J Med Syst (2017) 41: 17
DOI 10.1007/s10916-016-0661-8

MOBILE SYSTEMS

Mobile Telemedicine Implementation with WiMAX Technology: A Case Study of Ghana

Eric Tutu Tchao [1] **· Kwasi Diawuo** [2] **· Willie K. Ofosu** [3]

Received: 17 March 2015 / Accepted: 6 December 2016 / Published online: 14 December 2016

Abstract Telemedicine has become an effective means of delivering quality healthcare in the world. Across the African continent, Telemedicine is increasingly being recognized as a way of improving access to quality healthcare. The use of technology to deliver quality healthcare has been demonstrated as an effective way of overcoming geographic barriers to healthcare in pilot Telemedicine projects in certain parts of Kumasi, Ghana. However because of poor network connectivity experienced in the pilot projects, the success of the pilot networks could not be extended to cover the whole city of Kumasi and other surrounding villages. Fortunately, recent deployment of WiMAX in Ghana has delivered higher data rates at longer distances with improved network connectivity. This paper examines the feasibility of using WiMAX in deploying a city wide Mobile Telemedicine solution. The network architecture and network parameter simulations of the proposed Mobile Telemedicine network using WiMAX are presented. Five WiMAX Base Stations have been suggested to give ubiquitous coverage to the proposed Mobile Telemedicine sites in the network using adaptive 4 × 4 MIMO antenna configurations.

Keywords Mobile telemedicine · Developing country · WiMAX · Healthcare · Simulation · MIMO configuration

This article is part of the Topical Collection on *Mobile Systems*

✉ Eric Tutu Tchao
ettchao.coe@knust.edu.gh

[1] Department of Computer Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

[2] Department of Electrical/Electronic Engineering, University of Energy and Natural Resources, Sunyani, Ghana

[3] Department of Electrical Engineering Technology, Penn State Wilkes-Barre, Lehman, PA, USA

Introduction

Telemedicine involves the delivery of healthcare and related information over long distances by combining biomedical signals with information technology and means of communication [1]. The use of wireless technology to deliver health information has been demonstrated as an effective way of overcoming certain barriers to healthcare, particularly for communities located in rural and remote areas. Telemedicine has helped to bridge the gap in providing crucial care for those who are underserved, mainly due to inadequate health personnel [2]. Mobile Telemedicine is an improved form of Telemedicine, in which advanced wireless communication systems are used to deliver the biomedical signals of patients anywhere and anytime [3]. Mobile Telemedicine uses high capacity mobile communication systems such as 3G+, WiMAX and LTE to deliver protected health information over long distances. This capability of mobile Telemedicine has made it possible to deliver improved medical services such as emergency ambulance service [4], mobile hospital [5], general healthcare and early warning systems for diseases [6].

Ghana currently has a doctor to patient ratio of 1: 10,380 and 1:23, 456 in the urban and rural areas respectively [7]. This is a major challenge in delivering quality healthcare especially in the rural areas. In order to provide quality healthcare to the rural areas, the government of Ghana is striving to use the advances in healthcare delivery to provide quality healthcare to its citizenry. As part of research works at U.C. Berkeley and Intel Research, a pilot Teleconsult based on experiences and reports from similar applications implemented in developing countries reported in [8] was implemented for selected health centers in Ghana [9]. Other pilot Telemedicine projects have also been implemented as part of the Millennium Villages Project in about 23 remote villages to help deliver affordable and accessible healthcare to the deprived communities. The major setback to a nationwide implementation of these pilot Telemedicine projects was found to be inadequate bandwidth to support these Telemedicine applications. The data rates provided by the existing 3G networks in outdoor locations in Ghana currently is inadequate to support the major Telemedicine applications as specified in [10]. The Government in its quest to provide quality healthcare to the people plans to deploy reliable WiMAX networks in several cities in the country to provide improved network connectivity for the existing Pilot Telemedicine projects.

This case study evaluates the existing Telemedicine systems in Kumasi and examines the possibility of a citywide deployment using WiMAX to develop a mobile Telemedicine system with multi-communication links for the city of Kumasi.

Review of existing telemedicine applications in Ghana

One of the more significant developments over the past decades has been the emergence and pilot usage of information and communication technologies in healthcare delivery in Ghana. There are several pilot Telemedicine applications in Ghana. These Telemedicine applications are focused on diagnostics and consultation. These systems have also been used for other healthcare service applications and have been considered to be particularly useful in many remote areas in the Millennium Villages Project (MVP) in Ghana [11]. The pilot implementation of Telemedicine solutions in 23 villages as part of the Millennium Villages Project in the Bonsaaso cluster aims at; (i) reducing transportation time and healthcare costs for patients and their families, (ii) increasing medical knowledge and safety in primary healthcare facilities, and (iii) Strengthening local capacities in e-health within the cluster of villages. The MVP Telemedicine Project has been able to leverage the use information and communications technologies (ICTs) to improve the medical referral system and reduce unnecessary travel to seek medical attention. This is particularly important since road networks and healthcare facilities within the cluster of villages are very poor. The Telemedicine platform enables healthcare personnel in the remote villages to consult with health personnel at the regional and national health facilities. This structured consultation ensures that the most important questions by the personnel in the remote areas are answered in an accurate and timely manner, which ultimately helps decide whether or not a patient requires referral to the regional or national hospitals.

While Telemedicine systems in developed countries can have different goals, the basic objectives of the existing systems in Ghana have to be scalable. These scalable goals include the setting up of basic Telemedicine services, and later an upgrade to advanced up to date functionalities. The basic concepts of the existing systems are based on creating the necessary basic Medical Information Systems (MISs) and Electronic Health Records (EHR) in hospitals and developing a framework and interfaces where various multiplatform MISs could interconnect in an integrated MIS. This objective is more evident in pilot projects implementations by the Millennium Villages Projects and many Teaching Hospitals in the country. The KomfoAnokye Teaching Hospital (KATH) and Kwame Nkrumah University Hospital, for example, have developed a Teleconsulting platform which enables medical students at Kwame Nkrumah University of Science and Technology (KNUST) learn and Teleconsult on the University campus. An overview of the platform is shown in Fig. 1.

