviour profiles based on each person's profile database index.

Cloud computing allows simple and easy user access, handles users' dynamic and elastic demands effectively, and provides convenient metered usage for its resources and hence it is increasingly being adopted by individual users as well as enterprise users. It may just be the right technology for healthcare infrastructure. However, several serious issues concerning security, data protection and ownership, quality of services, and mobility need to be resolved before Cloud computing can be widely adopted. To address these concerns, this paper proposes a new solution that includes a cloud platform designed to deal with those issues that are relevant for an assistive healthcare infrastructure. Within this assistive health infrastructure, the cloud platform offers a high level abstraction and its services can be accessed easily with simple web interface to the users. The new solution includes mechanisms for early detection of networks and network auto-switch function to ensure a ubiquitous computing, which can guarantee a wireless consistent connectivity with back-end processing centre for a high QoS (quality of service). To address the power limitation issue, the new solution includes mechanisms for controlling the energy consumption while maintaining the quality of care. Possible approaches include auto-switch network and algorithm to efficiently control monitoring interval. The new solution will emphasize on data contexts and context-sensitive applications to deal with deviations in physiological state variations. More importantly, MoCAsH adopts a federated Cloud model to address aspects of data ownership, protection and privacy.

The rest of the paper is organised as follows. Section II describes related works in healthcare system, cloud computing and context-aware technology. Section III presents our infrastructure and the overall system architecture design from sensors and mobile agents, intelligent mobile cloud middleware, cloud computing platform based on Grid infrastructure, to cloud portal. Section IV concludes the paper with discussion on future work.

II. RELATED WORK

With the advance of IT technology, modern healthcare has driven significant development of distributed systems that can deal with smarter environments, adapt to specific context, and respond to critical events. This section describes recent researches in emerging healthcare systems.

Smart Home systems such as the University of Virginia's AlarmNet system [6], the University of Rochester's Smart Medical Home [7], the Georgia Tech's Aware Home [8], and the University of Washington's Assisted Cognition project [9] focus on context-aware wireless sensor networks for monitoring and context-aware computing to provide an environment and system for health and residential activity monitoring. AlarmNet supports extensible heterogeneous network middleware with novel context-aware protocols to implement a pervasive healthcare environment with smart power management to ensure long term medical monitoring and continual maintenance. Smart Medical Home collects personal health data and presents it to health professionals. Aware Home is a living laboratory that can monitor itself and the activities of its inhabitants. Assisted Cognition deploys artificial intelligent techniques in clinical research for patient care.

[10] presented a context-aware architecture that offered delivery of multiparty services in heterogeneous and mobile environments. This model enabled quick-dynamic network switch according to current network conditions to guarantee a successful content delivery for multimedia streaming in a heterogeneous network.

[11] offered an efficient context-aware system to reduce energy consumption in mobile devices. The researchers designed a testing battery consumption architecture supported by Nokia Energy Profiler tool to analyse the battery consumption based on different sensor configuration and background. With the testing architecture, context-aware approaches are used to determine and optimise energy consumption at different levels.

Overseer [12] is a mobile context-aware appliance from Carnegie Mellon University. Overseer is a collaboration and task management system for disaster response. The system includes a dedicated centralized disaster response engine distributed amongst diverse mobile agents, which reside in portable mobile device sensors and operate in heterogeneous environments.

All the above systems can be considered as context-aware, real-time responsive, energy-saving and smart. However, they lack features that are essential for a robust healthcare system: demand/resource scalability, load balancing and distributed architecture. These systems are all based on centralized management which does not scale well in heavy loads and distributed environments. Our research focuses on relevant features of cloud computing infrastructure with intelligent management and how to deploy them to achieve elasticity, scalability and load balance in the assistive healthcare environment.

Research in cloud computing has increased rapidly over the last few years due to its inherent benefits: rapid service delivery and increased IT efficiencies [13]. Other benefits cloud computing include: reducing IT management cost, reducing the complexity of performing tasks, efficient use of provisioned resources, increasing service accessibility, allowing simpler devices, flexibility, enabling multidisciplinary collaboration**.**

Research on mobile cloud computing for remote monitoring and management has also increased. Several related researches are described in order. [14] developed a mobile web service mediation framework (MWSMF) in cloud infrastructure to provide a load balancing solution by demonstrating an elastic cloud platform that meets the dynamic load requirements of a mobile enterprise application. This framework used the enterprise service bus (ESB) technology to provide QoS and discovery analysis. SmartUM [15], developed by Seoul National University Korea, is a ubiquitous cloud middleware for ubiquitous city. It used cloud computing platform to control remote devices with heterogeneous sensors intelligently. The system possesses a context-awareness intelligence based on domain ontology. [16] proposed a patient's data collection system in healthcare institutions based on cloud computing solutions which delivered the medical information to the cloud for storage, processing, and distribution. These systems are still evolving, but they only provides direct support for single user or single organization access, and typically have a high cost to integrate computing, data, or network transfers from outside of the cloud, especially the mobile portion of the overall system.

