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A Grid-Based Framework for Pervasive Healthcare Using Wireless Sensor Networks: A Case for Developing Nations

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Abstract: The advent of new emerging technologies such as ubiquitous mobile computing, telemedicine, Internet, grid computing, embedded systems and wireless sensor networks (WSN) offers great potentials to radically alter the existing modes of healthcare administration and delivery in developing nation. The phenomenon of 'standalone hospitals' and a healthcare service delivery paradigm that always require a physical one-on-one contact between the patient and the medical expert even for cases of simple diagnosis, needs to be radically altered. In this study, we present the design of a national healthcare grid infrastructure, based on a novel integration of wireless sensor networks and wireless grid computing, for the purpose of inter-hospital collaboration and pervasive real-time monitoring of healthcare patients. This holds the promise of improving the nature of healthcare delivery services in developing nations.

Key words: Wireless grid computing, wireless sensor networks, real-time monitoring, healthcare delivery

INTRODUCTION

The mortality rate in the less developed parts of the world is undoubtedly very high. In Africa for example, the prevalent incidences of war, epidemic of diseases and general poverty has been responsible for the untimely death of many. Also particularly disturbing is the high number of sudden death scenarios that are recorded yearly among patients with critical health conditions and elderly people. This category includes patients with cardio-vascular diseases, hypertension (high blood pressure), diabetes, asthma and cancer (Lo *et al*., 2002).

Although, the sudden death phenomenon is not just limited to Africa, it is particularly disturbing that Africa seems to be among the few remaining regions of the world where a solution approach is yet to be found. For example, it has been discovered that cardio-vascular disease is responsible for about 39% of all death in the United Kingdom each year. In response to this bugging problem, research into the application of wireless sensor networks as a solution approach is being actively pursued (Lo *et al*., 2002). Generally, there is a growing relevance of wireless sensor networks to medical applications globally.

A wireless sensor network (WSN) is a computer network consisting of spatially distributed autonomous device using sensors to cooperatively monitor physical or environmental conditions such as temperature, sound, vibration, pressure, motion or pollutants at different locations. The extremely small size of sensors, low power requirement and data processing ability make them suitable for medical applications (Chong and Kumar, 2003).

A grid is essentially an interconnection of several infrastructures that enable mutual sharing of resources for the attainment of set goals or objectives. Typical examples of a grid include Power Grid, Data Grid, Compute Grid, Science Grid and Bio Grid. The conceptualization of a Health Grid is based on the aggregation and integration of available healthcare infrastructures and resources that are available in disparate locations for the purpose of effective rendering of healthcare services. A National Healthcare Grid (NHcG) is therefore conceptualized as an aggregation and integration of all available hardware, software and human resources that are dedicated to the rendering of healthcare services. This is considered particularly needful in the context of many developing nations where most of the health institutions exist and operate in isolation ('Stand Alone Hospitals') with little or no active collaboration with other health institutions. Also, the general dearth of adequate expertise, equipments and infrastructures in many of these health institutions further compels the need for the implementation of NHcG that can provide a platform for poorly equipped hospitals to leverage on more advanced facilities that exist in better equipped health institutions that are members of the NHcG. The NHcG is an IT driven

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operational framework that will facilitate resource sharing, expertise networking and research and service collaboration in virtual space among various institutions. This is with the central goal of rendering generally improved healthcare services and pervasive real-time monitoring of healthcare patients.

There are a number of approaches to pervasive health monitoring that have been reported in literature. The Electronic Cardiogram (ECG) Holter monitoring is one of the most widely used means for providing ambulatory cardiac monitoring for capturing rhythm disturbance (Standing *et al.*, 2001). Also being actively engaged for the purpose of real-time health monitoring are wearable wireless sensor networks. These have been used for monitoring cardiac patients with some measure of success. The cardioNet (Ross, 2004) is a remote heart monitoring system that allows the transmission of ECG signals to remotely located server through PDA. MIThril is a system that allows ECG data, GPS position, skin temperature and galvic skin response to be captured by a PDA (Pentland, 2004). The design of a Body Sensor Network (BSN) was proposed in (Standing *et al.*, 2001). BSN is a class of physiological sensors that can be physically domiciled in patient's body without any harmful after effects (Lo *et al.*, 2002).

