Sustainable Rural Areas
Network-based Architecture

Farnaz Farid, Seyed Shahrestani and Chun Ruan
School of Computing, Engineering, and Mathematics

Keywords: Cellular Systems, ICT, Network-based Architecture, Wireless Networking.

Abstract: Communication technologies and broadband networks offer interesting solutions for improving human quality of life. However, the improvements are less prominent in the rural areas and in developing countries. Partially, this may be related to cultural and social acceptance of such technologies in rural areas. It can also be associated with the lack of a proper architecture for utilization of such technologies in those areas. This work in progress is an attempt in developing such architecture. It is based on mapping of existing or upcoming information and communication technologies to services and applications needed for sustainable rural areas. Based on analysis of the existing infrastructure and technical requirements, we show that wireless and cellular technologies are the most suitable choices for this purpose. Integrating these points, a network-based architecture, referred to as eVillage, is designed. To investigate the underlying issues, simulation studies for several interactive services in such an environment, using OPNET are then carried out. These studies show that the proposed architecture is capable of supporting a reasonable number of clients while meeting basic Quality of Service requirements.

1 INTRODUCTION

With the advent of emerging information and communication technologies (ICT), the world is experiencing a new wave of positive changes in terms of health, education, environment, and overall quality of life. However, the improvements are less prominent in rural areas and developing countries. People living in these areas are struggling to attain quality healthcare, education, and their general livelihood. According to United Nations' report, over one billion people from developing countries live below the poverty line. In countries such as Bangladesh, where the majority of the population lives in rural areas, half of the population live on less than $1.25 per day. Even worse, in Tanzania, 80% of the population live on $1.25 a day (UNDP, 2010) . This situation is contributing to a large number of rural-urban population (Rana, 2011). In turn, forming a vicious circle, that leads to environmental degradations, natural disasters, poor living standards, and impoverished healthcare.

In developed countries, access to broadband networks is seen as a means of closing the gap between rural and urban areas. Rural Advanced Community of Learners project in Canada has been successful in providing quality distance education for the children living in remote Alberta by using video conferencing (Anastasiades, 2009). This is achieved through the use of Supernet, a high capacity high bandwidth broadband network deployed by Alberta government. However, with the lack of funding to build fixed broadband infrastructure, the situation in developing counties is drastically different. As such, to realize similar opportunities, alternative means of communication need to be utilized. For instance, it can be noted that mobile technologies and cellular systems are quite popular in developing countries. The take-up rate of mobile phones in some of these countries surpasses that of the developed nations (Vital Wave, 2009). Consequently, mobile and cellular based technologies and related application models can play an important role in sustainability in such areas.

In this paper, we analyze how the Internet and communication technologies can be efficiently utilized to improve the quality of education, health and commerce service of rural areas. This is in part based on mapping the technologies with the possible service features. This mapping is then used to design an integrated network-based architecture, eVillage. The architecture comprises of three access networks

Farid F., Ruan C. and Shahrestani S..
Sustainable Rural Areas - Network-based Architecture.
DOI: 10.5220/0004130003610368
In *Proceedings of the International Conference on Signal Processing and Multimedia Applications and Wireless Information Networks and Systems* (WINSYS-2012), pages 361-368
ISBN: 978-989-8565-25-9

for provisioning of education, health and commerce services. Finally, education access network architecture is simulated using OPNET modeler. For reasonable testing and performance evaluation purposes, videoconferencing is considered. Delay, Packet delay variance, jitter, packet loss, and Mean Opinion Score (MOS) values are the key performance metrics used in the result analysis.

The remainder of this paper is organized as follows. Section II discusses the challenges in education, health, and commerce sectors in developing countries from a technological perspective, with emphasis on potential ICT solutions. Section III presents technical requirement analysis and the mapping of the technologies to required service features. Section IV illustrates the design of the network-based architecture, eVillage. The simulation scenarios and the analysis of their results are presented in Section V. The final section concludes the paper and discusses the future works. It needs to be noted that, as the focus of this paper is on infrastructure, we use the terms 'rural areas' and 'developing regions' interchangeably.

