A WiFi-based Reliable Network Architecture for Rural Regions

Md. I. Hussain, S. K. Dutta, N. Ahmed, I. Hussain
Department of IT
North-Eastern Hill University
Shillong, India
ihussain@nehu.ac.in, sushantatzp@gmail.com
nurzaman713@gmail.com, iftiy.muzik@gmail.com

***Abstract*—WiFi is being considered as an attractive option in providing low cost Internet connectivity to rural areas, and thereby reducing Digital Divide with urban areas. Most of the WiFi-based Long Distance network architectures extend Internet to rural regions through a single gateway node which is connected to high speed Internet. If the gateway node fails in such single gateway-based rural networks, the entire network gets collapsed. In this paper, we propose a reliable and low-cost WiFi based rural network architecture using multi-gateway concept. The proposed network architecture also allows load balancing among the available gateways. In such multi-gateway architecture, the network recovers from gateway failure and reestablishes the ongoing communication within 2-4 seconds time. The simulation results in NS-2 validate the claims of the paper.**

Keywords—Digital Divide, WiFi, WiFi based Long Distance Networks

I. INTRODUCTION

In the last few decades, the world has begun to undergo a new technologically driven revolution, allegedly leading towards what is commonly called "*the Information Age*". Most traditional communication media including telephone, music, film, television, etc., are being reshaped or redefined by the Internet giving birth to new services such as Voice over Internet Protocol (VoIP) and Internet Protocol Television (IPTV). The Internet has enabled and accelerated new forms of human interactions through instant messaging, Internet forums, and social networking. The Internet also provides greater flexibility in working hours and location. Nowadays Internet has become a very useful technology in education sector by the introduction of E-learning. Applications like Video on Demand, Video Conferencing, File transfer, Virtual Laboratory, etc., has emerged to provide education through Internet. Despite all utopian dreams, the Information age has so far touched only a small share of the world's population. Though Information and Communication Technology (ICT) has brought radical changes in human lives, but unfortunately, most of the gains of this digital revolution have been restricted to the urban regions leaving the rural areas aside. This phenomenon called "Digital Divide" is reflected within one country or population, or between industrialized countries and developing countries. The main reason behind this fact is the economy of a country which drives the affordability of high cost internet technologies. Wireless technologies like WiMAX and VSAT are capable of providing connectivity to rural regions but these are relatively expensive for the people living in rural areas.

The scenario of Digital Divide is not different in India. Fiber optic networks only reach the major cities and head quarters of every district leaving most of the countryside underserved. Thus, Internet connectivity is being facilitated only to the neighboring areas of the district head quarters and the areas that are far from the reach of optical fiber are deprived of proper Internet connectivity.

Although WiFi was originally designed for short distance communication, efforts are on to stretch WiFi link up to a few tens of kilometers. As a result, WiFi-based Long Distance (WiLD) network ([1], [2], [3], [4], [5], and [6]) is emerging as a viable option in providing Internet connectivity to the underserved regions that are usually far from the district head quarters. As a low cost alternative technology, WiFi is capable of supporting various multimedia applications including heterogeneous types of traffic (e.g. voice, video and best effort) with various QoS requirements. However, most of the existing WiLD network architectures found in the literature fails to establish reliability in the sense that the whole network topology is dependent on a central gateway node. The failure of the gateway node may disconnect the entire network from the outside world.

In this paper, we first present the different WiLD network architectures available in the literature. Then, we propose a reliable network topology for rural WiLD networks. The proposed architecture allows tolerance of gateway failure and load balancing among multiple gateways. Performance of the proposed reliable WiLD network architecture has been evaluated through simulation in NS-2 [7] considering some realistic traffic scenarios. The simulation results show that the failure of some links does not stop flows of traffic permanently rather resumes ongoing transmission immediately.

The rest of this paper is organized as follows. Section II describes various low cost technologies having potential to solve the Digital Divide problem. Architecture of WiFi-based long distance network is briefly explained in Section III. The proposed reliable low cost network architecture is presented in Section IV. Section V shows the performance of the proposed network architecture. Some pertinent research challenges of multi-gateway based WiLD networks are presented in Section VI. The final section provides the conclusion of the paper.