MATERIALS AND METHODS

Overview of wireless sensor networks: A sensor is typically a device or system that can measure and respond to physical or chemical quantities. It has the capacity to detect and process signals. A sensor can be a control or processing electronics, software or an interconnection network. Therefore, a sensor network is composed of a large number of sensor nodes that are densely developed for a purpose either to monitor space, things or interaction among things and space.

A WSN is constituted of low cost, lower and multi-functional sensor nodes that are small sized and communicate in short distances. A WSN is essentially a wireless ad hoc network in which the communication links are wireless and each node is willing to forward data to other nodes, but the determination of which node to forward data is made dynamically (in ad hoc manner). This makes it different from traditional wireless technology where the nodes to forward data are pre-designated. The development of WSN just like many other technological inventions originated from the military, based on the need for battlefield surveillance. As at today, the application of WSN has extended into many other areas such as healthcare, home automation, environment monitoring, traffic control and many more.

Wireless sensor networks integrates a wide range of information technology that spans hardware, systems software wireless networking and embedded systems programming technologies. A sensors node in a wireless sensor network consist of a microprocessor, data storage, sensors (for sensing), analog-to-digital converter (ADC), a data transceiver, controllers that tie the pieces together and an energy source (battery) Fig. 1.

Features of WSN: Generally, the essential features and characteristics of wireless sensor networks include the following (Lewis, 2004).

Self-Organizing capabilities: WSN are able to spontaneously create ad hoc networks, assemble the network themselves and dynamically adapt to incidences of device failure, degradation, manage the mobility of sensor nodes and react to changes in task and network.

Cooperative processing: Nodes in ad hoc sensor network are able to collaborate and process data to generate useful information.

Data processing capabilities: They can use their processing attributes to carry out local computations and transmit only the required and partially transformed data.

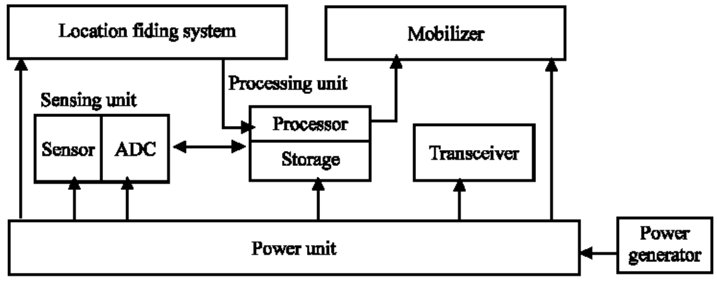

Fig. 1: Components of a Sensor node (Akyildiz *et al.*, 2002)

Table 1: WSN Vs Wireless Networks (WiFi)

	Number of nodes in Network	Mode of deployment	Performance of nodes	Topology	Mode of signal transmission	Node power capability	Node addressing
WSN	Several order of magnitude more than WiFi networks	Densely deployed in specific locations	Prone to failure very often	Not fixed, constantly changing	Broadcast transmission	Limited computational capabilities	No global identification IP addressing
WiFi Nets	Rela atively much fewer number of nodes	Distinct nodes	Relatively more reliable	Fixed and predetermined	Point-to-point transmission	Relatively enormous processing capability	IP addressing available for all nodes.

Limited power: Sensor nodes require very little power to function and can retain little.

Harsh environmental conditions: WSN can be successfully deployed in harsh environmental conditions with no human support and still perform excellently well (e.g. by the military for surveillance in enemy territory).

Node failures: WSN nodes are prone to failure and performance degradation but this may not necessarily impair the whole networks as long as there are sufficient number of nodes that are working.

Dynamic network topology: There is no fixed network topology like ring, star, bus, mesh etc. in a WSN. This is because of its dynamic ad hoc nature of node interconnectivity.

Large scale deployment: Nodes in WSN are usually densely deployed (i.e. like thousands of sensor nodes in a particular vicinity).

Mobility of nodes: Sensor nodes because of their very light weights can also be moved form from one location to another and this does not impair their functionality.

Operational autonomy: Sensor in WSN can function unattended by human control.

Heterogeneity of nodes: Sensor nodes in WSN do not have to be of exactly the same make, power or processing capacity. The important thing is that they are able to do a measure of partial independent data processing and forward data to the next available node.

Table 1 shows the differences between WSN and Traditional Wireless Networks (WiFi-based networks).

