Reachability in Telemedicine: Concepts, Design and Engineering

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***Abstract*—** *In a developing society such as Nigeria, hospital consultants are not available in good enough ratio. The result of which is that one consultant may be engaged in up to ten hospitals within the metropolis and therefore unable to rotate his services effectively in order to attend patients in emergency situations. In advanced nations, technology has come to aid further the availability of immediate attention in emergencies. Thus for medical facilities such as ours, rooted in traditional methods, there is urgent need to avail the best in technology to maximise medical care and productivity. This can be achieved through evolutions in GSM, Personal Area Network, within the framework of Telemedicine.*

***Keywords*—** MANET, WPAN, WWAN, WLAN, VPN, Intranet, Video Streaming, IPSec.

I. INTRODUCTION

Fig. 1 Distant doctor in consultation

Telemedicine may be defined as health care at a distance, Fig. 1, through the medium of telecommunications [1]. It contrasts with traditional medicine where the patient seeks attention through appointments and consultations in outpatient's department. Moreover, in serious cases, the patient may require very frequent observations and monitoring, thus an admission into a hospital.

Medical services are hardly ever in enough provision, even in developed countries. The advent of telemedicine, through advances in computer technology, has been most welcome. Emergencies such as epidemics and field situations are now amenable to accommodation in health care planning, through mobile hospitals. Furthermore, constraints in care to due to limited number of experts and even bed capacity of a hospital can be overcome through technology. One can then be an in-patient within the convenience of his home, attended to by consultants and nurses in remote locations.

Telemedicine answers the yearnings of many in developing nations for improvement in health care delivery. The impact would be far reaching indeed and so the focus of this proposal is how the benefits can be extended to local hospitals in Nigeria. The optimal use of any technology rests on adaptation and customization. Telemedicine is broadly in two categories, namely Synchronous and Asynchronous models [2]. While synchronous model is real time consultation involving complex hardware and technology, the latter is based on Store and Forward approach that allows lab tests and images to be sent online and in return over the interval, prescription recommendations.

Off-the-shelve solutions designed for a particular country or environment may prove unsuitable in a different country. In fact, history is replete with abandoned turn-key systems of such nature and for any success therefore, an adaptation or customisation would be essential. This would depend on a good study of health care in the region of interest in order to identify the key challenges for a modelling solution.

II. NIGERIAN MODEL

Health care in Nigeria is typified by shortage of medical experts, and in addition, inadequate number of standard hospitals. With a rapidly growing population, the projection is not encouraging. Any specialist help must be sought from any of the major cities in and around the country or abroad. That leaves the bulk of the population largely in desperate situation, a race against time whenever a critical condition develops in rural areas.

The challenge of a typical consultant is that, in addition to his residency, he is often required in up to ten hospitals within and outside the metropolis.

As a result, he is unable to revolve his services effectively in order to attend to patients in emergencies, such that after surgery delays could occur in follow up actions. Not surprisingly too, many consultants encounter fatigue in trying to cope with overwhelming workload. The result is that judgements maybe fraught with haste, which in the circumstances may lead to undesirable outcome.

Besides shortage of consultants, in many private hospitals available staff is minimal, confined as it is to within the resources of management. So often, it is the case that while on duty, and attending to a particular emergency, it could be hours before the doctor or nurse is able to investigate other patients in declining condition.

It would be safe in the foregoing, to state that the key challenge facing health care in Nigeria is shortage of medical expert. Furthermore, that where medical consultancy is available, the scope of service is further undercut by excess workload. Were there means through which the consultant can perform in parallel and patients can reach him as when needed, the state of health care would vastly improve.

III. PROJECT

The immediate answer to underlying constrains in health care rests on design and implementation of a reachability network. It brings with it, real time availability and thus a relief to current restrictions.

Reachability has a footing in the subject of Graph Theory [3]. The concepts of path matrix and connectivity can be represented in a graph diagram.