II. BACKGROUND

Recent advancement in ICT has brought the world to a small village by enabling easier and faster communication. But unfortunately, most of the gains of the digital revolution have been restricted to the developed regions leaving the rural areas aside which have created Digital Divide. A Digital Divide is an economic inequality between groups, broadly construed, in terms of access to, use of, or knowledge of ICT which is reflected within one country or population, or between industrialized countries and developing countries. The digital divide is manifested in unequal penetration of telecommunication and Internet infrastructures. The world's most diverse region, Asia encompasses 30% of the total land mass and 60% of the world's population (4.6 billion people) which turns out to be the world's most populous continent [8]. Out of the world's Internet users, 44.8% resides in Asia. Internet penetration ranges below 30% in countries like India, Bangladesh, Bhutan, Myanmar, Nepal, and Afghanistan whereas countries like China, Japan, South Korea, and Malaysia have Internet penetration above 50% [9]. According to NSSO (2014), in India among the households with at least one member of age 14 years and above, nearly 16% of rural and 49% urban households have Internet access. This greatly reflects the existence of digital divide in India.

The major cause of digital divide is economy. People residing in the rural areas cannot afford high cost Internet connectivity. In rural areas of developing countries like India, Bhutan, and Bangladesh, low user density and low income levels of the people limits the affordability of existing Internet technologies which incur a high deployment cost. Extension of Internet to rural underserved areas through the use of wired technologies are considered to be costlier and inefficient. None of the traditional wire-line connectivity solutions (Fiber-Optics, Coaxial Cable, etc.) are going to be economically viable for such regions at least over the next decade. In such a situation, wireless technologies could be the most promising and cost effective alternative to wired solutions [10].

Wireless technologies can to be looked into from two perspectives: that of access network and the backhaul network [1]. So far, most of the wireless networks are primarily used to distribute Internet in short ranges. However, recently such technologies are being tried to be used for extending Internet connectivity for longer ranges too. Some low cost technologies suitable for extending Internet connectivity to the rural region are discussed below-

1) Bluetooth [11]

Bluetooth is a short range communication technology that can connect devices like laptops, cell phones and computers within a radius of around 10 meters. It is primarily used in personal area networks (PANs) which offers limited data rates. Efforts are being made to use Bluetooth beyond its intended purpose. Raman et al. through their research project Lo3 [12] are trying to extend the range of Bluetooth to provide Internet services in rural villages.

2) WiMAX [13]

WiMAX (IEEE 802.16 standard) is said to have the potential to replace many forms of telecommunications. While WiFi is good for campus buildings, WiMAX can provide connection to areas spanning more than 25 kms from the base station with line of sight (LoS). Its ability to offer broadband connection makes it suitable for a wide range of applications too. WiMAX can be used in creating backhaul for extending connectivity to remote areas. Unfortunately, despite of its promising characteristics, just because of cost inefficiency, WiMAX is not well accepted for providing rural connectivity.

3) Very Small Aperature Terminal (VSAT) [14]

VSAT is a wireless technology worth discussing especially when designing rural network architecture. Here, transmitting and receiving station transfers Internet traffic via artificial satellite. Its biggest advantage in remote areas is that it can provide Internet access irrespective of the terrain where other technologies are not deployable. Because of very long distance link between the satellite and the sending and receiving stations, high transmission delay is inevitable which makes VSAT unsuitable for today's Internet.

4) WiFi [15]

Originally, WiFi was designed to support Wireless Local Area Networks (WLANs) for short range communication operating in license-free spectrum. Recently, research works have started in using WiFi to extend connectivity to remote areas that can stretch for a few tens of kilometers. The popular standards of WiFi; 802.11b/g/n use spectrum frequency of 2.4 to 2.4835 GHz and 802.11a operates in the frequency of 5.725 to 5.85 GHz. A lot of end user devices are now WiFi compatible and are available at low prices from vendors because of its standardization and interoperability between different vendors.