The Ministry of Health in conjunction with the National Road Safety Commission has also deployed emergency ambulance service on pilot basis in major cities and highways over the country. These emergency response ambulance services have played an important role in reducing the number of deaths caused by motor accidents and other medical emergencies in Kumasi. The architecture of the current system is shown in Fig. 2. The structure of the implemented Emergency Ambulance Service is similar to the model proposed by Mandellos et al. in [12].

With the implemented ambulance service model shown in Fig. 2, voice communications over a Third Generation (3G) network is used between the paramedics and the emergency ward physicians at the district centers or health facilities to provide relevant pre-hospital medical care. 3G data connectivity is used onboard the ambulance to transmit data to the district support centers. The district centers are linked to the regional centers the by National Communication backbone Company (NCBC) liaisons Gigabit Ethernet.

The next section presents field trial measurements results done as part of a performance evaluation of the 3G network which is used to provide data connectivity onboard the Emergency Ambulance Services at four locations within the Kumasi metropolis.

Performance evaluation of existing networks

To effectively promote the possibility of future recovery, better medical care should be provided between the time at which paramedics arrive at an accident or emergency scene and before an ambulance arrives at a hospital. This can only be achieved in a mobile Telemedicine application if there is reliable data connectivity. This section evaluates the network performance of the 3G network used in deploying the Emergency Ambulance Services in four locations in Kumasi. The throughput field trial measurements were carried out within a 14-day period. The measurements areas are shown in Fig. 3.

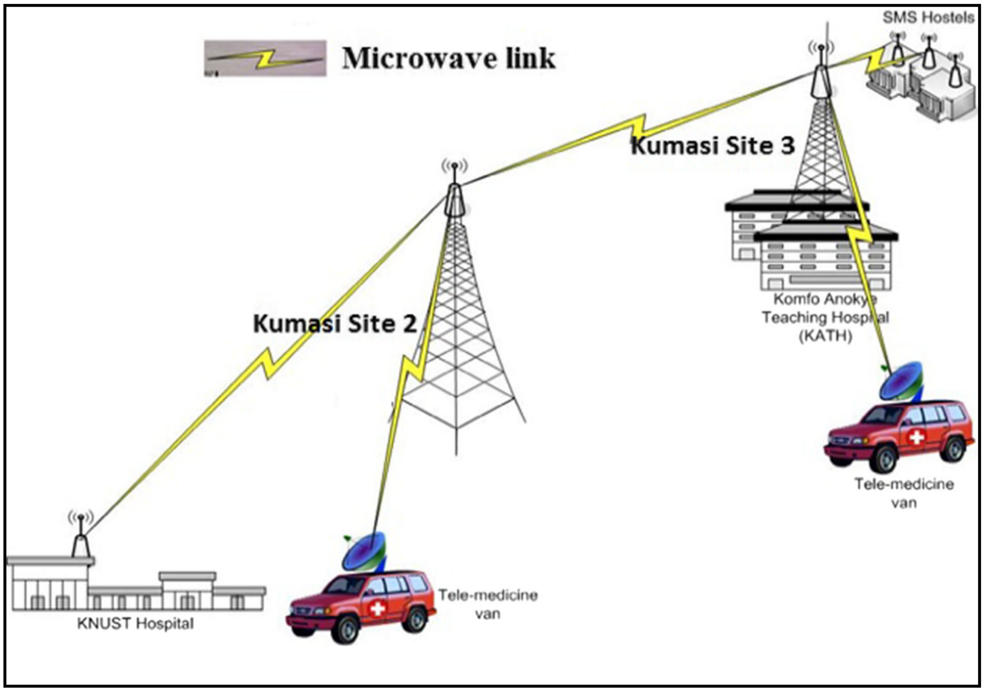

Fig. 1 Overview of KNUST teleconsult platform

The result of the measurements is summarized in Fig. 4. The requirements of 500Kbps in outdoor locations specified for 3G networks by Gállego et al. in [13] for reliable video and FTP transmission is used as the threshold for the analysis.

From the result in Fig. 4, it can be seen that the performance of the 3G network at the four locations is notenough to support the minimum 1Mbps needed to reliably integrate mobile Telemedicine frameworks to multiplatform MIS. This problem has hindered an efficient delivery of the services provided by the Emergency Ambulance Services and other Telemedicine projects initiated by the Millennium Villages Projects. The implementation of the many pilot Telemedicine systems in Ghana have not been able to incorporate the development of frameworks and interfaces where various multiplatform management information systems (MISs) have been interconnected in an integrated MIS. This is mainly because of the lack of telecommunication technologies to support connection of the integrated MIS to enable provision of advanced medical services in the country. This limits the use of the integrated MIS for various Telemedicine applications such as sharing knowledge, experience and expertise among physicians in different hospitals even within the Kumasi metropolis.