2 THE SCENERY: RURAL AREAS AND ICT

The countries with higher GDP generally have higher broadband coverage. However, this is not the case for mobile phone network coverage. Cellular technologies are quite popular in developing countries. For instance, with the lowest GDP and the lowest broadband coverage, Uganda has 100% mobile network coverage, which exceeds even that of Republic of Korea (UNDP, 2010). With almost eighty percent of world population living in the developing world, two thirds of the mobile phones are used in these countries. Another point to consider is that, in spite of high popularity, cellular technology based solutions developed for these areas are lagging behind those for developed regions. Generally speaking, in developing countries, the cellular technology based education, health or commerce services are mostly dispersed projects, not being joined properly to establish a common goal (Vital Wave, 2009), (PSK, 2010), and (COL, 2008). In many cases, there is little connection with the community after completion of these projects. Moreover, low bandwidth, illiteracy among the target audience, lack of interactivity of the applications, and ineffective policies in defining architecture and operational cost-benefit analysis make it hard for these projects to be ultimately successful. Global System for Mobile Communications (GSM) and General Packet Radio Service (GPRS) centric cellular infrastructure are quite efficient in providing text or voice calls based mobile applications. Nonetheless, these solutions rarely use the interactive features such as video streaming and conference, recommended for distance education (Trucano, 2009).

The underlying concerns in education services for both developed and developing nations are similar. These include insufficient number of teachers, high dropout rates, and insufficient facilities, particularly for disabled children. But they are more problematic for developing nations. Some examples may help in clarifying this point. At least one in every four children in Sub-Saharan African countries is out of school due to poverty, hunger, and various forms of discrimination (United Nations, 2010). To overcome such problems, many mobile-based open education solutions have been proposed. However, different studies show that many of these solutions lack the open schooling models that can benefit from suitable cost effective technologies (Col, 2008) and (Trucano, 2009).

There are significant shortcomings in providing quality healthcare in developing countries. For instance, the number of hospital beds in these countries is quite low, just fractionally better than two per one thousand people (Vital Wave, 2009). Only one in every three women in developing regions receives the recommended care during pregnancy, resulting in high mortality rates (United Nations, 2010). The uses of the Internet and networked systems have received widespread attention in providing solutions in this area. For example, UN Foundation and Vodafone have pursued projects in mHealth (Vital Wave, 2009). These projects cover education and awareness, remote monitoring, communication and training for healthcare workers, disease and epidemic outbreak tracking, diagnostic, and treatment support. Yet, different studies have shown that lack of quality video transmission and effective data storage technologies, make these projects inefficient (Wen-Pai, 2010) and (Kumar, 2010).

As for the commerce, developing countries are facing enormous challenges in coping with the population growth, poverty and illiteracy. The world population is forecast to reach nine billion by 2050, with most of the growth occurring in the developing world (UNDP, 2010). To meet the demands of this population, like other sectors, ICT solutions can be of significant value. But these remain mostly unrealized. A study of existing ICT solutions in agricultural sector for instance, reveals that although farmers are eager to use ICT services, many persisting issues prevent them doing so (PSK, 2010). For example, computer based systems are not operable in the fields due to poor or non-existent network connectivity. Moreover, the existing ICT infrastructure is poor and many are operator based solutions. In addition, farmers need to pay high monthly bills for the SMS and voice based applications. High illiteracy among rural mass is also affecting the efficiency of the applications. Apart from cellular technologies, low cost solutions based on IEEE 802.11 and mesh topologies have been built for specific developing countries (Subramanian, 2006) and (Raman, 2005). However, the emphasis has been on less densely populated areas.