Applications of WSN: The application of WSN can be broadly categorized into three according to Culler *et al.* (2004), these are:

Monitoring space: environmental and habitat monitoring, precision agriculture, climate control, surveillance, treaty verification and intelligent alarms.

Monitoring things: structural monitoring, eco-physiology, condition-based equipment maintenance, medical diagnostics and urban terrain mapping.

Monitoring interaction of things with each other and the encompassing space: Wildlife habitats, disaster management, emergency response, ubiquitous computing environment, asset tracking, healthcare and manufacturing process flow.

Classification of WSN: Classification of WSN can be achieved based on a number of varied parameters such as mode of signal transmission and detection, mode of application or nature of the composition of sensor nodes. Some of the most common types include Multi-hop Sensor Networks, Unpartitioned Homogenous Sensor Networks, Heterogenous Sensor Networks and Visual Sensor Networks.

Overview of grid computing: Grid computing can be defined as a computing paradigm for collaborative problem solving within a virtual organization facilitated through coordinated resource sharing and the rendering of mutual non-trivial services (Daramola and Ayo, 2007). A Computational grid is a hardware and software infrastructure that provides dependable, consistent, pervasive and inexpensive access to high-end computational capabilities. It is concerned with the coordinated resource sharing and problem solving in dynamic, multi-institutional virtual organization (Foster *et al.*, 2002; Meliksetian *et al.*, 2004; Jacob *et al.*, 2005). Also, according to Daramola and Ayo (2007), grid computing was defined as flexible, secure, coordinated resource sharing among dynamic collections of individuals, institutions and resources.

The core characteristics of a grid system include resource sharing from the grid resource pool, availability of resource brokering strategies, security and access control, a set of protocols and sharing rules and the existence of a virtual organization. The other significant attributes of a grid are the coordination of resources that are not subject to centralized control; the use of standard, open, general-purpose protocols and interfaces; and the delivery of non-trivial quality of service.

The capabilities of a computational grid in terms of its advantages include the fact that it facilitates: the exploitation of underutilized resources; the engagement of parallel CPU capacities for parallel computations which can result in significant speed ups; collaboration and interoperability of different virtual organizations making available their heterogeneous resources; access to other specialized devices apart from computers, such as telescopes, cameras and other kinds of embedded systems; provides healthy resource balancing through optimal job prioritization and job scheduling; boost reliability of services and overall management of resources.

The architecture of a computational grid: A basic grid architecture consist of: Grid Security Infrastructure (GSI) (which is responsible for authentication, single sign-on, delegation through proxy certificates and other security interfaces); Grid Resource Allocation Manager (GRAM) (that handles resource allocation and job management and file I/O staging provided by the Global Access to Secondary Storage (GASS) interface); Monitoring and Discovery Services (MDS) (that provides information services, it is composed of a Grid Resource Information Service (GRIS) at each resource and of one or more information aggregation services referred to as Grid Index Information Services (GIIS)); Grid File Transfer Protocol (GridFTP) (which together with the Replica Location Service (RLS) is responsible for File-transfer and File-replica management) (Jacob *et al*., 2005).

The topology of a computational grid: The topology of a computational grid is largely dependent on the nature of requirements that exist within a virtual organization and the nature of such virtual organization. The main grid topologies according to Joseph *et al*. (2004) are:

Infragrid (Cluster): This usually comprised of a few machines and homogenous systems (running the same kind of operating system). The machines (nodes) also exist within a department of an organization and may not require much policy or security concerns. They do not normally include scheduling concerns.

Intragrid: This is comprised of heterogeneous systems (not having the same operating system) that have more resources available for sharing. An Intragrid will have scheduling concerns and so normally includes some scheduling components, while file sharing may be accomplished through networked file systems. The nodes in the grid may include those for multiple departments but within the same organization.

Intergrid: This consists of heterogeneous systems from different organizations forming a virtual family. An Intragrid has more concerns for policy of coordinated sharing, security and scheduling; indeed security is a major concern. It has dedicated grid machines that may be added to increase the quality of service for grid computing, rather than depending entirely on scavenged resources. Also dedicated communication links may have to be provided between the organizations such VPN tunneling or other technologies to connect the different parts of the organizations. The intergrid offers the prospect of trading or brokering resources over a much wider audience, which makes it an ideal tool for virtual collaboration in global context.