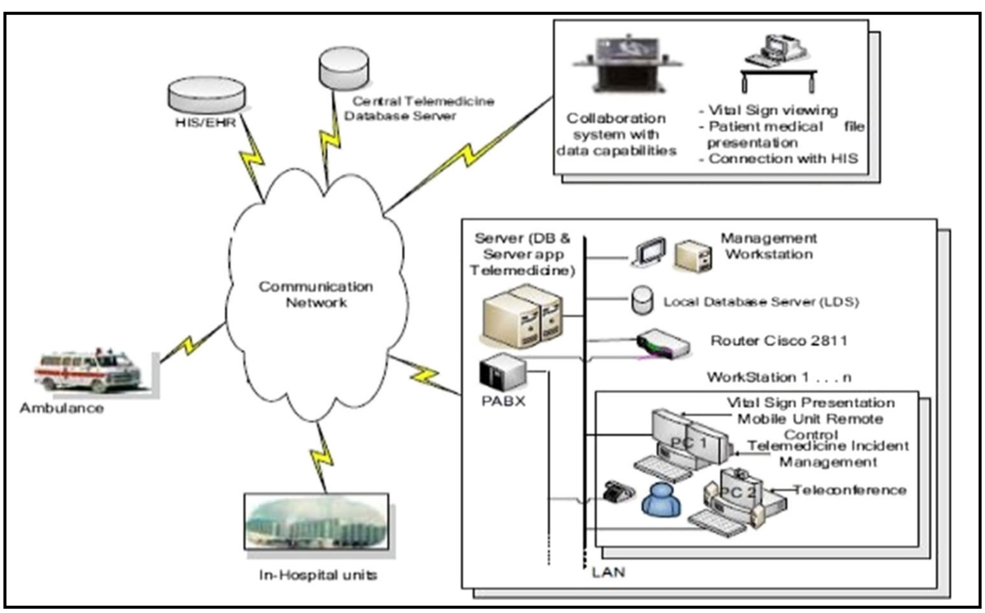

Fig. 2 Deployed emergency ambulance services model

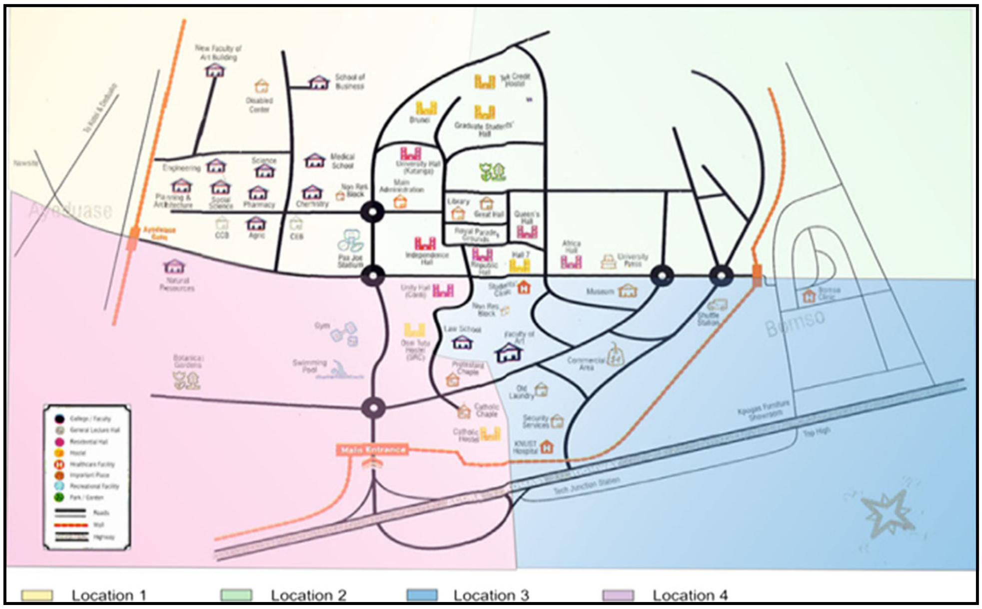

Fig. 3 Overview of the measurement locations

Worldwide Interoperability for Microwave Access (WiMAX) technology has gained growing interest due to its applications and advantages. It is fast emerging as a last-mile problem solution for broadband access technology. WiMAX offers a platform which provides increased coverage and low-cost services [14]. WiMAX is a broadband internet access technology that provides wireless transmission of data using different transmission modes. The transmission mode ranges from stationary point-to-multipoint links to portable, nomadic and fully mobile internet access. This makes WiMAX a superior broadband technology in terms of coverage and network capacity [15]. The standard is defined by IEEE (Institute of Electrical and Electronic Engineers) 802.16×. WiMAX is commonly referred to as Broadband Wireless Access (BWA) by many technology industry experts.

WiMAX network deployments in many developed countries has proven the technology to be an efficient and a capable end-to-end technology that provides low deployment cost and last mile solution for enabling broadband wireless access to areas which are underserved by fixed broadband infrastructure. The IEEE 802.16 technology provides coverage of up to 48 km compared to other technologies; Generalised High-Bitrate Digital subscriber Line (G.SHDSL) can cover 7 km; Wireless Fidelity (WiFi) can only cover 3 km in Line of sight (LoS) deployment scenario. The unique characteristics of WiMAX allow the Base Stations to provide a collision-free Media Access Control (MAC) Uplink/downlink (UL/DL) channels and simultaneously handle thousands of Customer Premise Equipment [16].

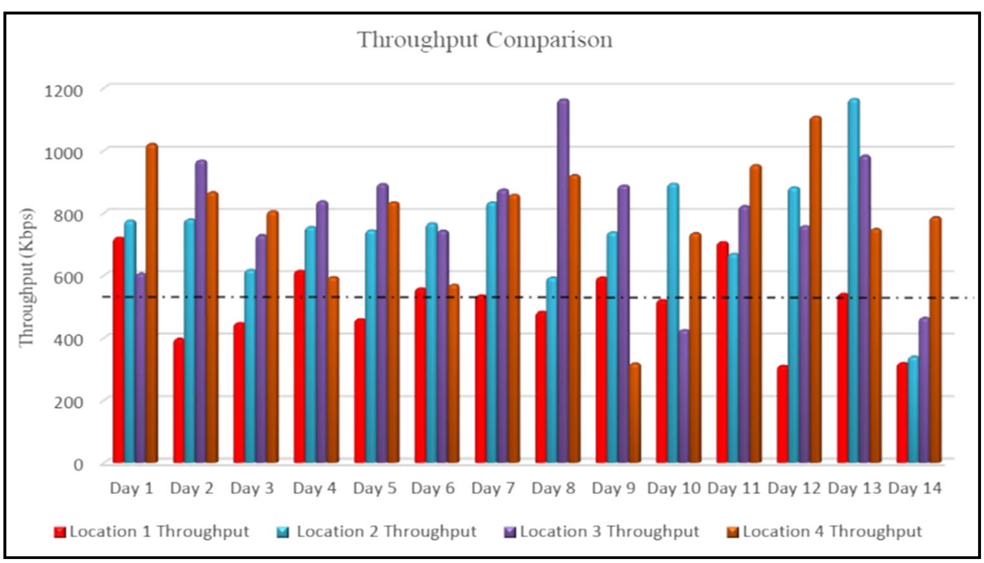

Fig. 4 Summary of field measurement results

Recent deployment of WiMAX in Ghana has delivered higher data rates at longer distances with improved network connectivity [17]. With the improved network connectivity WiMAX deployment in the country promises, WiMAX will be a better alternative to the existing 3G networks which are widely used in the pilot Telemedicine applications. With improved network connectivity, it will be possible for medical personnel onboard the Emergency Ambulance to carry out voice and video interactions for pre-hospital medical care in the ambulance. Documented results in implemented mobile Telemedicine services suggest that real-time video distributed over a reliable high speed internet connection is a valuable aid in diagnosing and improving treatment in the case of suspected stroke victims in [18–20].

