Green WOBAN: A Review

Meetu Singh, Vandana Sharma, Roshan Jain

Abstract— **With the increase of bit-rate requirements in access networks, future-proof access technologies should be energy efficient. This paper first presents an architecture and a vision for the WOBAN and articulates why the combination of wireless and optical presents a compelling solution that optimizes the best of both worlds. We recapitulate the design techniques dedicated to build "green" hybrid access network for a high throughput and low energy consumption. We devise novel energy saving techniques on a access network paradigm, called wireless optical broadband access network (WOBAN).**

The hybrid WOBAN is a promising architecture for future access networks. Recently the wireless part of WOBAN has been gaining increasing attention, and early versions are deployed because of low energy efficiency and lack of service quality. This architecture saves on network deployment cost because the fiber need not to penetrate each end-user, and it extends the reach of optical access solutions. To develop a green WOBAN, it is important to focus on reducing its power consumption, and in this work, we present an efficient resource management technique for WOBAN that reduces the power consumption of the optical line terminal (OLT) and optical network unit (ONU) by introducing sleep modes for the OLT and ONU, based on the service class and traffic load. We can conclude that there are large scopes of energy saving if we incorporate energy saving design and routing in access networks.

Index Terms— **Access, green, hybrid, network, wireless-optical, wireless-optical broadband access network (WOBAN).**

I. INTRODUCTION

INFORMATION and communication technology (ICT) has p transformed our society with environment-friendly technologies (e.g., online shopping, teleworking, remote communication, virtualized office environment, smart buildings, etc.), thereby reducing human impact on nature. ICT makes other business sectors capable enough to visualize and optimize their energy needs and green house gas (GHG) emissions to make them more energy efficient. With the growing ICT sector, there is another question: What impact does pervasive ICT have on energy consumption?

Research has given a estimation that ICT consumes around 8% of total electricity all over the world [1]. If energy consumption of the ICT sector continues to grow at an alarming rate, energy shortage problem will occur for future ICT and telecom network expansion. Therefore, it is essential to generate energy-efficient ("green") network solutions to maintain ICT growth.

Meetu Singh, Department of Electronics and Communication, Rajasthan Technical University ,Rajasthan College of Engineering for Women, Jaipur , India.
Vandana Sharma, Department of Electronics and Communication, Rajasthan Technical University ,Rajasthan College of Engineering for Women, Jaipur , India.
Roshan Jain, Department of Electronics and Communication, ,Rajasthan College of Engineering for Women, Jaipur , India

In this paper we focused on access network, which is the "last mile" of telecommunication network that connects the telecom Central Office (CO) to the residential and business customers. Access network power-consumption reduction not only has the potential of significant cost savings, but also it will provide us the opportunity to achieve the ultimate goal of evaluating environment-friendly technologies to build the future "green" Internet. Therefore, future access networks should be green featuring efficient energy management techniques to cut down their "carbon footprint." There are several access technologies proposed and deployed in the market – Digital Subscriber Line (xDSL), Cable Modem (CM), Wireless and Cellular networks, fiber-to-the-x (FTTx), Hybrid Wireless-Optical Broadband Access Network (WOBAN), etc. Access technologies such as xDSL, CM, Wireless, and Cellular networks do not live up to satisfying future broadband Internet demands. FTTx technologies can provide higher bandwidth but still remain cost-prohibitive. WOBAN –a novel hybrid access network prototype with the amalgamation of high-capacity optical backhaul and wireless front-end – can provide higher bandwidth in a cost-effective manner [10].

In this article we present the experiences gathered during study of WOBAN architecture and design and discussed its future challenges. Combining wired and wireless access technologies in hybrid architecture to supply broadband access, as in WOBAN, not only presents a cost-effective solution [3], but also enables great chances for energy savings.

WOBAN comprises a wireless front-end which provides flexibility of rerouting traffic towards various optical access points, so the network use can be improved by shutting down low-load optical elements while rerouting the affected traffic through other live parts of the network.

The rest of the paper is organized as follow. In Section II, we briefly discuss related work on energy management in access networks. Section III describes the WOBAN architecture, techniques for energy-aware WOBAN design. Finally, we conclude with section IV.

II RELATED WORK

Different research efforts focus on different panorama of energy management in telecom networks. The wireless networking community has proposed many techniques for energy-efficient wireless technologies. A survey of energy-efficient protocols for wireless networks can be studied in [11]. Here, we concentrate on efforts to improve the energy efficiency of access networks.