Grid technologies can also be classified based on the networking platform as wired (traditional) and wireless (mobile) grid. The wireless grid is the special realization of grid computing via wireless networking (Lo *et al*., 2002).

Wireless grid computing: Wireless grid computing (also known as mobile grid) is a new type of resource-sharing network that connects sensors, mobile phones and other edge devices with each other and with wired grids (McKnight *et al*., 2003). It extends the sharing potential of grid computing to mobile, nomadic or fixed devices temporarily connected via ad hoc wireless networks, such that users can come and go in a dynamic wireless grid, interacting with a changing landscape of information resources. The wireless grid is indeed a collision of two technologies grid computing and wireless networking.

Wireless grid computing becomes very promising because it offers new opportunities and possibilities for ubiquitous computing. It enables the integration of new resources such as cameras, microphones, GPS receivers, accelerometers, Cell, radio, WiFi, Bluetooth and other kind of embedded systems to the traditional grid computing. It also offers new places and new institutional ownership and control patterns and extends grid computing to wider variety of applications (Lo *et al*., 2002). Wireless grid applications can be classified into three main categories, which are: Applications aggregating information from the range of input/output interfaces found in nomadic devices; applications leveraging the locations and contexts in which the devices exist; and applications leveraging the mesh network capabilities of groups of nomadic devices (McKnight *et al*., 2004). At the moment, wireless grid computing finds it dominant application in such fields as: Health Systems, Multi-media Processing, e-Business Systems and Global Positioning Systems. Figure 2 shows a typical configuration of a wireless grid environment consisting Computers, Personal Digital Assistants (PDA), Mobile phones, Mobile Grid Gateway and other collaborating devices.

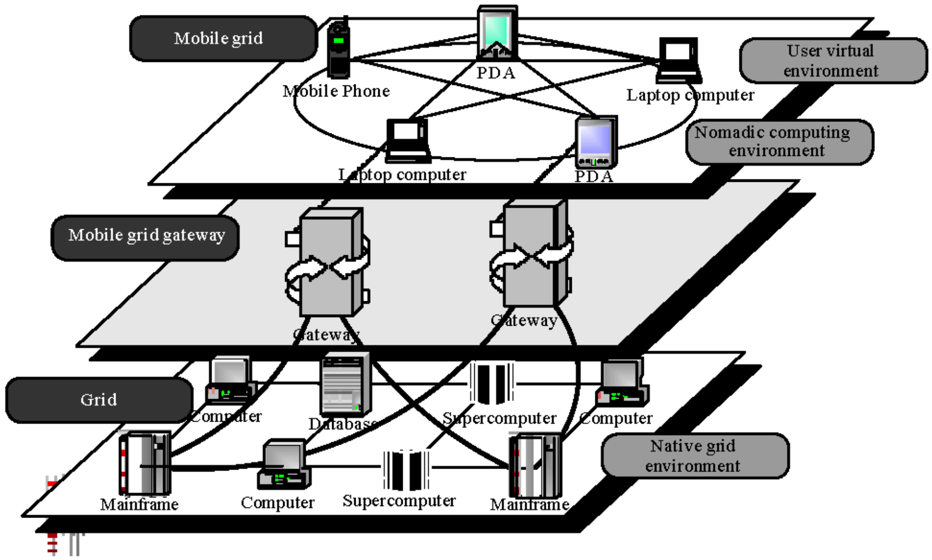

Fig. 2: Wireless/Mobile Grid Environment (Kyung, 2002)

Review of some notable grid projects: Some of the famous grid computing projects that have been reported around the world include the following:

Access grid: The Access Grid® is an ensemble of resources including multimedia large-format displays, presentation and interactive environments and interfaces to Grid middleware and to visualization environments the Access Grid (AG) is used for large-scale distributed meetings, collaborative work sessions, seminars, lectures, tutorials and training.

The GriPhyN: The GriPhyN Project is an ongoing development of grid technologies for scientific and engineering projects that must collect and analyze distributed, petabyte-scale datasets. GriPhyN research will enable the development of Petascale Virtual Data Grids (PVDGs) through its Virtual Data Toolkit (http://www.griphyn.org).