Our new infrastructure grows out of our earlier "Active wireless-grid infrastructure for assistive health care" but addresses the limitations of Grid with new Cloud features, and incorporating new innovative technologies such as intelligent context-aware behaviour analysis for dynamically monitoring health condition for individual patients, and introducing federated mobile cloud infrastructure with configurable cloud platform as the back-end. The new infrastructure retains its distributed nature and focuses on demand/resource scalability, load balancing, and context-aware management for adaptability, energy-saving and fast response.

III. SYSTEM ARCHITECTURE DESIGN

The proposed Mobile Cloud for Assistive Healthcare (MoCAsH) retains the three important concepts of the Active wireless-grid infrastructure for assistive health care: mobile sensing and actuating; active health records; and collaborative protocol [4]. However, the proposed MoCAsH relies on intelligent mobile agents and context-aware sensor records in its context middleware component for adaptive monitoring and power/resource-saving. It introduces novel protocols for extending existing Cloud to handle device mobility and network selectivity. MoCAsH also addresses the limitations of Grid infrastructure by deploying best-suited Cloud features for resource/demand scalability and user accessibility. MoCAsH suggests a federated P2P cloud model to address aspects of data protection, ownership and privacy.

The overall proposed new infrastructure consists of four main components (Fig.1): 1) sensors and mobile agents, 2) intelligent context-aware mobile cloud middleware, 3) collaborative cloud computing platform, and 4) a Cloud portal. The "active record" concept is taken care of by the intelligent context-aware mobile cloud middleware which processes and manages its local environment based on learned contexts. This component also provides interfaces for communication and management of users, mobile agents, and the collaborative cloud. The Cloud portal is intentionally distinct from other component so that users can independently make use of the services of the Cloud and/or manage the services of the Mobile Cloud Middleware and its environment.

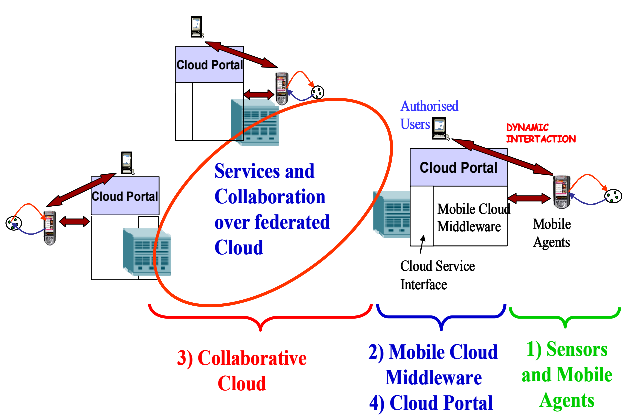

Figure 1: Infrastructure for Assistive Healthcare Cloud

The Collaborative Cloud component provides not only software services, platform services, and infrastructure services but also a collaborative layer for users' collaboration.

A. *Sensors and mobile agents*

This component is responsible for data sensing/ collecting and managing its sensors wireless sensors networks (WSNs). Collected data are then streamed from mobile devices directly or multi-hop through the Wi-Fi or other wireless network to the intelligent context-aware mobile middleware for further analysis, storage, and processing. The mobile devices mediate interaction between WSN and back-end intelligent cloud platform. Our new mobile mediation platform will turn to the latest open-source Google Android 2.2 OS. Comparing with other mobile platforms such as Symbian S60, windows mobile, iPhone and J2ME, Google Android OS is well-suited for our assistive healthcare system. Currently, the newest version of android OS is 2.2 [17] offers exclusive features such as: 1) open platform, support java development 2) use of the highly efficient Delvik Virtual Machine, 3) support embedded database SQLite for data storage 4) support various connectivity technologies including WiMAX, GSM/EDGE, CDMA, Bluetooth, and Wi-Fi etc. 5) open-source WebKit layout engine and Chrome's V8 JavaScript engine in web browser, 6) excellent sensor and hardware support including GPS, accelerometers, magnetometers, accelerated 2D bit blits and accelerated 3D graphic. 7) Multitasking support and new cloud to device messaging framework (C2DM), two-ways push sync functionality. Android phones have been released in the past years by Google corporation that have proved successful, increasing manufacturers are committing to it.