3 ICT-BASED POSSIBLE SOLUTIONS

This section presents an in-depth analysis of appropriate solutions based on the identified research gaps. Then a mapping is formulated to match those solutions to various cellular and wireless technologies.

For each service type, potential areas of development are pointed out. The primary focus is to promote virtual and collaborative models by linking rural facilities with urban ones. To achieve this target, the first step is to design cost-effective, efficient and robust network-based architecture. In order to design such architecture, identification of available technologies that meet the requirements of the proposed solutions needs to be carried out. The next step is to consider the implementation of effective policies and usability of the underlying systems. Effective policies can reduce network deployment and operational costs, leading to stable models. In addition, given the underlying levels of technology awareness in rural areas, to achieve reasonable levels of deployment, user friendliness of the systems are significantly important. Table 1 exemplifies some of the potential areas of technical developments in line with these discussions.

We have undertaken detailed analysis of the various service functionalities and their associated networking requirements, to identify suitable technologies to meet these requirements. These include videoconferencing, video on demand, telemedicine, e-learning, audio lectures, web browsing, newspaper browsing, e-mail, text chat/ short message service/ multimedia message service, electronic banking and other similar types of services. Each of these has its own bandwidth and QoS support requirements. For example, SMS services can be accomplished with GSM that provides a bandwidth of 14.4 Kbps. However, the minimum bandwidth required for video conferencing is 110 Kbps and for ideal cases, a bandwidth of 800 Kbps is desirable. Such a service, will therefore, require other technologies such as 3G, 2.5G, WiMAX or Wi-Fi. The required bandwidth for different features is also related to the utilized coding scheme. That is, with appropriate coding schemes, one may be able to alleviate bandwidth requirement for accessing some features. This will, however, require more technology awareness and possession of computing power.

Considering these criteria, a mapping of requirements of each service to communication technologies can be carried out, as shown in Table 2. This Table identifies different service functionalities, their requirements, and the technologies suitable for accomplishing these requirements.

Table 1: Areas of development for different collaborative perspectives.

Application	*Networking*	*Policy and Design*
• **Connect urban facilities to rural ones.** • **Design a common platform to share resources, and data among rural and urban counterparts.** • **Design interactive, rich, and collaborative models.**	• **Design efficient network architecture to improve the data bandwidth.** • **Match the requirements with available networking technologies.** • **Design interoperable solutions.**	• **Define effective policies to reduce the deployment and operational cost of network technologies.** • **Design user friendly, easy to use system.**

Table 2: Mapping of service provision requirements and communication technologies.

Service	***Minimum bandwidth***	***Desired bandwidth***	***Selected Communication Technology***	***Communication Technology Details***
Videoconferencing	110 Kbps	800 Kbps	HSPA/UMTS/LTE/WiMAX/IEEE 802.11/EDGE	• HSPA: Downstream 1400 Kbs • WiMAX: Downstream 40 Mbs • LTE: Downstream <20 Mbps • 802.11 a/b/g: 1-2 Mbps, 6-54 Mbps, 11 Mbps • UMTS: 2 Mbps • EDGE: 384 Kbps
Telemedicine, E-Learning Audio lectures	110Kbps 110Kbps 110kbps	1.5-7 Mbps 1.5-7Mbps 700 Kbps	HSPA/UMTS/LTE/WiMAX/IEEE 802.11/EDGE	• HSPA: Downstream 1400 Kbs • WiMAX: Downstream 40 Mbs • LTE: Downstream <20 Mbps • 802.11 a/b/g: 1-54 Mbps • UMTS: 2 Mbps • EDGE: 384 Kbps
Electronic Banking	40 kbps	400 Kbps	GPRS/EDGE	• EDGE: 384 Kbps • GPRS: 114 Kbps
Video on demand	1Mbps	1.5 – 7 Mbps	HSPA/UMTS/LTE/ WiMAX/IEEE 802.11b/g	• HSPA: Downstream 1400 Kbs • WiMAX: Downstream 40 Mbs • LTE: Downstream <20 Mbps • 802.11 b/g: 6-11/54 Mbps • UMTS: 2 Mbps
Web browsing & Enhanced web browsing/ E-mail	< 30.5 Kbps < 24 Kbps < 10K	< 10K	GSM/GPRS/EDGE	• EDGE: 384 Kbps • GPRS: 114 Kbps • GSM : 14.4 Kbps
Text chat/ Multimedia message service (MMS)	< 1K	< 1K	GSM/GPRS/EDGE	• EDGE: 384 Kbps • GPRS: 114 Kbps • GSM : 14.4 Kbps