As such, we propose the implementation of a nationwide Telemedicine system deployment using WiMAX network. The proposed nationwide system is discussed in the next section.

Network structure of the proposed National Telemedicine System

In order for Ghana as a developing country to achieve the objective of national development, it is very important for the country to adopt existing technologies and optimize the use of these technologies. In light of this, we propose the setting up of a nationwide Telemedicine infrastructure using WiMAX to provide effective and efficient delivery of healthcare services to the citizenry, and to provide the people in remote areas access to the quality healthcare. This Telemedicine infrastructure will be a component of an overall plan for a Government *e*-Health Project. The National Telemedicine network is proposed at over forty sites through the whole nation as shown in Fig. 5.

WiMAX technology will be used to cover urban areas and that is currently being done in cities such as Accra, Tema and Kumasi. The network structure of the proposed national Telemedicine infrastructure is shown in Fig. 6. The WiMAX Telemedicine network will comprise the Accra and Kumasi sub networks which will be connected to Vodafone's backbone transmission by National Communication backbone Company (NCBC) liaison Gigabit Ethernet (GE) whiles Telemedicine sites at Tamale, Nkawkaw, Obuasi, Koforidua, Takoradi, Ho, Sunyani and Cape Coast networks will be linked to Vodafone's backbone transmission by the NCBC liasons fast Ethernet. Sites at remote parts of the country, thus, Wa and Bolga will be linked by Satellite.

The WiMAX network design will incorporate a distinctive distributed Base Station which consists of Base Band Unit (BBU) for indoor installation and Remote Radio Unit (RRU) for mounting on walls or poles. An Advanced Power Module (APM) will be used to accommodate BBU for outdoor installation. The use of optical fiber cable to connect BBU and RRU will ensure low cable loss and high tolerance to noise.

As mentioned earlier, this paper intends to undertake feasibility studies into the possibility of providing the existing