Many research efforts provide approximation of energy consumption in different types of access networks [2], [8]. They liken the energy consumption of point-to-point optical links, passive optical network (PON), fiber to the node (FTTN), and WiMAX. The results show that PON gives more energy efficiency than point-to-point or active optical access networks.

Data centers and server clusters consume a great deal of electricity power for searching, cooling, and other purposes. Various scholarly papers address the power management issues of data centers and individual server. Researchers are also discussing to relocate data centers near the renewable energy sources to build "green" grid technology.

Authors of [7] advocate power-aware design and configuration of core networks. They apply optimization techniques to find minimal configuration of the router chassis for supporting different traffic loads, thereby reducing network power consumption. An initial proposal on the required architectural change of the network to support selective connectivity, a state where a host can choose whether to stay connected or disconnected, is given in [9]. Despite all these efforts, significant challenges to deploy energy-efficient schemes over the Internet, especially over the access networks, occurs.

III GREEN WOBAN

In this section, we present the architecture of WOBAN and an energy-aware routing algorithm for WOBAN.

A. WOBAN Architecture

WOBAN is an ideal access network architecture with an optimum combination of an optical backhaul (e.g., a passive optical network (PON)) and a wireless front-end (e.g., WiFi and/or WiMAX). Fig. 1 presents the architecture of WOBAN. WOBAN optimizes the deployment cost due to less-expensive wireless front-end and increases the bandwidth performance of a broadband access network [10].

The WOBAN architecture can be employed to captivate the best of both worlds: 1) the reliability, robustness, and high capacity of wireline optical communication and 2) the flexibility ("anytime–anywhere" approach) and cost savings property of a wireless network. A WOBAN consists of a wireless network at the front end, and it is supported by an optical network at the back end (see Fig. 1). Noting that the dominant optical access technology today is the PON, different PON segments can be supported by a telecom CO, with each PON segment radiating away from the CO. Note that the front end of each PON segment is driven by an OLT, which is located at the CO. The back end of each PON segment will have a number of ONUs, which typically serve end-users in a standard PON architecture. However, for the proposed hybrid WOBAN, the ONUs will connect to wireless base stations (BSs) for the wireless portion of the WOBAN. The wireless BSs that are directly connected to the ONUs are called wireless "gateway routers," because they are the gateways of both the optical and the wireless worlds. Besides these gateways, the wireless front end of a WOBAN contains other wireless routers/BSs to efficiently manage the network. Thus, the front end of a WOBAN is essentially a multihop wireless mesh network with several wireless routers and a few gateways (to connect to the ONUs and, consequently, to the rest of the Internet through OLTs/CO).

The wireless portion of the WOBAN may employ standard schemes such as WiFi or WiMax. Since the ONUs will be placed far away from the CO, efficient spectrum reuse can be expected across the BSs with much smaller range but with much higher bandwidth; thus, this WOBAN can efficiently support a much larger user base with high bandwidth needs.

In a typical WOBAN, end-users, e.g., subscribers with wireless devices at individual homes are dispersed over a geographic area. An end-user sends a data packet to one of its neighborhood wireless routers.

This router then puts the packet into the wireless mesh of the WOBAN. The packet travels through the mesh, possibly over multiple hops, to one of the gateways (and to the ONU) and is finally sent via the optical portion of the WOBAN to the OLT/CO. In the upstream direction of the wireless front end (from a wireless user to a gateway/ONU), the WOBAN is an anycast network, i.e., an end-user can try to deliver its packet(s) to any one of the gateways (from which the packet will find its way to the rest of the Internet).