Out of the wireless solutions available for creating long distance rural networks such as WiMAX, VSAT, WiFi, etc., WiFi is considered to be an attractive low cost solution ([1], and [10]). WiFi-based Long Distance (WiLD) backbone is being used to extend Internet connectivity to the remote areas of the developing regions. The probable reasons for choosing WiFi include its wide availability of commodity IEEE 802.11 hardware at low cost and its license free operation in the ISM band.

III. WIFI BASED LONG DISTANCE (WILD) NETWORK ARCHITECTURE

Although WiFi was originally designed to provide connectivity for short distances in indoor environment but it can be enhanced for long distance through proper planning. WiLD networks are usually extended to multiple hops featuring long distance point-to-point wireless links. In this type of networks, wireless nodes are equipped with multiple radios co-located on the same tower. The long distance point-to-point wireless links are enabled by high-gain directional antennas with gains as high as 24-27dBi. The heights of the towers are normally set in the range of 25 to 50 meters to cover a few tens of kilometers of distance by a single link. This network architecture is best suited to extend Internet connectivity to the rural areas. With such architecture, most of the villages can be reached from the district head quarters using 2 to 3 hops.

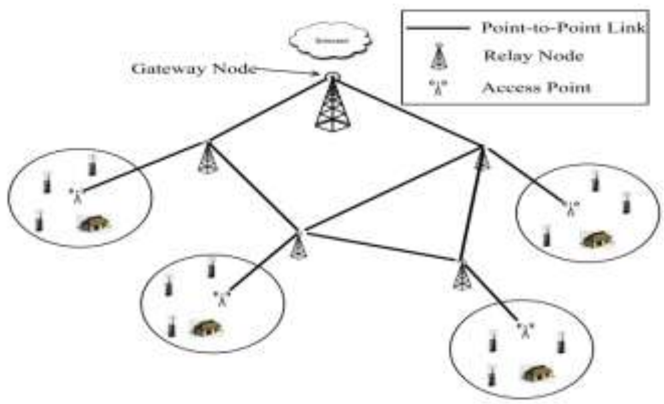

Figure 1:WiLD network architecture for rural connectivity.

Figure 1 shows a typical WiLD network architecture which consists of several point-to-point WiLD links. The entire network is connected to the Internet through a gateway node. The intermediate nodes work as relay nodes which forwards traffic towards the gateway and back. The leaf nodes (access points) provide end-user connectivity.

Configuration of a typical point-to-point link is depicted in Figure 2. Parabolic grid antenna with 24-27dBi gain is used to provide directional connectivity which cost approximately 6,000 to 10,000 rupees. With its light weight, it is easy to mount on tall towers. To establish a point-to-point link, there has to be LoS between the receiver and transmitter antennas. It is achieved by mounting the antennas on tall towers which constitute the major cost of network deployment. To avoid obstacles between nodes, the height of antenna is required to be erected 25 to 50 meters of height. Point-to-multipoint links using sector antenna are also used to serve multiple stations in a given region.

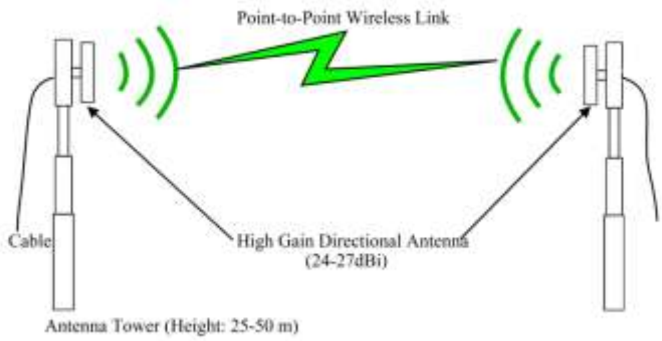

Figure 2: A typical point-to-point link **[10]**

IV. A RELIABLE LOW COST RURAL NETWORK ARCHITECTURE

WiLD networks are emerging as a backbone for providing low-cost connectivity and are increasingly being deployed in developing regions. However, most of the WiLD network architecture fails to provide reliability in the sense that the whole network topology is dependent on a single gateway node. The failure of the gateway node may lead to the collapse of the entire rural network.