4 ARCHITECTURE DESIGN

In this section, we present the conceptual design of the proposed network-based architecture, eVillage. As pointed out earlier, this will be based on considering three access networks that complement each others functions and services.

4.1 eVillage Architecture

The core architecture consists of three main parts. They are Rural Area Network (RAN), Urban Area Network (UAN) and Connectivity Network (CN). IEEE 802.11, cellular, and WiMAX technologies are considered as suitable technologies in the design since these technologies are easy to deploy and widely available in developing countries. Satellite technologies are costly in compare to these technologies even though they can serve larger areas. In addition, “last-mile connectivity” technology WiMAX can cover a larger area and efficiently serve as a backbone network.

Rural Area Network (RAN): RAN consists of three access networks aimed for for education, health and commerce. Rural schools, libraries and other education facilities are included in education access network. A remote student connects to rural area network to get access to urban facilities. The health access network involves hospital, medical centers, rural hospital workers, emergency system, and remote patients. Similarly, agricultural workers and farmers are connected via one stop ICT center. The core technologies in RAN are IEEE 802.11 and existing cellular technologies such as GSM, GPRS, and Universal Mobile Telephone System (UMTS). Rural residents use wireless local area network and cellular technologies for local connection. A remote patient connect to a doctor in the nearest rural facility using IEEE 802.11 and cellular technology. Longer distance from a base station results in weak signal strength in GSM and GPRS networks. Moreover, the maximum number of broadband users UMTS technologies can accommodate is affected by interference. As a result, only the users near Node B can get the benefit of broadband. For this reason, UMTS uses the concept of Femto cells, which results in large number of cell towers leading to high infrastructure costs. To overcome these shortcomings, IEEE 802.11 technology and mesh topology can be deployed to extend the coverage area of UMTS.

Urban Area Network (UAN): UAN consists of three access networks same as RAN. Schools, teachers, students, libraries and other education facilities in urban area are connected to education access network. And this is connected to education access network of rural areas. Similarly, health and commerce facilities are connected using their own access network and in turn they are connected to their own rural counterpart. In UAN both wireless and wired technologies are considered available in that region. They use the available access technologies to communicate within urban area and connect to the Internet. However, they use the integrated WiMAX, Wi-Fi and cellular infrastructure to connect to rural areas. One part of rural area might not able to access high speed broadband yet they are able to get necessary services from urban areas using integrated architecture.

The connectivity network is responsible for connecting urban facilities with rural ones. The core technologies are cellular base stations and IP network. WiMAX base stations also work as backhaul technology for cellular networks to connect RAN with the Internet.

4.2 Access Networks

The proposed architecture is further divided into three access networks. They are learning access network, health access network, and commerce access network.

The primary focus of this study is to formulate a cellular and wireless technology based school cluster (SC) model for learning access network. In proposed SC, the rural and urban education facilities are connected over wireless and cellular technologies. The rural schools and students in remote area are connected with each other via wireless local area network and cellular technologies. They use Wi-Fi and cellular access technologies to connect to urban schools and Internet.

One of the considered scenarios is that rural students want to join a lecture from a renounced urban school. However, they do not have broadband access. In such case, if urban school is connected to rural school using integrated WiMAX, Cellular and IEEE 802.11 technologies the students of rural schools can still view the lecture in spite of not having high speed broadband network. The teachers of urban schools can teach the rural students directly using live streaming, video, and audio conferencing features.