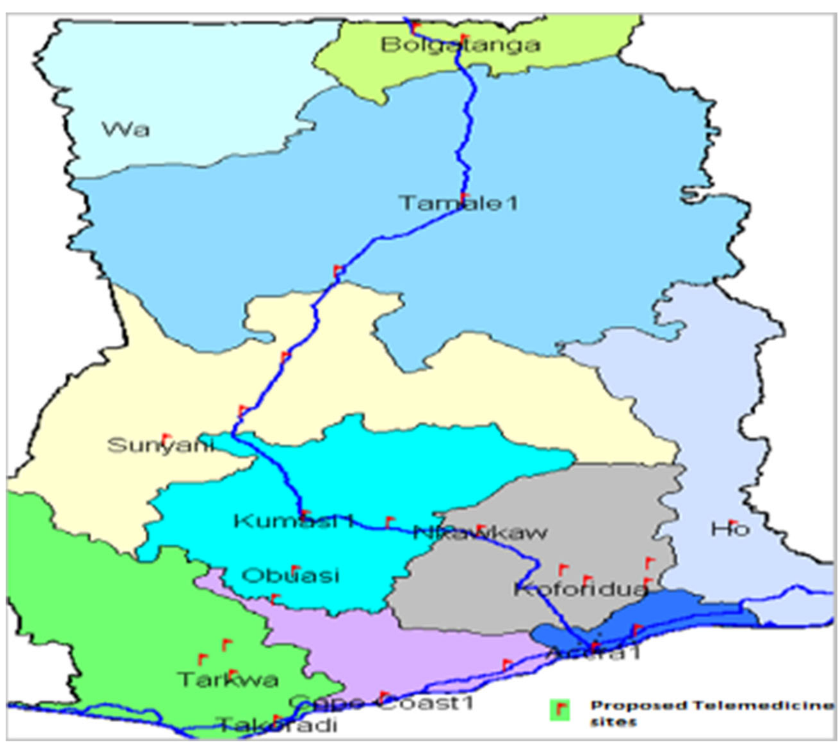

Fig. 5 Proposed Telemedicine sites

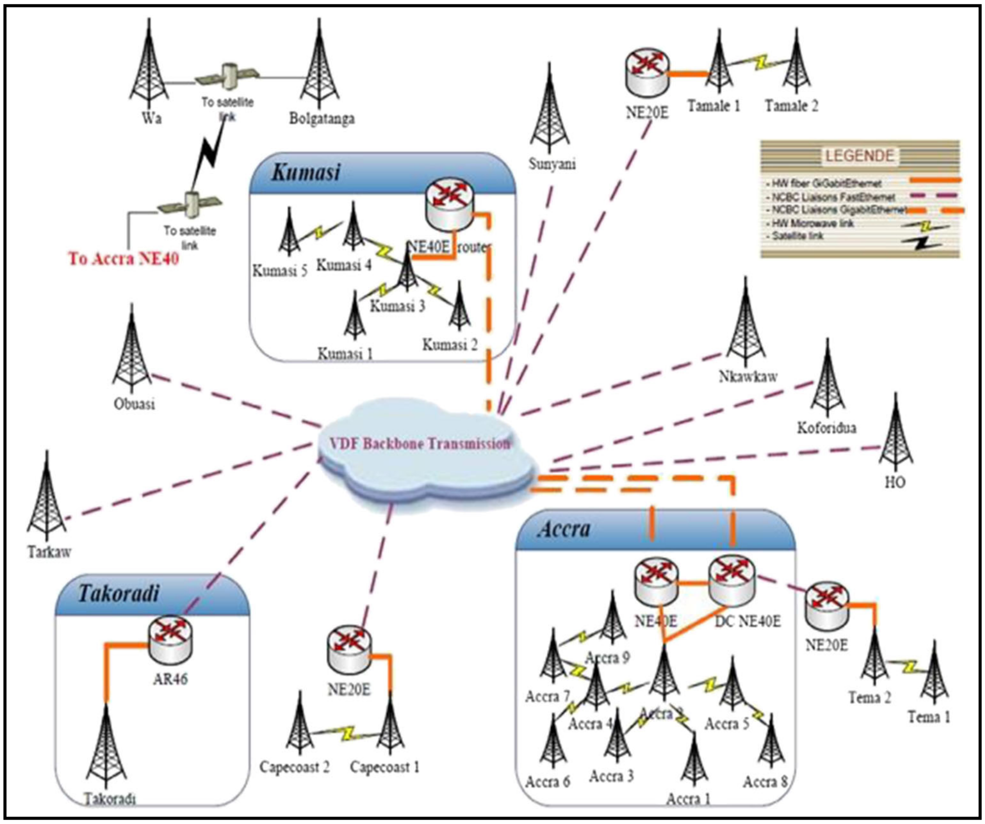

Fig. 6 Proposed National Telemedicine Network structure

telemedicine sites in Kumasi using WiMAX as the wireless technology. The paper will study the number of sites which would be possible to provide a city wide coverage using two antenna configurations which are being considered for deploying the WiMAX network in the city.

Network simulation

In designing a Telemedicine network, the transmission platform and transmission speed should be considered. WiMAX has been chosen as the microwave access system for a citywide network deployment based on factors such as real-time operation, transmission reliability, interference and system bandwidth. There are ongoing plans to deploy WiMAX in Kumasi using either Adaptive 2 × 2 Multi-Input Multi-Output (MIMO) or Adaptive 4 × 4 MIMO Base Station (BS) antenna configuration. Fractional Frequency Reuse (FFR) would be considered in the network simulation presented in this section with the aim of reducing interference to improve network connectivity at the cell edges. FFR divides the cell into inner and outer region. Available bandwidth is divided among inner and outer regions in a way that the inner region employs reuse 1 while the outer region applies frequency reuse 3 [21]. Hence, users located in a cell border mitigate co-channel interference because of frequency reuse 3. This section presents the coverage and capacity simulation of the WiMAX network for the Telemedicine sites and customer

Table 1 Simulation parameter

Parameter	Value
Resource frequency	2.5–2.53GHz
Channel Bandwidth	10 MHz
Van Speed	80 km/h
Average users per sector	10
Fast Fourier Transform (FFT) Size	1024
Subcarrier spacing	10.93 kHz
Useful symbol time	91.4 μs
Guard time	11.4 μs
OFDMA symbol time	102.8 μs
Modulation	QPSK, 16-QAM, 64-QAM
Antenna frequency Range	2.3–2.7GHz
Input Impedance	50 Ω
Gain	18dBi
Horizontal Beamwidth (3 dB)	60°
Vertical Beamwidth (3 dB)	7°
Electrical downtilt	2°
Maximum power(dBm)	43
BS Antenna height	42 m
CPE antenna config.	1 × 2 MIMO
CPE antenna height	1.5 m

Table 2 Network coverage simulation results

BS Antenna config.	SS type	DL traffic CINR(dB)	Cell edge RSSI(dBm)	Cell Radius(Km)	Site-Site Distance(Km)
Adaptive 2 × 2 MIMO	Outdoor CPE	3	-92	2.99	4.5
Adaptive 4 × 4 MIMO	Outdoor CPE	3	-92	3.61	5.4

Premise equipment (CPE) on the e-Government network in the city using the two configurations.

The Software used for simulating the radio network plan and capacity is Genex-Unet. The simulation parameters are summarized in Table 1.The simulation assumes a CPE with a 1 × 2 MIMO antenna configuration. The coverage and capacity results simulated for the twoBS antenna configurations under consideration are summarized in Tables 2 and 3 respectively. The parameters in Table 1 are used in the simulator for the radio network dimensioning using the coverage and capacity estimation models for 4G–WiMAX MIMO BS antennas proposed by VitalyTeterin in [22]. The obtained BS intersite distances for the two MIMO configurationshave been summarized in Table 2. From the coverage results shown in Table 2, it can be seen that the adaptive 4 × 4 MIMO configuration provides a greater coverage than the 2 × 2 MIMO configurations.

From the simulation parameters in Table 1, at 10 MHz the OFDMA symbol time is 102.8microseconds and so there are 48.6 symbols in a 5 millisecond frame. Of these, 1.6 symbols are used to cater for the TTG (Transmit to Transmit Gap) and RTG (Receive to Transmit Gap) leaving 47 symbols. If $n$of these symbols are used for DL, then $47-n$are available for uplink. Since DL slots occupy 2 symbols and UL slots occupy 3 symbols, it is best to divide these 47 symbols such that $47-n$ is a multiple of 3 and n is of the form $2k+1$.

Based on the propagation mode and application, the frequency reuse scheme and the Downlink/Uplink (DL/UL) channel ratio are used. For a capacity limited Telemedicine network, a 35:12 DL/UL ratio can be used to serve the sites in the network. When the sole purpose of the network is to cover a larger area, a DL/UL ratio of 26:21 can be used. Under the adaptive 2 × 2 MIMO deployment scenario, the maximum average DL and UL throughput per sector is 9.68 Mbps and 3.67 Mbps respectively for a coverage limited network using a 26:21 DL/UL ratio and a FRR 1x3x3 reuse scheme. For example, in deploying a mobile Telemedicine network which requires a higher UL throughput, a DL/UL split ratio of 26:21 is best suited for such network deployments whiles a DL/UL ratio of 36:12 can be used to deploy a network that provides patients monitoring facilities.

Based on the results in Table 2, Six (6) would be required to provide network coverage for the ambulances and CPEs on the Kumasi network using the 2 × 2 MIMO configuration whiles Five (5) BS would be required to provide coverage for the Telemedicine sites based on the mapping of the equipments in the proposed network shown in Fig. 8. From the mapping results of the ambulances in Kumasi, it can be seen that, the locations of the ambulance service lies within the proposed WiMAX network. The final radio plan for the 2 × 2 MIMO configurations is shown in Fig. 7.