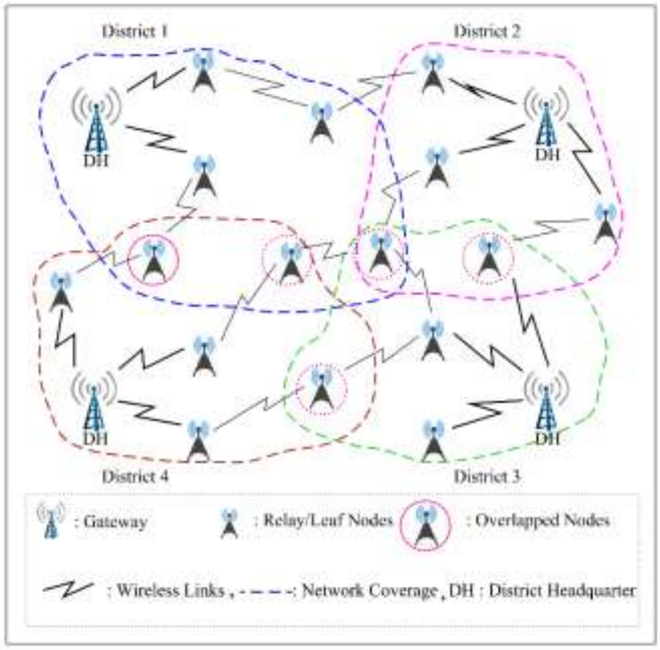

Figure 3: A reliable rural network architecture

The proposed reliable rural network topology is explained in Figure **3**. In our design, we consider that all the district head quarters are connected to high speed Internet using Fiber Optics. The gateways of the WiLD networks are necessarily located in the district head quarters. The nodes in the network are connected to each other using wireless point-to-point or point-to-multipoint links. A planned network setup provides nodes in the network with seamless connectivity to all possible gateways, i.e., the gateways of the neighboring districts.

The network consists of multiple intermediate nodes usually formed using high-raised towers about 25-50m. The nodes are connected by long distance point-to-point wireless links with high-gain (24-27dBi) directional antennas and beam-widths of about 8^0. Each node in the network is equipped with multiple radio interfaces which enable multi-hop transmission of traffic over such links. The village nodes get connectivity to the gateway through the intermediate nodes and provide connectivity to the village access points using point-to-multipoint links. Internet traffic can reach from village nodes to any one of the gateways over multiple hops. In such scenarios, TDMA-based MAC protocols are preferred to enhance the network performance by ensuring non-interference from other simultaneous transmissions ([1], [16], [17] and [18]) and hence meeting some sort of QoS demands of various real-time applications.

In presence of multiple gateways, a node has freedom to choose any gateway based on the availability and its requirements. The network can be made gateway fault tolerant by allowing the nodes to choose any other gateway in case of the failure of the current one. The nodes situated in the overlapped regions take the responsibility to route the packet from one network to another. The out-bound network traffic can be evenly distributed among the available gateways to achieve gateway load balancing.

V. PERFORMANCE EVALUATION

We performed extensive simulation in modified version of NS-2.34 [7] to evaluate the performance of the proposed reliable WiLD network architecture.

Table 1: Simulation Parameters

Parameters	Value
Traffic Types	CBR, FTP
Packet Size	1400 Bytes
Routing Protocol	Extended AODV
Radio Propagation Model	Two Ray Ground/Reflection Model
Link Bandwidth	11Mbps
Antenna Type	Grid Parabolic Antenna
Antenna Gain	24dBi
Distance Per Hop	9kms
No. of Nodes (Max.)	6
TDMA Slot Time (Default)	4ms
Guard Time	100µs
TDMA Queue Length	50

As shown in the Figure 4, we considered a topology of 6 nodes with at least two links connected with each of them. We have considered 11Mbps half-duplex link for the simulation of both UDP and TCP flows. The UDP flow generates constant bit rate traffic (CBR), one packet every 2ms with a packet size of 1400 bytes. The TCP flow is generated by a File transfer Protocol (FTP) application considering a maximum packet size of 1000 bytes. The variant of TCP considered is New Reno with default parameter settings.