In our system, mobile devices will not keep a consistent session connection with mobile cloud middleware unless some vital signals detected and specific context changed or offloading condition met. Simple healthcare analysis will be directly processed in the mobile component. Thus the mobile cloud computing middleware actually can be divided into two parts: client and cloud side with an intelligent monitoring module installed in a mobile phone to build up a session connection with cloud side's middleware. Fig.2 shows the data flow diagram of this component.

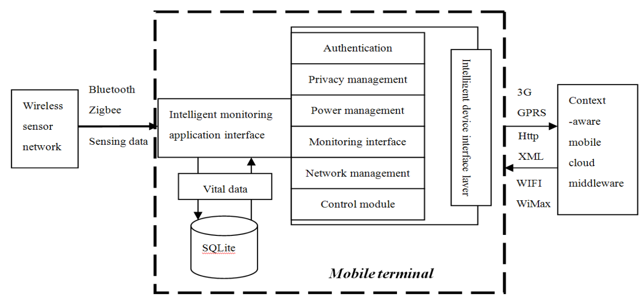

Figure 2: Sensor and mobile sensing data flow diagram

Mobile devices have always been constrained by their limited battery power supply, small size and computing capability. To maximize the utilization ratio, we adopt the following features in our platform.

- *Asynchronous message mode (AMM)*

The communication between mobile terminals to mobile cloud middleware occurs in an asynchronous message mode (AMM). Comparing to synchronous mode, AMM enables a mobile application to send a request to the cloud server, then goes on operating asynchronously until a response is received from the server by a push mechanism. During the waiting period, the mobile device is able to run at full capacity.

- *Push mechanism*

Push mechanism in network communication is more efficient approach than polling periodically to fetch latest data from the cloud server to update user physiological profiles, discovering new services or receiving an alarm notification. With push mechanism our application is able to operate in the background to save energy and is wakened up via an Intent broadcast when needed.

- *Disconnection management*

Disconnection is an inherent property of mobile computing as we can not guarantee a continuous connection with internet service for an entire session. The key technology to manage such disruption and achieve persistent operation is to relocate relevant data through embedded database storage which is SQLite in the Android system and cache processing. Once network coverage appears, the application will immediately transfer to online pattern to resume its operation.

- *Quality of Service*

We are exploring several approaches for providing fast response and minimizing the energy consumption of a sensor network application. REST rather than SOAP web services are considered over Http as the underlying Http protocol as they are lightweight, accessible via URIs, and provide much better performance in terms of smaller message size and faster response time [18,19]. These translate to less processing and transmission time and hence lower power consumption and faster web services in mobile devices. Message compression is also considered to efficiently improve the energy consumption in mobile platform without compromising the QoS of mobile web services. BinXML, a light-weight XML compression mechanism, will be used to reduce the size of message of some service by approximately 30%. For security mobile web service at this level, AES (Advanced Encryption Standard) symmetric encryption, however, to minimize the delay and processing performance, encryption will only be processed in some specific parts of a message which have high security requirements.

B. The context-aware mobile cloud middleware

In MoCAsH, *context-aware computing* is based on a capability to dynamically capture and utilize contextual information from mobile devices involving user profiles, session quality, network condition, and environment like temperature, humidity, sound, GPS location, etc. [20, 21]. It allows various forms of dynamic adaptation of services based on changed context through back-end intelligent that facilitates data analysis, context recognition, dynamic updates and critical event triggering. Our context awareness module includes a self-learning component to enable flexible and adaptive monitoring which varies with patients' profiles. The context-aware computing layer will implement the following functions：

- *Intelligent monitored data analysis*

The collected data could come from heterogeneous network with diverse sensor nodes (e.g., ECG, body temperature, pulse, motion, and time) and environments (e.g., body sensors, room, wheelchairs). Raw data will be pre-processed through data conditioning modules to provide quality data in terms of validity, noise-free, reliable, and scalability [22]. The data will be analysed and self-learned for appropriate context through an intelligent learning model and new learning result will be updated to their context repositories. The system is thus dynamic and able to adapt to different situations based on their recognised contexts.