Health access network architecture also consists of different wireless and cellular technologies. It proposes to form cluster of hospitals among urban and rural hospitals to facilitate rural residents. There is a common platform to share health information, patient data, and other resources. To form an interactive and collaborative virtual health model the proposed functionalities are video training for rural health workers, remote treatment, and consultancy with patients. Commerce access network adopts the similar service model architecture as well. The model proposes to create one stop virtual ICT centers and virtual market place to facilitate the rural entrepreneurs and connect the rural market with urban ones.

5 SIMULATION STUDIES AND ANALYSIS

We have used OPNET modeler 17.1 (Education version) to simulate different scenarios of the learning access network. The architecture is divided into three sectors they are: urban area network (UAN), connectivity network (CN) and rural area network (RAN) as discussed earlier in the architecture section. Both UAN and RAN are further divided into small zones based on the technologies the education facilities are using. Video conference is deployed over this architecture to evaluate the performance of the integrated architecture in terms of delay, jitter, packet loss, packet delay variance and

MOS. Table 3 represents the simulation specifications.

Table 3: Simulation specifications.

Application	***Specifications***	
	Metrics	**Acceptable performance level**
Video-conferenceing	Packet end-to-end delay	< =150ms
	Packet delay variance	<= 30ms
	Packet loss	<=1%
Audio conferencing	Mean Opinion Score (MOS)	1 to 5, 1 being the worst and 5 the best
	Jitter	<= 30ms
	Packet loss	<=1%
	Packet end-to-end delay	<=150

In these simulations, for RAN the key technologies considered are UMTS and Wi-Fi. On the other hand, for UAN, WiMAX is regarded as the central technology. RAN consists of UMTS and Wi-Fi client zone. In UAN there is one cluster, which consists of WiMAX server, WiMAX base station and the gateway node. CN has the IP backbone network, which connects RAN with UAN. There is also a proxy server zone which consists of Signaling initiation protocol (SIP) proxy server. The UAN and RAN are connected to SIP proxy server through IP backbone network. In scenario one, UMTS technology zone has three rural education facilities, which are in a video session with an urban education facility. Similarly, Wi-Fi technology zone has three facilities engaged in a video session with urban facility. All these facilities start the video session with urban facility at the same time. In the second scenario, the numbers of facilities are increased to twelve six in each zone and in the third one the numbers of facilities are increased to twenty.

In the simulated scenarios the video transmissions are set as unidirectional and voice transmissions as bi-directional connections. In rural areas the network has bandwidth limitations and constraints so it is natural for bi-directional video transmission to experience poor performance. Considering the device size and network bandwidth, for UMTS clients the time interval for video transmission is set to 10fps and frame size is set to 2500 bytes. For Wi-Fi clients the time interval is set to 30fps and frame is 4000 bytes. For Wi-Fi clients the type of service (TOS) is set to interactive multimedia and for UMTS client the TOS is set to best effort service. GSM Full rate silence supported coding scheme and SIP signaling protocol is used for voice transmissions. Compression-decompression delays are set to 0.02 seconds, incoming-outgoing silence lengths are set to 0.65 seconds, and incoming-outgoing talk spurt lengths are set to 0.352 seconds. TOS for voice transmissions is set to Interactive voice.

In OPNET it is possible to set user profile for each type of user. In this simulation, separate user profiles are set for UMTS and Wi-Fi clients. All the clients start the video conference session at the same time. As in OPNET the video conference do not have embed voice transmission so to create a more realistic scenario a voice transmission starts at the same time with video transmission.