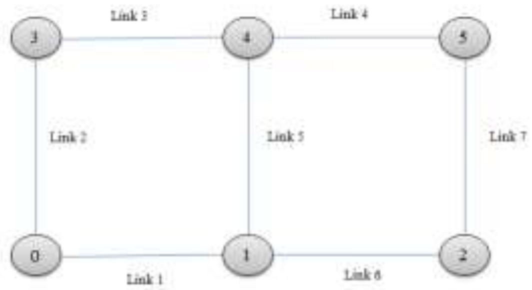

Figure 4: Network topology for simulation

The existing Ad-hoc On-demand Distance Vector (AODV) routing protocol fails to discover and exploit multiple links in multi-interfaces based multi-hop wireless network. Therefore, the AODV routing protocol is extended to provide multi-interface support for possible multi-gateway communications. In the extended AODV, the routing agent decides the outgoing interface through which the packets need to be forwarded to the destination. Also, it can pass the packets destined for outside the network through one of the available gatways and can switch gateways in case of gateway failure.

Figure 5 and Figure 6 show the aggregate throughput for UDP and TCP traffic in the cases-1) without gateway failure, and 2) with gateway failure. A failure of gateway in the path of current traffic flow is shown at times during 8-10 and 28-30 Seconds of the simulation time. The routing protocol successfully came out of that failure and found an alternative path (through another gateway) to forward the packets towards the destination. As the TCP protocol establishes a new connection after the discovery of alternate gateway, it takes more time than UDP to recover from the failure and re-establish the ongoing communication.

a) Measurement of UDP throughput with increasing time

Figure 5: UDP traffic flow from node 5 to node 0

b) Measurement of TCP throughput with increasing time

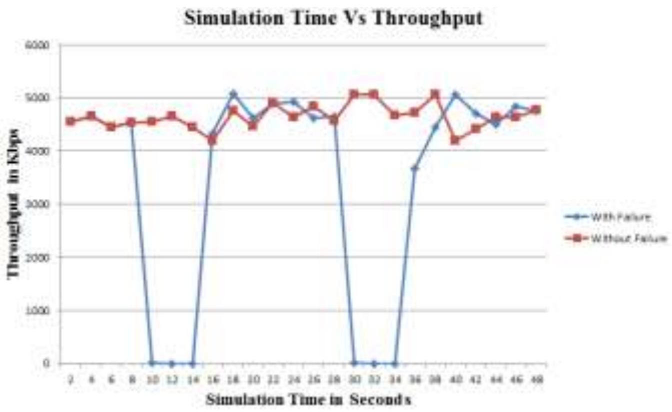

Figure 6: TCP traffic flow from node 5 to node 0

As shown in the Figure 7, delay incurred by UDP traffic is 292ms without failure of nodes in the path and 298ms considering a node failure in the path. Real time applications such as VoIP and Videoconferencing have strict delay requirements (<150ms). Hence, further schemes (MAC, Scheduling etc.) needs to be designed for provisioning QoS for the real-time applications.

c) Delay analysis

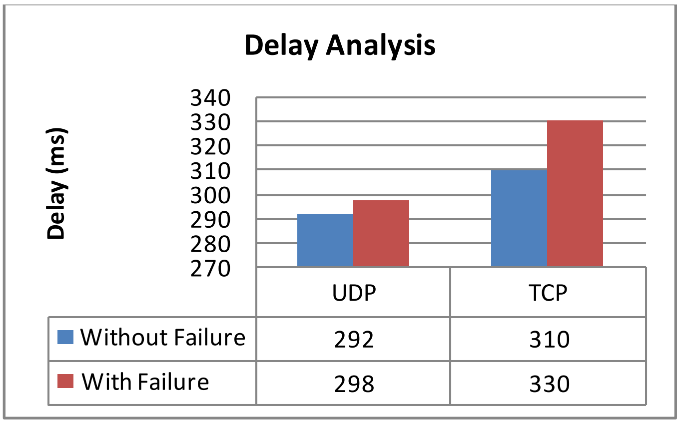

Figure 7: Delay incurred by UDP and TCP traffic from node 0 to node 5 in failure and without failure conditions

VI. SOME RESEARCH ISSUES OF MULTI-GATEWAY BASED WILD NETWORKS

Different research issues emerging in the proposed reliable architecture are layer wise explained as follows-

1) Physical Layer Issues

Some of the major physical layer components of WiLD networks, their issues and possible solutions are discussed here.