- *Network auto-switch*

Our system will be able to support mobile monitoring. In order to guarantee QoS of the monitoring, a frequent network latency test (metrics average response time) will be carried out between clients and servers. Once the test result indicates that the current network can not maintain a specified monitoring QoS due to limitations of network coverage or network quality, the cloud side will push a command to mobile terminals to search for other available networks. A new session configuration will be initiated with new mobile and cloud server addresses. If no network coverage is possible, the cloud would notify the mobile terminal to turn to offline pattern. When network coverage becomes available, the mobile client reconnects the cloud service for continuous monitoring.

- *Energy consumption management*

Energy consumption of a WSN application can be minimized at different levels according to the Hierarchical Energy Driven Architecture (HEDA) [23]. Depending on the monitored environment (coverage, topology, routing methods) and the objectives of the application (events to be sensed, degree of emergency, etc.), context data can be used to initiate different measures to minimize the energy consumption of the intended application at the device level, the communication level, or the collaborative level. For example, when the patient is sleeping which can be detected by context data of time, motion, and pulse, the cloud may notify mobile terminals to slow down the monitoring interval and reduce some unnecessary context data to be transferred. Wireless communication is energy-consuming with transferred data size, frequency, and computing intensity all affects the level of power consumption. This function will provide appropriate and dynamic configuration and management of dissipated power.

This middleware layer builds a communication bridge between the data acquisition layer and the back-end cloud computing. It is a major entity that performs context-aware power management, online intelligent analysis of sensing data, feed-back behaviour profiles, emergency activation, and dynamic allocation for back-end cloud resources. The upper layer mobile terminal firstly requires establishing a session connection to obtain relevant access authority, user profile and security mechanism. Enterprise service bus (ESB) technology [24], which communicates in asynchronous message infrastructure model, provides fundamental services for complex architecture via an event-driven and standards-based messaging-engine. This approach has the primary advantage of reducing the number of point-to-point connections that are necessary for mobile computing data communication. After a connection is established with the relevant cloud service, the context-aware computing layer will begin to take charge of the monitoring job.

Fig. 3 shows the overall context-aware component of our proposed architecture. Each type of context data can be identified by a specific [ID. values] array. The measured data from various sensors are transformed by the *context-converter* into context data to be processed by a *context-analyser.* The *Context-analyser* classifies the defined data and delivers them to responsible modules, simultaneously, relevant context rules are loaded from a *context repository* which stores dynamic rule files, context information, context resource, etc. The *Context-analyser* then preliminarily analyses these new context data according to the predefined rules in repository. The inference system in the *Context-analyser* has several subcomponents, some are for health analysis and others are for network QoS and application-power management. Diverse contexts are processed by different subcomponents through context IDs. In a normal situation, if the sensed context matches the rules in context repository, the *context analyser* will directly send the inferred context to the context broker, which is used to allocate service request IDs and deliver them to the cloud service interface. Otherwise, if an emerging condition is detected, the context repository should be updated through self-adaptation learning. New learned rules and ontology instance will be dynamically updated from the context manager and the new user profile and medical records will be also updated from cloud healthcare database to the context repository.

Cloud service interface layer serves as the cloud service entrance. Mobile terminals and healthcare cloud portal need to access this layer to communicate with back-end cloud computing resources. A high-priority service request can be processed in advance if its ID matches a service ID in the service repository. The resource manager will then allocate specific virtual execution resources in the virtual resource layer to execute the task. These virtual execution resources are normally the isolated environments where customer applications are executed, maintained and provided by underlying physical resources. A service can consists of one or several virtual execution resources and its number can be dynamically changed during the lifetime of the service.