In order to be sure that the 4 × 4 MIMO can provide ubiquitous coverage for the mobile ambulances, the coverage simulation of the network has been done and presented in Fig. 9. The 4 × 4 MIMO configurations gives a 3 dB increase in DL/UL coverage and higher throughput which reduces the number of WiMAX sites in the final radio plan. The current cost of building a WiMAX site in Ghana is $120,000 [23]. Therefore, if the adaptive 4 × 4 MIMO antenna configurations is used to deploy the Telemedicine network, only 5 BS are required instead of the 6 WiMAX sites needed by the 2 × 2 MIMO configurations.

This would reduce the initial startup cost by $120,000. Moreover, the cost of maintaining a WiMAX BS (maintaining the radio resources, power, air conditioning) under the current business environment in Ghana is shown in Fig. 10.

Since the 4 × 4 MIMO configuration reduces the number of BS by one (1), the total cost of ownership will be lower from

Table 3 Network capacity simulation results

Permutation	DL/UL ratio	WiMAX Carrier Average Throughput per sector			
		Adaptive 2 × 2 MIMO B (Mbps)		Adaptive 4 × 4 MIMO B (Mbps)	
		DL	UL	DL	UL
FFR 1x3x3	26:21	9.68	3.67	10.10	4.67
FFR 1x3x3	29:18	11.21	3.06	12.70	3.89
FFR 1x3x3	31:15	12.22	2.45	13.76	3.11
FFR 1x3x3	35:12	14.26	1.84	15.89	2.33