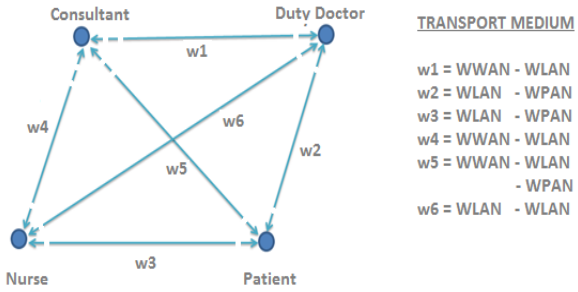

Fig. 2 Reachability Graph

Referring to Fig. 2, Reachability Diagram, the key actors in the network are represented as nodes. These are the patient, the consultant, the nurse and resident doctor, while the design allows connectivity between any pair. Data originates from one node and ends at another but the modes of transport are not the same. To explain this fact, the edges are labelled accordingly.

Wireless computer networks are classified depending on scope [4], [5]. WLAN stands for wireless local area networks, providing Wi-Fi hotspots and etc. It is an ideal configuration for hospital management. WPAN defines a network around a person and is of choice in configuring devices for monitoring a patient. WWAN is an acronym for Wireless Wide Area Network and is a GSM network. From the foregoing therefore, the path of data between the consultant and the patient involve three transport mediums, WWAN – WLAN – WPAN and vice versa. The whole configuration is a hybrid network, mainly in the category of MANETS, Mobile Ad-Hoc Networks [6]. It is an evolving technology and in its embryo, integration and improvisation is the main challenge to realisation.

IV. MODEL

Engineering is concerned with implementing the design. A starting point therefore is how to translate the reachability graph into a practical reality. The answer lies in a field diagram as illustrated below, in Fig. 3. The two towns, Lokoja and Enugu, are respectively the base of consultants to university clinic. The resident doctor is as shown, operating from duty post or from home outside the coverage of intranet. This is a representation of a model in operation. However, the processes to realization would be in various phases of development.

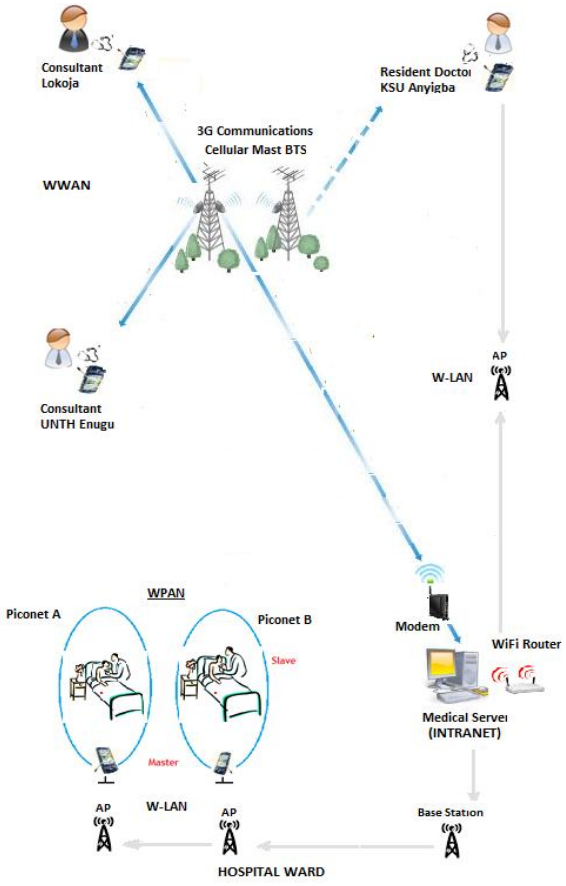

Fig. 3 Reachability Diagram

A. Intranet

A central provision is for an automated system for administration in form of a Hospital Information System, Fig 4. By way of hardware, it requires high performance servers to provide INTRANET, offering Wi-Fi services and hosting of hospital records, and e-administration. In addition, full complements of communication infrastructure, including modems and routers, and a set of tablet devices to serve as slates for patient's card are essential.