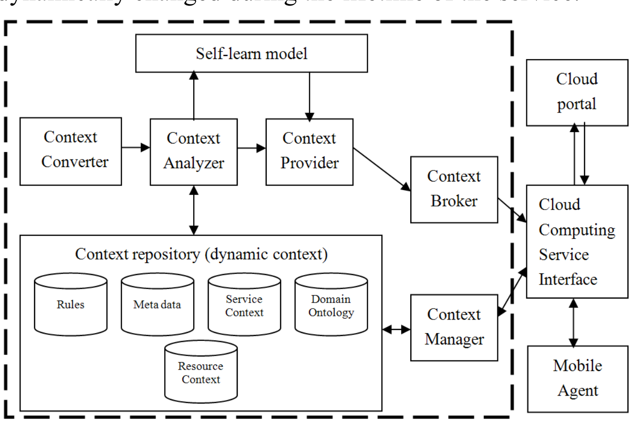

Figure 3: Context aware layer of mobile cloud middleware

C. *The Cloud computing component*

More and more enterprises and projects begin to establish applications based on cloud infrastructures. From the perspective of business, cloud computing federates utility computing to make its computational and storage resources as a metered service just like traditional public utility (such as electricity, water or natural gas). From the perspective of a delivery model, cloud typically offers three representational service types which are Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS) respectively. These diverse delivery models enable cloud to offer different services for satisfying different requirement of customers. Cloud infrastructure is usually based on a unified computing architecture and this core structure contributes to ease of deployment, performance, management, and security of virtual environments. Traditional servers hosting in a data centre are separated into service units. The servers are independent of each other, once peak-load occurs the number of specific servers may have be to increased to enhance the capability of the service. Cisco introduces the cloud unified computing system (UCS) [25] that is designed to provide a physical environment which unites compute, network, storage access, and virtualization into a cohesive system in a unified management domain. Under cloud unified computing system, all services can provide uniform support for hypervisors across all the servers. Thereby, the virtual resource pool can be moved dynamically on demand from idle server to peak-load server, the idle server also can be shut down to reduce the energy consumption and the total costs.

To further address the issues of scalability, load balancing, security and privacy in cloud, we propose a federate cloud layer to schedule distributed clouds according to user security and resource requirements. Normally, a federate cloud may consist of many UCSs in a single data centre or many connected data centres. The important issue is how to federate them seamlessly and efficiently. Fig.4 depicts a federate cloud model. At the top of this federation, a Mainscheduler will be responsible for the management of all virtual organizations in whole cloud environment. Subschedulers are only responsible their own site. An election is needed to choose the Mainscheduler among all subschedulers depending on their estimated capacity degree. The position of mainscheduler is thus dynamic. The schedulers should obtain instantaneous workload information to demonstrate their capacity degree thereby dynamically allocate virtual resources. The schedulers communicate with a P2P topology which is self organized for the flexibility. New schedulers may join or leave dynamically. Policy measures will be enforced to guarantee the quality of service of the whole system. Private clouds can be federated and/or partially federated with public clouds. Security and privacy of crucial data can be protected with proper policies concerning and restricting the ownership and the movement of data within the federated cloud.

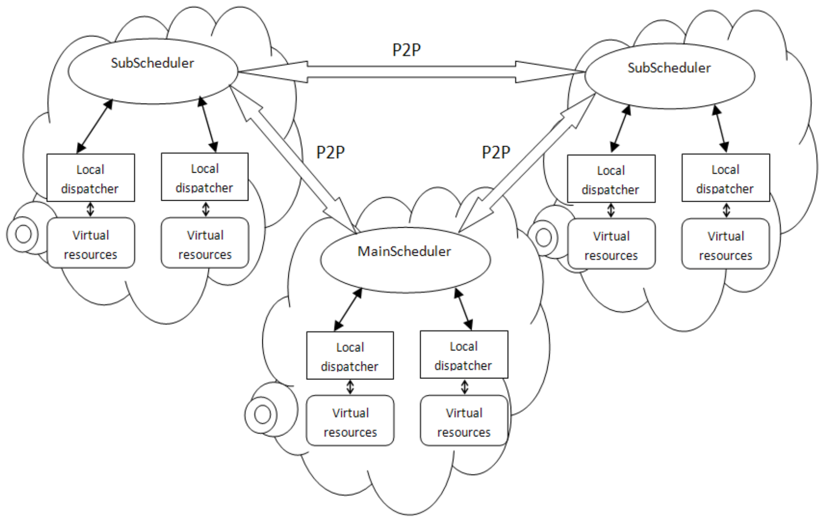

Figure 4: Federate cloud model with P2P topology

Currently, there are several public clouds on the market, one example is the Amazon EC2-S3 [26] system which provides underlying physical resource as a service, and users are allowed full control from the kernel to the entire software stack. We are experimenting with the Amazon cloud platform helps select a suitable operating system and deploying our mobile cloud middleware on Amazon hardware resources. As the Amazon EC2-S3 is compatible with other cloud system, for example, Eucalyptus [27] and OpenNebula [28], secure and private cloud systems can be established and deployed. For healthcare applications, the secure and private issues are critical as medical records and private information must be secured and protected. These issues must be addressed before Cloud computing can be accepted. Public clouds alone cannot provide adequate solutions. Initially, we deploy our existing Grid infrastructure to establish a private cloud computing platform.