The OGCE collaboration: Develops JSR 168-compatible portlets and Web services for building Web portals for science gateways (http://www.globusalliance.org).

TeraGrid: The TeraGrid is an open scientific discovery infrastructure combining leadership class resources at nine partner sites to create an integrated, persistent computational resource. TeraGrid is the world's largest, most comprehensive distributed cyberinfrastructure for open scientific research. TeraGrid is coordinated through the Grid Infrastructure Group (GIG) at the University of Chicago, working in partnership with the Resource Provider sites: Indiana University, Oak Ridge National Laboratory, National Center for Supercomputing Applications, Pittsburgh Supercomputing Center, Purdue University, San Diego Supercomputer Center, Texas Advanced Computing Center, University of Chicago/Argonne National Laboratory and the National Center for Atmospheric Research. The integrated resources include more than 102 teraflops of computing capability and more than 15 petabytes (quadrillions of bytes) of online and archival data storage with rapid access and retrieval over high-performance networks. Through the TeraGrid, researchers can access over 100 discipline-specific databases (http://www.teragrid.com).

The open science grid: Is a US grid computing infrastructure that supports scientific computing via an open collaboration of science researchers, software developers and computing, storage and network providers (http: //www.globusalliance.org).

The National Healthcare Grid (NHcG) framework: The National Healthcare Grid (NHcG) provides an infrastructural framework for pervasive and real-time monitoring of healthcare patients leveraging active collaboration among several health institutions. This will be realized through the application of several collaborating technologies such as wireless sensor networks, computer networking wireless grid computing, Internet and mobile telecommunication technology (Gaynor *et al.*, 2004). A schematic view of the NHcG model architecture is shown in Fig. 3.

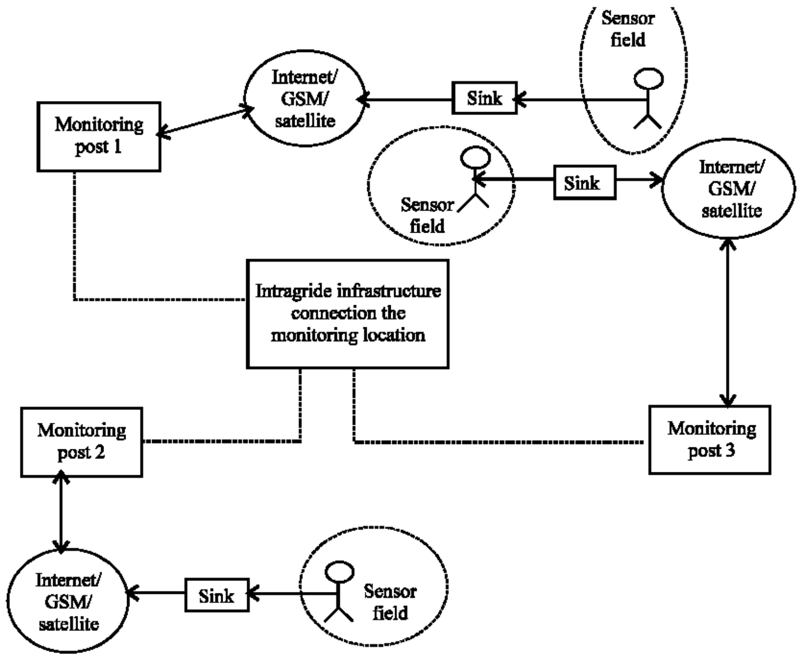

Fig. 3: Schematic View of the NHcG Architecture

Description of the NHcG architecture: The NHcG is comprised of a framework for real-time monitoring of health care patients and an intergrid of collaborating virtual organization, in the diverse health institutions. The focal points in the architecture are described as follows:

Monitoring locations: Each of the monitoring locations in Fig. 2 corresponds to a particular hospital that has implemented pervasive real-time monitoring of patients using wireless sensor networks. This can be achieved by making patients with critical health condition such as cancer, diabetes, hypertension and other forms of cardiovascular diseases to put on wearable wireless sensors or have biosensors inserted into them. These kinds of sensor networks have the capacity for continuous monitoring of patient's vital signs and analysis of physiological parameters, as well as context aware sensing through global positioning systems to locate the specific location of a patient per time. Therefore it becomes possible for the medical experts to monitor patients from remote locations and recommend appropriate healthcare procedure in case of an impending emergency, thereby forestalling sudden episodes. Thus, the real-time monitoring could be from a remotely located patients' database server, a doctor's PDA, mobile phone or laptop.