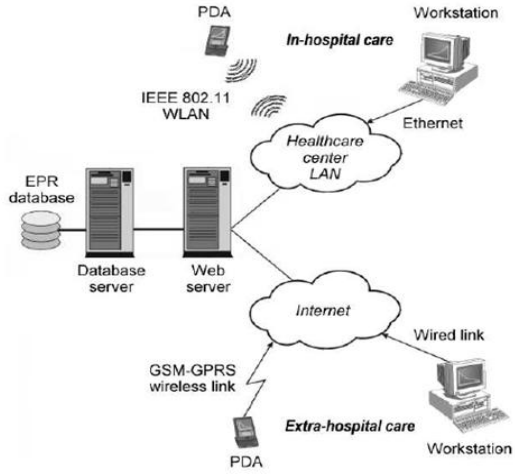

Fig. 4 System Overall Architecture

Bringing it all together, the designs involve inter-disciplinary team with very clear objectives, namely [7], [8]:

- To convert the intranet into a tool that would form part of everyday hospital routine, familiar to and used by all the professional staff
- To facilitate the work of the hospital staff by improving:
  - Access to and exchange of information
  - The quality of the relationship between employee and institution
- To create a tool of knowledge management
- To transform the intranet into the main channel of internal communication

In general, there are three phases of development:

1. Planning**:** Internal analysis of the institution and benchmarking in order to define needs, identification and involvement of key persons in the project, definition of technical requirements, budget and schedule
2. Implementation**:** Identification of contents of internal and external origin, assignment of responsibility for content maintenance, database design, development and adaptation of applications, graphic design of website, inclusion of contents and utilities, testing, launch, publicity, and training and technical support for users
3. Evaluation**:** Collection of statistics on use, suggestions and user satisfaction questionnaires, creation of new services, evaluation of impact on the institution

In conclusion, developing and fine tuning an intranet into an improved tool for hospital management and continuing education, for access to knowledge, is only one part of the challenge. Equally important and a task, is the goal of being successful as the main channel of communication, and therefore a strategic organizational resource. In order to achieve this aim, thus, it is essential that the following conditions are met:

- The administration must support the project fully
- The users must be involved in the project
- Intranet contents must be updated frequently
- The content must meet the needs of the users
- The project must be adequately publicized and technical support made available to users

B. WWAN

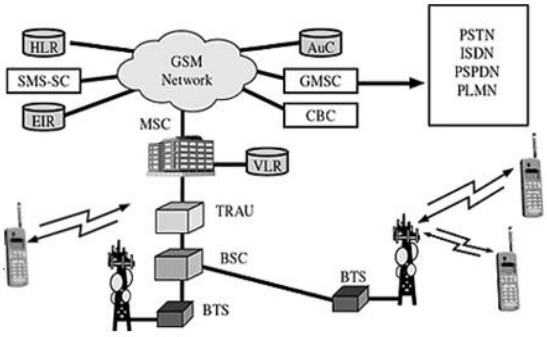

Fig. 5 GSM Architecture

The key features of WWAN architecture is described in Fig 5. It comprises of the mobile equipment (ME), the BTS – Base Transceiver Station, BSC – Base Station Controller and MSC - Mobile Switching Centre. The latter has the duty of forwarding and connecting to public networks, internet and intranet [9].

WWAN networks are distinguished by standards and have been evolving since first inauguration. It started with basic voice and message services in GSM, the second generation of mobile system. Then

2.5G, with GPRS/EDGE, added multimedia and internet services. As of current, there are now 3G and 4G LTE in operation. While the later is predominant in main cities, the minimum coverage in rural areas is at EDGE standard. Hence the following services are feasible:

- Mobile TV.
- Video conferencing
- Telemedicine
- Location – based services

C. Extranet

Given the availability of WLAN for corporate administration, and also WWAN, it is a simple matter of conjecture how they may relate [10]. Indeed, it has always been common, when necessary, for many to work from computer terminals at home rather than operate in corporate office. And this is possible by using modems and telephone lines to establish link with office computer network.