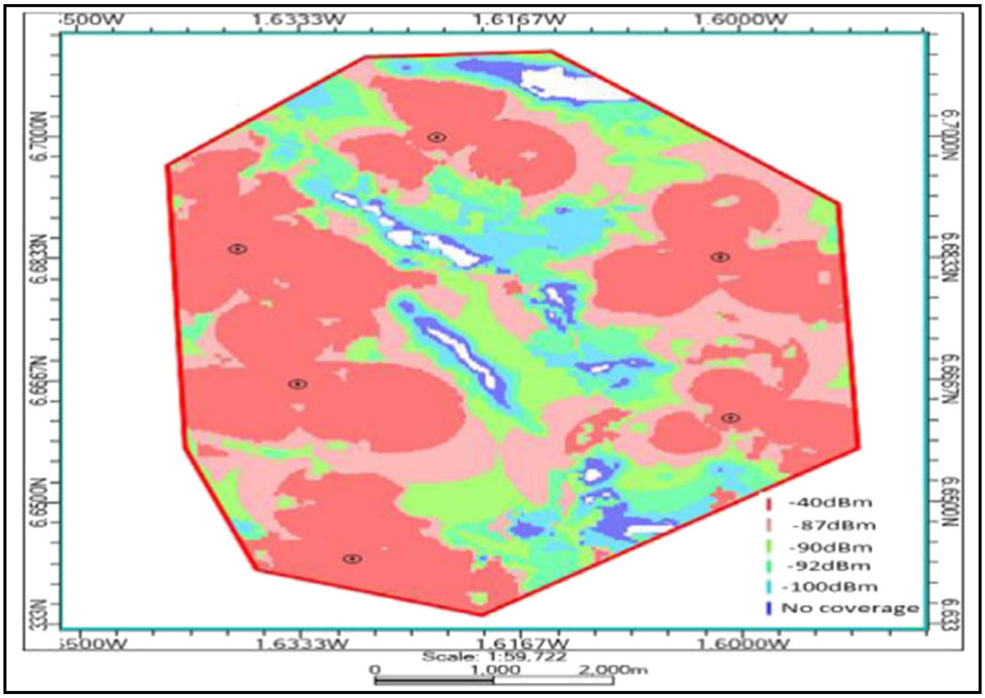

Fig. 7 Adaptive 2 × 2 MIMO radio network plan

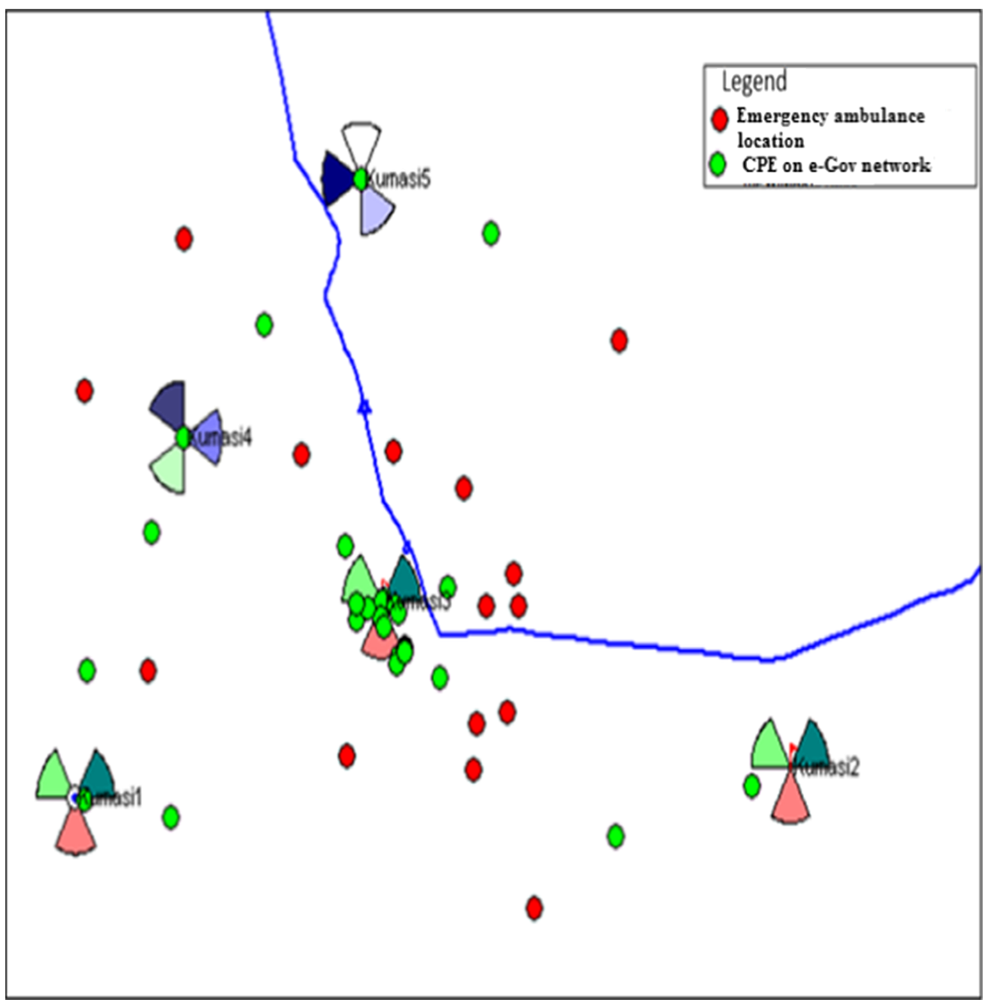

Fig. 8 Mapping of the locations of the CPEs on the network

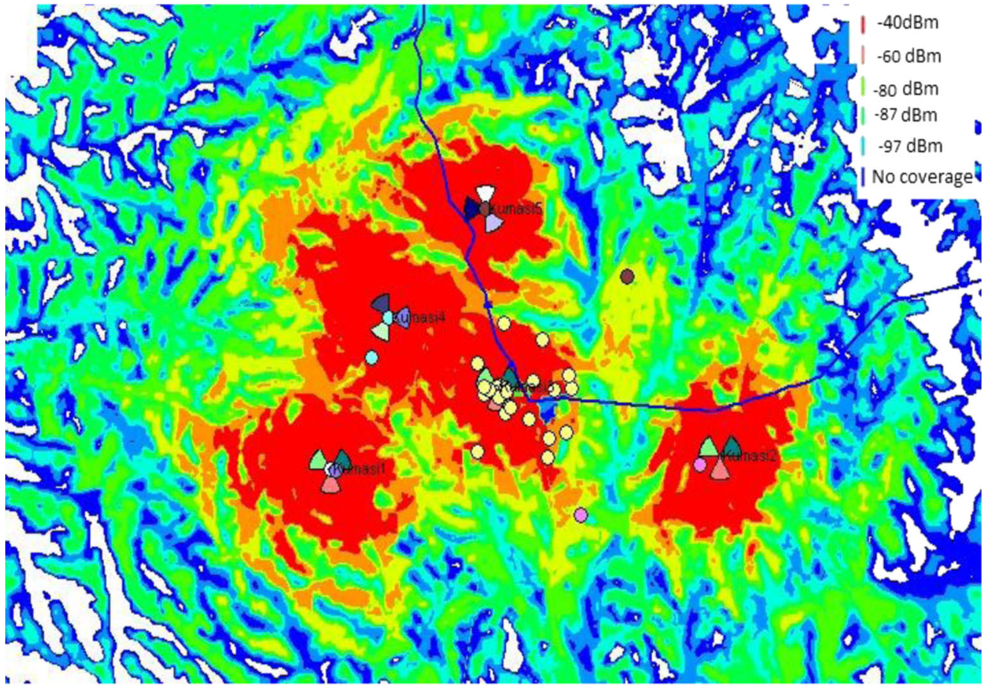

Fig. 9 Adaptive 4 × 4 MIMO radio network plan

the short to medium term as compared to using 2 × 2 MIMO configuration for deploying the network. From the coverage and capacity simulations of the two MIMO configurations, the 4 × 4 configurations is recommended for deploying the WiMAX Telemedicine network. The network performance of the 4 × 4 MIMO will cater for future expansion and guarantee reliable network connection for an efficient Mobile Telemedicine system implementation in the city.

There are several research works that have presented several frameworks for mobile Telemedicine implementation. The authors in [24] and implemented a WiMAX based integrated system for e-medicine in the Republic of Macedonia. They presented various telemedicine multimedia services parameters and studied the Quality of Service (QoS) related to them. Authors in [25] an [26] adopted technology evaluation models to study the performance of some selected mobile Telemedicine frameworks and subsequently optimized the models for implementation in development countries. This work however is unique in the sense that, it leverages the use of an existing under-utilized 4G–WiMAX network to provide a data-centric mobile Telemedicine solution which extends healthcare delivery to remote and deprived areas. Capacity and coverage results have been provided to validate the work.

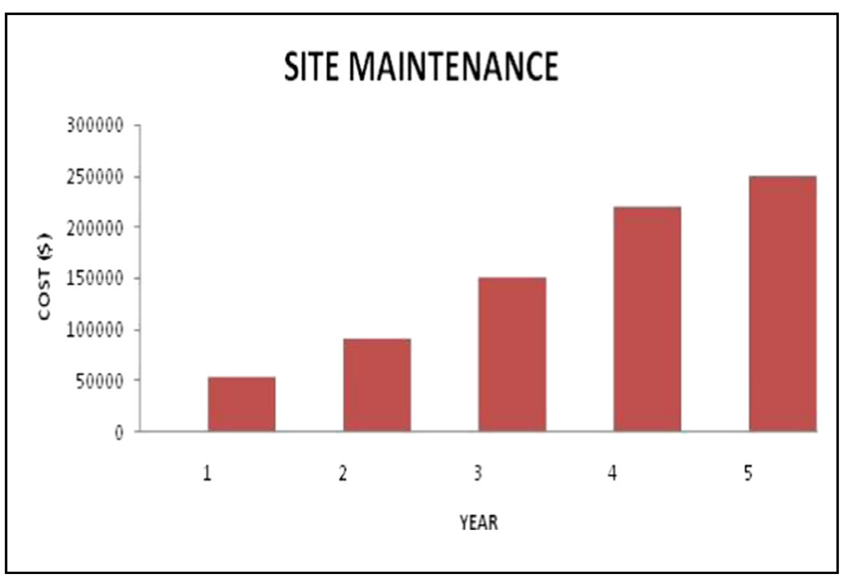

Fig. 10 Cost of site maintenance over a 5 yearperiod in US Dollars

Conclusion

Mobile Telemedicine services generally aim at facilitating and improving healthcare provision. The proposed Mobile Telemedicine solution in this case study is expected to help in coping with some major challenges faced by the national and regional health systems as a consequence of demographic and socio-cultural changes.