The intragrid: This is a wireless grid infrastructure connecting the collaborating health institutions. It ensures that information about patients, data and other available resources at the various disparate locations can be shared for the purpose of improved health care delivery. Some the services that will be made available via the Intragrid will include:

Messaging and emergency alert service: It possible for messages and emergency alerts to be sent from one location to another on the grid. For example, in case of an emergency situation concerning a patient when outside his primary domain, an emergency alert can be sent from the monitoring location to the nearest available hospital on the grid to his current location. Thus the patient can get necessary attention and ambulatory services.

Referrals and collaboration: The professional and expertise profile of all medical personnel can be made available on the grid, which makes it possible for a remotely located medical practitioner to have knowledge of the location and identity of other experts in particular fields. This will ensure that the patients are directed to the right personnel and hospitals when referrals are to be made.

Resource sharing: Rare and expensive hardware resources available on the grid can be accessed by less endowed institutions in distant locations apart from the domain where they are physically located. This ensures that remotely located telescopes, X-ray machines computers and cameras can be engaged for local tasks.

Outsourcing services: Jobs that lie outside the immediate capacity of a particular health institution possibly be due to tightness of schedule or lack of adequate manpower or equipment can be outsourced to other collaborating health institutions on the grid.

Data transfer services: Various forms of data and information exchange can take place among remotely located institutions through the Intragrid platform. This can also be achieved within a prescribed acceptable level of security and privacy.

RESULTS AND DISCUSSION

Implementation requirements for the NhcG: The implementation of the NHcG will require the integration of several collaborating technologies namely: wireless sensor networks, internet, grid computing, wireless grid computing, software engineering and embedded systems programming. These requirements have been broadly classified as Hardware and Software as follows:

Hardware:

- Wireless sensor networks (WSN).
- Internet connectivity.
- LAN (Wired networking).
- Wireless Ad hoc networking.
- Computers, PDAs, Laptops.
- Mobile Grid gateways.
- Routers.
- Sensor nodes.

Software:

- WSN operating System (TinyOS, eCos, realtime, MNATIS etc.).
- Programming languages for WSN like nesC, galsC, SNACK etc.
- WSN Simulators such as TOSSIM, ns-2.
- Globus toolkit (for Grid software development).
- Database Management System such as ORACLE, DB2, SQL Server.

Benefits of NhcG: Some of the potential benefits inherent in the existence of a National Healthcare Grid are listed as follows:

Leveraging existing healthcare infrastructures: Scares medical facilities that can only be found in few health institutions can be made available to other institution that lack such, without incurring additional cost of procurement. This especially relates to equipment that can accept and process data electronically.

Ubiquitous healthcare delivery: The existence of a national healthcare grid will facilitate quick and effective of healthcare delivery to patients everywhere and every time. Patients can access the nearest health institutions for health care services and enjoy the quality health service irrespective of location. Important information about patients like such patient's case file can be transferred via the grid.

Accurate inventory of available expertise: The profile of all medical experts in the various fields becomes available on the grid and this will facilitate accurate and effective referrals. This can also be useful for national planning. It becomes possible to run queries that can generate list of experts in specific fields, places where some particular equipment are available etc.

Improved research collaborations: The interaction and cross-fertilization of ideas can be greatly enhanced through virtual collaboration and resource sharing made available by the existence of the NHGIS.

CONCLUSION

The implementation of national grid infrastructure such as NHcG as presented in this paper, offers enormous potential benefits especially in the context of a developing nation. This will also be a technological emulation of what obtains in many parts of the developed world, where leveraging on existence of technological grids has become a standard practice. Examples include the Korean Grid (http://www.gridcenter.or.kr/), the Asian Pacific Grid (http://www.apgrid.org/) and the Japanese Science Grid (Muira,2006).

The advantages of the NHcG will be particularly felt in the area of reduction in instances of sudden death of patients with critical health condition through pervasive real-time monitoring and general improvement in quality and mode of health care delivery.

As an immediate next step, we intend to implement the concepts presented in this paper on a small scale among a limited number of health institutions in Ota area of Ogun State, Nigeria.

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