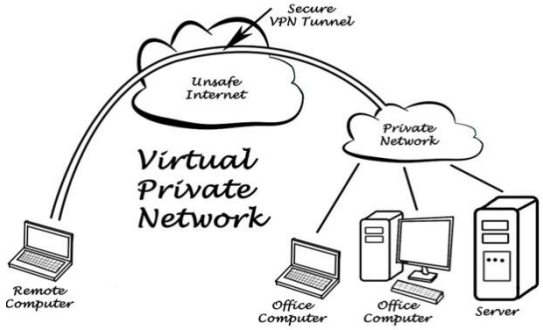

Fig 6. Virtual Private network

In the same vein, WWAN achieves this extranet facility with any corporate system, through VPN Virtual Private Network [11]. By this arrangement therefore, Fig 6, a Consultant in a remote location, can log into hospital intranet and view records of his patient [12]. And if WPAN connection is also available, then ward visits becomes a reality, at any time, from remote locations.

D. WPAN

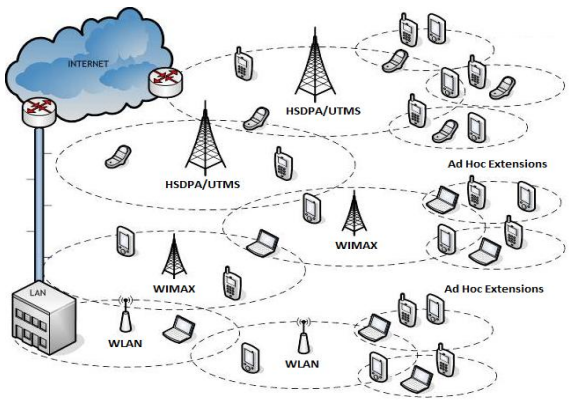

Fig. 7 Ad Hoc Extensions

WPAN is a field within Mobile Ad Hoc Network. In this respect, it can be seen (Fig 7) as ad hoc extensions to WWAN and WLAN. When defined around the patient, it is also known as Body Area Network [13], [14].

The key technology centres around IEEE 802.15, but given the trend in technology, the emphasis is on Bluetooth, IEEE 802.15.1. Quite a number of issues arise in the use of Bluetooth for WPAN, such as range and data speeds, routing and security, and video streaming.

1. Range and Data Rate:

TABLE 1
BLUETOOTH CLASS

Class	Power mW	Range (meters)
Class 1	100	~100
Class 2	2.5	~10
Class 3	1	~1

Range and data rates in Bluetooth transmissions depend on the class and versions, respectively as shown in Table 1 and 2. However, in this application of devices within the proximity of a patient, Class 2 devices with low power consumption will be adequate. The data rate depends on the edition, Table 2, and while Version 1.2 supports 1Mbit/s, Version 2 (Enhanced Data Rate) can operate at 3 Mbit/s. With consideration for video streaming, the best option would be Version 3 (High Speed), but on balance, Version 2 (EDR) is adequate. In higher versions, Bluetooth operates adaptive frequency hopping (AFH) to minimize interference by WLANs.

TABLE 2
BLUETOOTH DATA RATES

Bluetooth Version	Data Rate (max)
Version 1.2	1 Mbit/s
Version 2.0 + EDR	3 Mbit/s
Version 3.0 + HS	24 Mbit/s

The actual data transfer is based on provisions of Bluetooth wireless specifications, including Baseband, Link Manager

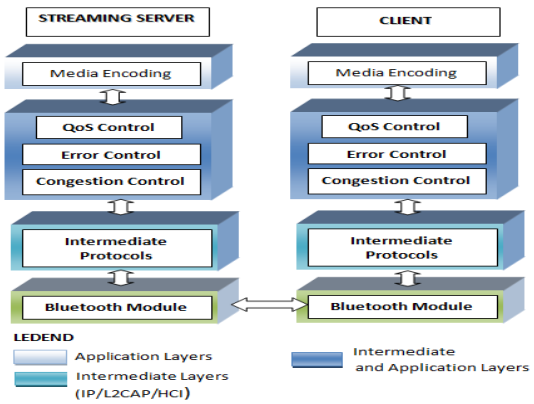

Fig. 8 Data Streaming Architecture

Protocol (LMP) and, Link and Control Adaptation Protocol (L2CAP), as defined in Protocol Stack. For the given options, in data streaming, L2CAP is highly recommended [15]. The architecture for data streaming is illustrated in Fig 8.