The proposed WiMAX network using 4 × 4 MIMO BS antenna configurationis useful and economically viable to build, deploy and operate for the existing pilot mobile Telemedicine services in Kumasi. Since the mobile Telemedicine solution will use reliable WiMAX infrastructure, it will help immensely in increasing response times in cases of medical emergencies and also deliver quality healthcare to complement the efforts of the limited health professionals in the country. The preliminary results based on the network simulation show that it is possible to provide stable and reliable mobile medical services using WiMAX technology.

References

1. Kyriacou, E., Voskarides, S., Pattichis, M.S., Pattichis, C.S., and Istepanian, R., Wireless telemedicine systems: an overview. *IEEE Antennas Propag. Mag.* 41:143–153, 2002.
2. Shimizu, K., Yamamoto, K., Mikami, T., Hoshimiya, N., Murakami, H., and Kondo, K., Telemedicine using mobile satellite communication. *IEEE Trans. Biomed. Eng.* 41:488–497, 1994.
3. Salcedo, V.T., Sanchez, E.M., Rashvand, H.F., and Iliescu, D., Ubiquitous wireless telemedicine. *IET Commun.* 2:237–254, 2008.
4. Chen J. Y. Shiu R. H. Lin, C. F. and S. H. Chang. A Ka band WCDMA based LEO transport architecture in mobile telemedicine. In: Martinez, L., and Gomez, C. (Eds.), *Telemedicine in the twenty-first Century*, pages 187–201, 2008.
5. Laxminarayan, S., Pattichis, C.S., and Istepanian, R.S.H., *Mhealth: emerging mobile health systems*. Springer, New York, 2006.
6. C. F. Lin and H. W Lee. Wireless multimedia communication toward mobile telemedicine. Proceedings of the 9th WSEAS International Conference o, pages 232–237, 2009.
7. Ghana health service: 2012 annual report. accessed online: www.ghanahealthservice.org on 20/06/2013.
8. Demmer, M., Du, B., Ho, M., Kam, M., Nedevschi, S., Pal, J., Patra, R., Surana, S., Brewer, E., and Fall, K., The case for technology in developing regions. *IEEE Computer*. 38(6):25–38, 2005.
9. Ho, R.L.M., and Aoki, P.M., Applying user-centered design to telemedicine in Africa. *Journal of Telemedicine*. 6:177, 2002.
10. Angela, H.S., Canales, M., Javier, J., Antonio, V., Gallego, J.R., and Julin, F.N., Performance analysis of multiplexed medical data transmission for mobile emergency care over the UMTS channel. *IEEE Trans. Inf. Technol. Biomed.*:13–22, 2005.
11. Melleninium Villages Projects Ghana: http://millenniumvillages.org/the-villages/bonsaaso-ghana/
12. Mandellos G. J, Lymperopoulos D, Koukias M, Tzes A., Lazatou N.: A Novel Mobile Telemedicine Systems for Ambulance Transport; Design and Evaluation, 26th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, San Francisco, Sept 204 pp 3080–3083
13. Gallego, J.R., Hernandez-Solana, A., Canales, M., and Lafuente, J., Performance analysis of multiplexed medical data transmission for mobile emergency care over the UMTS Channel.IEEE transaction on information technology for. *Biomed. Eng.* 9:13–22, 2005.
14. D. Kim, H. Cai, M. Na, and S. Choi. Performance measurement over Mobile WiMAX IEEE 802.16e network. In in Proc. of WoWMoM, pages 1–8, June, 2008.
15. IEEE Standard 802.16. Part 16. Air interface for fixed broadband wireless access systems, 2004.
16. Wang, F., Mobile WiMAX systems: performance and evolution. *IEEE Commun. Mag.* 46:45–48, 2008.
17. E. T. Tchao, W. K. Ofosu, K. Diawuo: Radio Planning and Field Trial Measurement of a Deployed 4G WiMAX Network in an Urban Sub-Saharan African Environment; In proceedings of IEEE Wireless Telecommunications Symposium, Phoenix, Arizona, April 2013.
18. P. Hu D. Gagliano M. N. Bahmouth R. D. Gunawardane C. F. Mackenzie W. R. Gaasch M. P. LaMonte, Y. Xiao and J. Cullen. Shortening time to stroke treatment using ambulance telemedicine: Telebat. *Journal of Stroke*, 2004.
19. M. P. LaMonte, P. Hu, W. Gaasch, R. Gunawadane, Y. Xiao, D. Gagliano and C. Mackenzie. Design and evaluation of a real-time mobile telemedicine system for ambulance transport. *Journal of High Speed Networks*, 2008:47–56.
20. IEEE document 802.11-04-172r1 The "Black-Box" PHY Abstraction Methodology, (Atheros, Mitsubishi).
21. Vitaly Teterin: Optimized Network Dimensioning andPlanning for WiMAX Technology; PhD Thesis, Jan 2012
22. Huawei Ghana White Paper, A proposal for a nationwide WiMAX implementation in Ghana, submitted to NITA (2013)
23. Ivan Chorbev, Martin Mihajlov: Building a Wireless Telemedicine Network within a WiMax based Networking Infrastructure, In Proc. Of IEEE International Workshop on Multimedia Signal Processing, 2009. MMSP '09, Rio De Janeiro, pp 1–6, doi:10.1109/MMSP.2009.5293305
24. van Dyk, L., A review of telehealth service implementation frameworks. *Int. J. Environ. Res. Public Health*. 11(2):1279–1298 , 2014. doi:10.3390/ijerph110201279.Published online 2014 Jan 23
25. L. van Dyk, C.S.L. Schutte and J.B. Fortuin: A Systems Engineering Approach to Telemedicine System implementation in South Africa, ISEM 2011 Proceedings, ISEM 122–127, Stellenbosch, South Africa, September 21–23