WiMAX MAC layer has four service classes to support QoS needs for different applications. They are Unsolicited Grant service (UGS), real-time polling service (rtPS), non real-time polling service (nrtPS), and best effort (BE) service. These classes are related to several important parameters, they are: maximum sustained data rate, minimum reserved data rate, scheduling type and maximum latency. In simulated scenarios initially rtPS service class is used for both video and voice transmission. 802.11b MAC protocol is used for Wi-Fi technology zone.

After configuring the relevant parameters for clients and servers, each scenario is run with the defined setup. Previously stated metrics are calculated for each scenario. In the first scenario, video transmissions experience 1.5 µs of packet delay variance and 7.8 to 8.3 ms of end-to-end delay. There is no packet loss in this case. In the second scenario, the packet delay variance and the end-to-end delay both exhibit higher values compared to the first one. They are 1.6 to 4 ms and 80 to 110 ms, respectively. For this case, packet loss levels in the order of 2.2% can be experienced. In the third scenario, video transmission packet delay variances have values ranging from 0.4 to 2.2 ms. The packet end-to-end delays are between 100 and 150 ms, which are still within the acceptable performance levels. However, the transmissions experience large levels of packet loss, which are beyond acceptable performance levels. Figure 1 shows the packet loss ratio for video transmissions.

It seems fruitful to try to identify the reasons for such levels of packet loss. The conference server to base station uplink connection shows a significant packet loss. To enhance the performance, the service class for videoconference is changed to UGS from rtPS. This way, the packet delay variance and packet end-to-end delay do significantly improve. They are

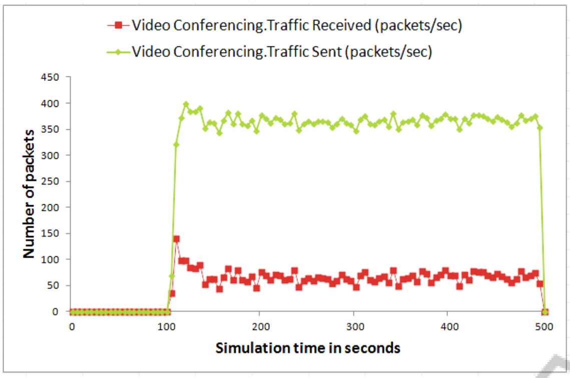

Figure 1: Packet loss for video transmission.

0.5 µs and 110 ms respectively. Perhaps more importantly, packet loss improves dramatically. It comes down to around 0.7% in most of the cases. Some stages of the simulation even experience no packet loss. Figure 2 shows the improved performance in terms of packet loss.

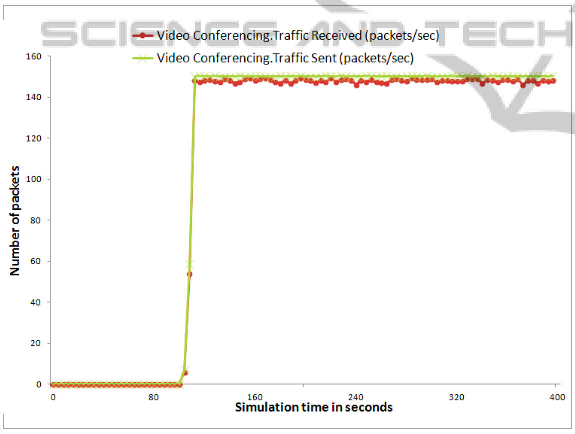

Figure 2: Video transmission packet loss improvements, after change of service class.

In the first scenario, the MOS value for voice transmission is 4 and in the second scenario it is 3. However, in the third scenario it varies within a range from 1.9 to 4.3. In the first scenario, the jitter is between 25 and 35 µs and packet end-to-end delay is 110 to 120 ms. For the second scenario, voice transmissions experience a jitter value between 200 and 400 µs and packet end-to-end delays of 150 ms. In both cases, there are insignificant packet losses. With the increased number of rural clients, the third scenario jitter values are seen to be between 0.02 and 0.24 ms and packet end-to-end delays are between 80 and165 ms. Figure 3 shows the packet loss for voice transmission.