2. *Routing and Security:*

Routing and security are pivotal in data transmissions. WPAN is governed by routing specifications of MANET which is best described as self-organizing, adaptive and infrastructure less network [16], [17]. The nodes can therefore serve as both routers and hosts, forwarding packets on behalf of other nodes and run user applications.

A number of challenges arise with respect to data transmission, notably as applies to real time audio-video streaming. The key constraints are limited bandwidth, high degree of error rates, security and time varying nature of radio link [18].

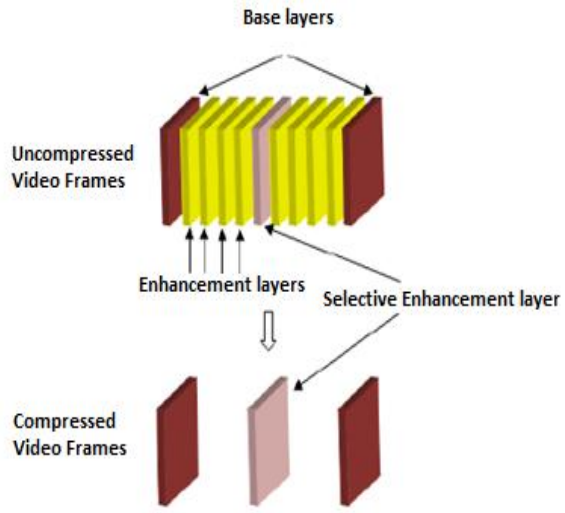

Fig. 9a Video Compression

There have been various suggestions on how to overcome high bandwidth consumption. One of these is reviewing codec options and the adoption of Scalable Video Coding [19]. By this technique, the video frames in the SVC (Scalable Video Coding) model are split into base layers, comprising of basic video information and enhancements for refinement of video data. The base layers and only a few enhancement layers are then compressed to achieve low bandwidth consumption. Decompression follows at the destination, employing Motion Compensation and Frame Replenishment techniques [20].

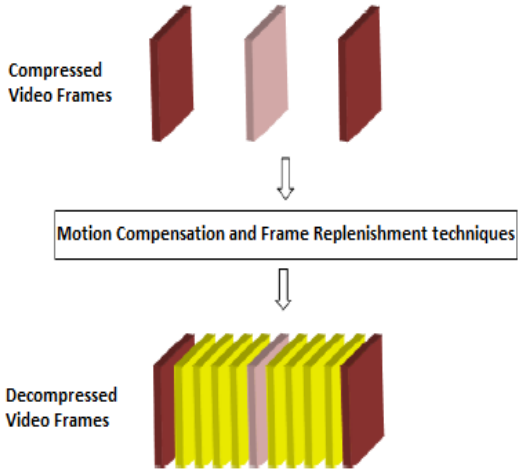

Fig. 9b Video Decompression

Routing protocols aim to establish and maintain possible end-to-end paths from source to destination. The main challenge in video streams is to classify the routes that ensure video delivery meets the standards of reliability [21]. In general, Multiple Channel routing can improve QoS by providing the following:

- Improved performance and reduction of end-to-end delay
- Traffic decongestion through load balancing in the network
- Resilience, with extra paths adding robust response to reduce the effect of network failures, and preserve video quality

A wide selection of conventions is available, but Zone Routing Protocol (ZRP) is a hybrid variant that includes both proactive and reactive techniques. It may thus incorporate AOMDV and DSDV models, and in broad sense is very suitable for this application.

In any data communication, in particular where medical information is involved, confidentiality and integrity is important. A sufficient level of security is achieved through encryption. This is in form of symmetric key encryption technique, Fig 10.