Radio Access: With the support of single interface support in a high-rise tower, communication among neighbors using link is not possible and hence simultaneous channel access fails. We need to support multiple interfaces to achieve communication with the neighbor using point-to-point links.

Channel: Use of single channel in a node (using high gain antenna) disturbs simultaneous transmission and hence possibility of interference is high. Multiple channels for multiple interfaces will increase the performance of the network.

Antenna Processing: Antenna alignment is one of the major issue. A node equipped with multiple antennas which need to be aligned to achieve a point-to-point link where beam-width is very small (about 8 degrees).

2) Medium Access Control Issues

The standard 802.11 MAC protocol uses CSMA/CA channel access mechanism which was originally designed to resolve contention in indoor conditions. As it was not designed for long distance operation, real WiLD links show abysmal end-to-end performance [19]. Patra et al. [20] pointed out the key reasons for this as (a) collisions at longer distances, (b) inefficient link-level recovery, and (c) inter-link interference.

On the contrary, TDMA-based channel access mechanisms permit several users to share the same channel by dividing the time into different time slots. It saves the unnecessary overhead of contention for gaining access to the shared medium. Based on the schedule prepared, each node gets a particular share of non-overlapping time to transmit and thus TDMA-based MAC protocols are collision-free. The main task in preparing a TDMA schedule is to allocate non-overlapping time slots to each station depending on the topology, the packet generation rates of nodes, traffic priorities considered, etc. TDMA-based MAC protocols enhance network performance by ensuring non-interference from other simultaneous transmissions. These advantages make TDMA-based MAC protocols more suitable for WiLD networks.

A careful TDMA transmission schedule preparation in order to optimize the network performance is a challenging problem.

3) Routing Issues:

The existing routing protocols such as AODV, DSR and DSDV are not suitable for WiLD networks as these protocols work only in single radio environment. Although most of the WiLD networks use static routing protocol taking the architectural advantages, but static routing protocol do not support multiple gateways as the protocol assign fixed routes. These protocols cannot choose the alternative nearest gateway in case of gateway failure. Further, in static routing, the failure of a link leads to starvation until a new gateway is choosen again. Therefore, the routing protocol in multi-gateway rural network should provide supports so that the ongoing communications are continued by choosing another gateway.

In such situations, a set of nodes may find the same gateway as a part of their optimal paths which will overburden that gateway node. Multiple gateway-path selection may help in balancing the traffic among the available gateways in such situations.

4) Transport Layer Issues

Responsibility of connection oriented Transport layer is to provide end-to-end reliability. In WiLD networks, delay is relatively high because- a) Long distance wireless links and 2) Multi-hop operation. In such situation, the acknowledgement lost or timeout may occur repeatedly and reliability issues arise. Harras et al. [22] points out different solutions in providing reliability through different acknowledgement mechanisms in delay tolerant networks. Those are- a) hop-by-hop b) active receipt, and c) passive receipt. These approaches can be applied to achieve more end-to-end reliability in the proposed network.

VII. CONCLUSION

In this paper, we have proposed a reliable network topology for WiFi based long distance rural networks. The proposed architecture allows achieving tolerance of gateway failure and load balancing among multiple gateways. Designing a suitable routing protocol for multi-gateway mesh network and load balancing among the available gateways using multipath routing have been left as future work.

ACKNOWLEDGMENT

This work has been supported by the research project entitled “QoS Provisioning in WiFi-based Long Distance Networks for Hilly Terrain Areas” (Ref. No. 14(8)/2011-CC&BT dated: 06/01/12) funded by DeitY (CC & BT), Govt. of India.