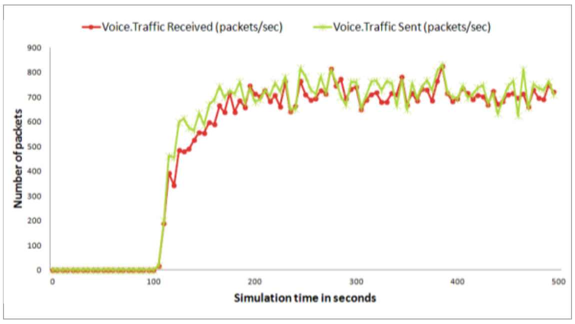

Figure 3: Packet loss for voice transmission.

6 CONCLUSIONS

Wireless and cellular technologies provide viable solutions for sustainable rural community developments. However, they pose serious limitations in delivering real-time interactive applications. However, interactivity is among the key prerequisites for successful deployment of many several network-based solutions in such areas. This study examines some of the relevant principal issues and investigates how they may be overcome. In this work, a wireless-cellular based integrated architecture is designed and analysed through simulation studies. More specifically, important QoS parameters including delay, jitter, packet delay variance, MOS, and packet loss for deployment of some interactive services over this architecture have been studied. The results indicate that this architecture can support a reasonable number of clients in rural areas. Obviously, beyond a certain number of clients, QoS becomes an issue, which to some extent can be addressed through appropriate reconfiguration of the underlying network-based systems. Our future works will expand the deployment and the study of the range of technologies utilized in the proposed architecture.

ACKNOWLEDGMENTS

We would like to thank OPNET for providing us with Modeler software license, which has been really useful for simulating the integrated architecture.

REFERENCES

Anastasiades, P. S., 2009. *Interactive videoconferencing and collaborative learning for K-12 students and* *teachers : theory and practice*. New York: Nova Science Publishers.

COL., 2008. *Using Mobile Technology for Learner Support in Open Schooling*: South Asian Institute for Distance Education.

Kumar, B., Singh, S. P., and Mohan, A., 2010. Emerging mobile communication technologies for health. *Proc Computer and Communication Technology (ICCCT).*

PSK, K., 2010. *Mapping and Preliminary Evaluation of ICT Applications Supporting Agricultural Development*. An IFC World Bank Group sponsored study in Uganda, India and Indonesia: IFC World Bank Group.

Raman, B., and Chebrolu, K., 2005. Design and evaluation of a new MAC protocol for long-distance 802.11 mesh networks. *Proc 11th annual international conference on Mobile computing and networking*.

Rana, M. M. P., 2011. Urbanization and sustainability: Challenges and strategies for sustainable urban development in Bangladesh. Environment, *Development and Sustainability*, 13(1), 237-256.

Subramanian, L., Surana, S., Patra, R., Ho, M., Sheth, A., and Brewer, E., 2006. Rethinking Wireless for the Developing World. *Proc Hotnets-V*.

Trucano, M., 2009. *Surveying the use of mobile phones in education worldwide*. http://blogs.worldbank.org/edutech/surveying-the-use-of-mobile-phones-in-education-worldwide .

UNDP, 2010. *The Real Wealth of Nations: Pathways to Human Development. New York*: United Nations.

United Nations, 2010. *The Millennium Development Goals Report*: United Nations.

Vital Wave Consulting, 2009. *mHealth for Development: The Opportunity of Mobile Technology for Healthcare in the Developing World*. Washington, D.C. and Berkshire, UK: UN Foundation-Vodafone Foundation Partnership Vital Wave Consulting.

Wen-Pai, L., Leung, H., and Estrada, E., 2010. Transforming telemedicine for rural and urban communities Telemedicine 2.0 - any doctor, any place, any time. *Proc 12th IEEE International Conf e-Health Networking Applications and Services (Healthcom)*.