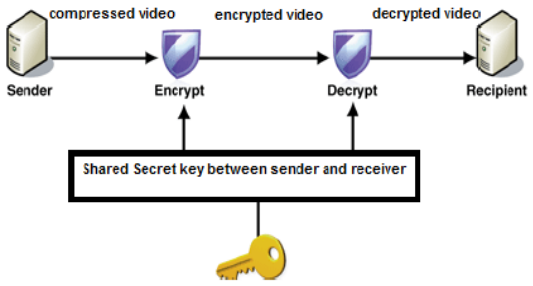

Fig. 10 Symmetric Key Encryption Technique

3. *Programming Approach:*

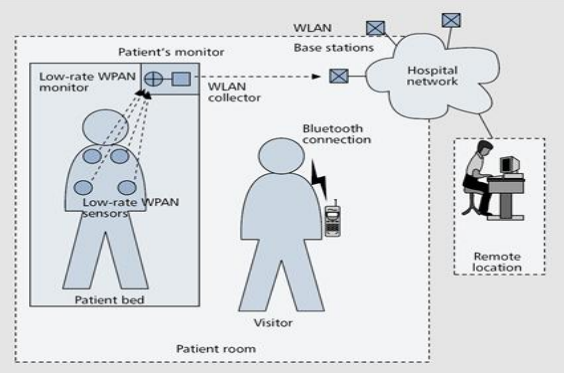

Fig. 11 Patient's Room Topology

Programming approach is best based on a clear understanding, in context of patient's room topology and architecture. A typical example is described in Fig 11. In patient's bed are attached sensors that communicate with WPAN monitor. A WLAN collector transmits to a base station, thereby effecting communication with hospital intranet. Further communications through WWAN then links to doctors and nurses, in remote locations [22]. It is a synthesis of model engineering.

Software development involves mobility devices programming, and cross platform of operating systems namely, Android, Linux and Windows. For language options, Java is recommended with extension for Spatial Programming. This is considered an ideal platform for programming Mobile Ad Hoc Networks [23], [24], [25].

V. IMPLEMENTATION

The focus of this venture is to bring the benefits of telemedicine to communities in rural areas through Reachability, a framework for Remote Monitoring and Real-Time Interactive services. It is of note however, that many health institutions in developing nations have limited budgets. Therefore, the emphasis is on project take off with affordable and cost effective solutions, and within minimal time frame. Whereas in scope of concepts, system design is comprehensive to accommodate future requirements and expansion, implementation though, at infancy, could be in phases with basic operations and subsequent augmentation to full design.

Against this background, there are three essential project stages for a working model:

1. Health Information System: This is fundamental to the scheme involving in most cases extensive software development, as discussed in IV (Section A). However, an option exists in OpenClinic, a customisable open source software system that have found applications in many African countries [26].
2. Virtual Private Network (VPN): A VPN is central in providing a means for the Consultant to gain access to hospital intranet, through a mobile device and from remote locations. Options in implementation include third party products, often built-in with system software. At developer's level, OpenSSL are available in online libraries. Another good alternative is IPSec, with advantage of more flexibility and security [27], [28]. It can be further secured against DoS attacks as in [29].
3. Wireless Personal Area Network: The configuration of WPAN is primarily to provide audio-video communications with the distant doctor, through smart phones and tablet computers. So if embedded and other devices are not envisaged at the present phase, then it would suffice to treat the network as static, rather than dynamic. Furthermore, if devices are in adjacent proximity to Access Points, Fig. 3, then routing protocols for data streaming, with less hopping, becomes straightforward.

Fig. 12 PC Slate for medical records

Overall, health staff and patients can be in real time communication. A distant consultant can log into the hospital server, read the latest report, engage the patient in discussions and update prescriptions on line. Similarly, a duty staff can monitor patients in the ward, Fig. 12, from the convenience of the duty office, or while in another emergency.

VI. CONCLUSION

Drawing from common experience and observations, this project is very important for improved healthcare. It is also very feasible, and cost-effective. The trend in technology illustrated by various applications, video conferencing, and the prospects for a heterogeneous network [30] comprising of WWAN, WLAN and WPAN, further embosses the project. In the same vein, there would be collaboration with manufacturers of hardware, for custom medical devices and seamless integration.

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