Fig.5 shows the cloud architecture based on Grid infrastructure. This cloud architecture of cloud utilizes Service Oriented Architecture (SOA), Utility computing, and Grid computing technologies to implement higher-abstractions, available and flexible and accessible capabilities and services. The available solution from Nimbus toolkits [29] is such an instance. As an open resource tool it integrates clusters into an IaaS cloud. It uses Globus Grid computing toolkit 4.0 to achieve task dispatching, scheduling, load balancing, usage accounting and QoS/security management.

Specific capabilities of current Grid systems are used to implement a number of core functionalities of our cloud system including [30]: 1) System management and monitoring 2) Authorization/ authentication/ accounting 3) Resource virtualization (compute, data, communication) 4) Scalability, fail safety, QoS, SLA 5) Physical distributed system infrastructure. However, a Cloud portal will be

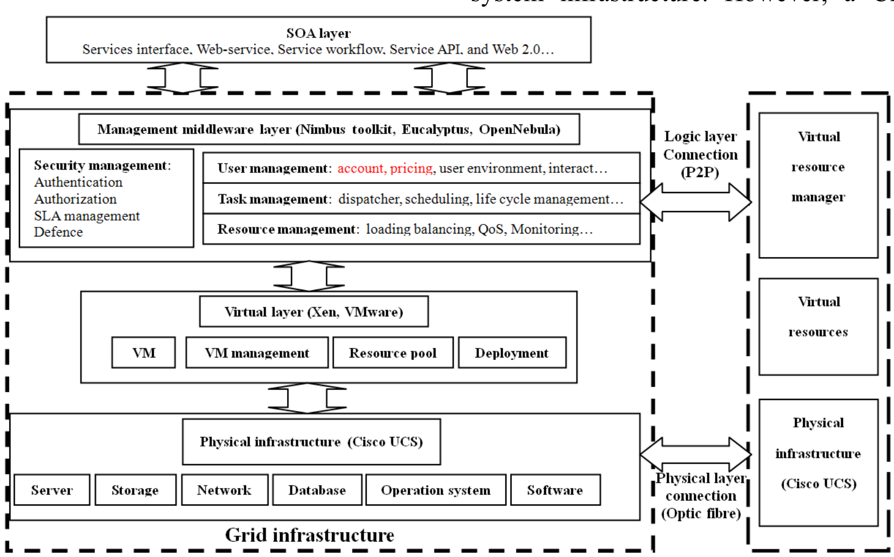

Figure 5: Cloud computing architecture based on Grid infrastructure

developed to enable easy access to the users.

D. The Cloud Portal

The Cloud Portal is one of the deciding factors as the success of the whole system depends heavily on the ease with which users can access offered services. Through the cloud portal authorized users can observe remote sensors status and data, control remote mobile devices, update context-aware rules, reconfigure emergency scenario, and tailor other useful operations. The portal resembles a website back-end management centre which connects to back-end cloud platform, only authorized users are able to access it. Furthermore, in healthcare systems, patients' data is sensitive and its privacy has to be protected. Measures, often policy-driven must be implemented to handle this issue based on application, environment, and user contexts. For example, when the context-aware module detects serious anomalous behaviour that may affect the life of patients, sensible decision must be made that may compromise the patient's privacy as a nurse or a doctor requires immediately authority to access the "private" data to provide appropriate emergency response. In addition, the Cloud Portal needs to incorporate mechanisms to these and many other issues effectively.

IV. CONCLUSION AND FUTURE RESEARCH

This paper proposes a Mobile Cloud for Assistive Healthcare infrastructure. The infrastructure addresses the limitations of our earlier Active Grid infrastructure, deploys Cloud computing features such as user easy access, elasticity of resources demands, scalability of infrastructure, and metered usage and accounting of resources. The new infrastructure also addresses a number of issues with current Cloud architecture including some security and privacy issues, data protection and ownership. P2P paradigm is deployed to federate clouds that may belong to different administrators to address security, data protection and ownership. Part of the infrastructure has been implemented or migrated from the Active Grid. The first version of the mobile platform was implemented with J2ME on Nokia phones; the platform is being migrated to an Android platform. Part of the intelligent Mobile Cloud Middleware was implemented within an active database. In the next version, part of the middleware will reside in the mobile platform to handle local issues efficiently in terms of speedy response and energy minimization. Part of the component will reside in the Cloud Middleware component to provide rich context analysis, recognition and decision support. A collaborative workflow editor has been developed over the existing Grid, it will be deployed in the newly Cloud infrastructure.

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