REFERENCES

[1] K. Chebrolu and B. Raman, "FRACTEL: A Fresh Perspectiveon (Rural) Mesh Networks," in *ACM SIGCOMM Workshop onNetworked Systems for Developing Regions*, August 2007.

[2] D. Aguayo, J. Bicket, S. Biswas, D. S. De Couto and R. Morris, "Architecture and Evaluation of an Unplanned 802.11b MeshNetwork," in *Proceedings of the 11th Annual International Conference on Mobile Computing and Networking (MOBICOM)*, 2005.

[3] D. Wu, D. Gupta and P. Mohapatra, "QuRiNet: A Wide-area Wireless Mesh Testbed for Research and Experimental Evaluations," *Ad Hoc Networks*, vol. 9, no. 7, pp. 1221-1237, 2011.

[4] "The Akshaya E-Literacy Project," [Online]. Available: http://www.akshaya.kerala.gov.in/index.php/e-literacy.

[5] P. Bhagwat, B. Raman and D. Sanghi, "Turning 802.11 Inside-Out," *ACM SIGCOMM Computer Communication Review*, vol. 34, no. 1, pp. 33-38.

[6] S. Surana, R. Patra, S. Nedevschi and E. Brewer, "Deploying a Rural Wireless Telemedicine System: Experiences in Sustainability," *COMPUTER*, vol. 41, no. 6, pp. 48-56, 2008.

[7] "Network Simulator- ns2," [Online]. Available: http://www.isi.edu/nsnam/ns/.

[8] [Online].Available:http://www.nationsonline.org/oneworld/world_population.htm.

[9] M. M. Group, 2013. [Online]. Available: www.internetworldstats.com.

[10] "RuralNet (Digital Gangetic Plains: DGP) 802.11-based Low-Cost NetworkingforRural India," [Online]. Available: http://www.cse.iitk.ac.in/users/braman/dgp.html.

[11] J. C. Haartsen, "The Bluetooth radio system," *Personal Communications, IEEE,* vol. 7, no. 1, pp. 28-36, 2000.

[12] B. Raman and K. Chebrolu, "Lo3: Low-cost, Low-power, Local Voice and Messaging for Developing Regions," *Networked Systems for Developing Regions(NSDR),* 2009.

[13] J. G. Andrews, A. Ghosh and R. Muhamed, Fundamentals of WiMAX: Understanding Broadband Wireless Networking, Pearson Education, 2007.

[14] N. Abramson, "VSAT data networks," *Proceedings of the IEEE,* vol. 78, no. 7, pp. 1267-1274, 1990.

[15] M. Gast, 802.11 Wireless Networks, O'Reilly, 2006.

[16] M. Alicherry, R. Bhatia and L. E. Li, "Joint Channel Assignment and Routing for Throughput Optimization in Multi-radio Wireless Mesh Networks," in *Proceedings of the 11th Annual International Conference on Mobile Computing and Networking (MOBICOM)*, 2005.

[17] M. Kodialam and T. Nandagopal, "Characterizing Achievable Rates in Multi-hop Wireless Networks: The Joint Routing and Scheduling Problem," in *Proceedings of the 9th Annual International Conference on Mobile Computing and Networking (MOBICOM)*, 2003.

[18] A. Raniwala, K. Gopalan and T. Chiueh, "Centralized Channel Assignment and Routing Algorithms for Multi-channel Wireless Mesh Networks," in *ACM SIGMOBILE Mobile Computing and Communications Review*, 2004.

[19] B. Raman and K. Chebrolu, "Design and Evaluation of a new MAC Protocol for Long-distance 802.11 Mesh Networks," in *Proceedings of the 11th Annual International Conference on Mobile Computing and Networking (MOBICOM)*, 2005.

[20] R. Patra, S. Nedevschi, S. Surana, A. Sheth, L. Subramanian and E. Brewer, "WiLDNet: Design and Implementation of High Performance WiFi Based Long Distance Networks," in *Networked Systems Design and Implementation (NSDI)*, 2007.

[21] I. D. Chakeres and E. M. Belding-Royer, "AODV Routing Protocol Implementation Design," in *Proceedings of the 24th International Conference on Distributed Computing Systems Workshops*, 2004.