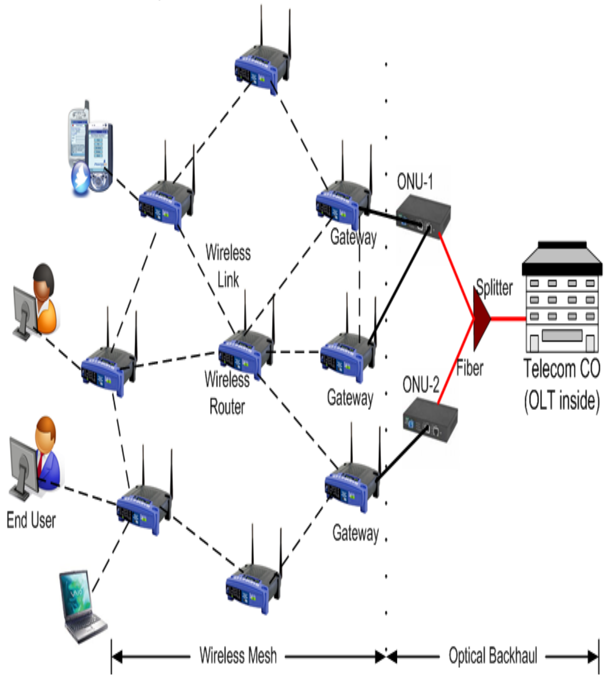

Fig. 1. WOBAN architecture

In the optical back end, the upstream (from an ONU to an OLT/CO) of a WOBAN is a multipoint media-access network, where ONUs are placed in a tree network with respect to their OLT, and they contest for a shared upstream resource (or bandwidth), but in the downstream direction of the wireless front end (from a gateway/ONU to a wireless user), this network is a unicast network, i.e., a gateway will send a packet to only its particular destination (or user). In the optical back end, the downstream (from an OLT/CO to an ONU) of a WOBAN is a broadcast network, where a packet, destined for a specific ONU, is broadcast to all ONUs in the tree and accessed selectively only by the destination ONU (all other ONUs discard the packet), as in a standard PON [1]. Fig. 2 presents a WOBAN's upstream- and downstream-transmit modes.

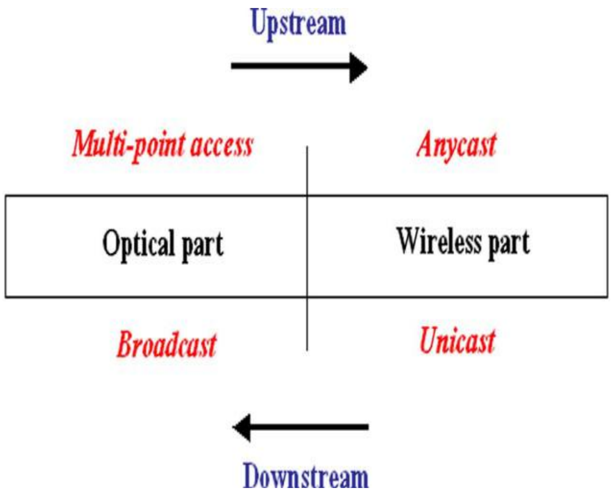

Fig. 2. WOBAN's upstream and downstream protocols.

In the upstream direction of the wireless mesh, WOBAN is an anycast network. The gateway can then send the packet to the ONU connected to it. In the optical backhaul (from ONUs to OLT), WOBAN is a shared-medium access network where ONUs contest for shared upstream channel to OLT in a time division manner. The optical backhaul in the downstream is a broadcast network where packets are broadcasted to all ONUs. Only the destination ONU keeps the packet, while others cast them out. However, in the downstream direction from the wireless gateways, WOBAN is a unicast network, since a gateway will send the downstream packets towards the particular destination routers.

B. Energy-Aware WOBAN Design

WOBAN presents a hierarchical access architecture with gateways as the initial traffic accumulation points. ONUs are the next accumulator level in the hierarchy, while OLT is the highest accumulation point and connects the access network with the rest of the Internet.

1) Enabling Factors for Energy Savings in WOBAN: Several aspects of WOBAN need to be discussed for its energy- aware design. Current WOBAN design, deployment, and management schemes provide fault tolerance, reliability, and robustness as well as a high level of performance. Traffic can be rerouted through alternate paths in case of failures such as a fiber cut, or a failure of a wireless router or gateway or ONU using mesh-front end. Moreover, there is a capacity mismatch between the wireless front-end and the optical backhaul. The surplus capacity in the optical backhaul can provide extra reliability during the failure so that traffic can be rerouted through alternate paths. At a specific instant, it is possible to find several WOBAN topologies that can satisfy the required capacity and reliability objectives.

All these are possible due to the thickly-interconnected wireless mesh front-end which has many surplus paths to route traffic. The flexibility provided by the wireless front-end of WOBAN can be exploited to enable energy savings in the optical part. Another important aspect of the access network is its traffic profile. The traffic load on the access network comes directly from customers, and it is well known that there are continuous fluctuations of this load. During WOBAN deployment, the common practice is to deploy network equipments so that they can support the peak traffic load. Therefore, during low-load hours, some parts of the network may be underutilized.

Thus, to design WOBAN topologies with lower power consumption, we need to consider the following points: 1) a WOBAN topology can provide several redundant paths for a packet to reach its destination; and 2) traffic load variation during different hours of the day. Thus, we can selectively shut down during low-load hours, thereby reducing network-wide power consumption.

In the wireless front-end of WOBAN, we demand to keep all the wireless routers on to assure availability of the network. In this paper, we mainly focus on how to put optical components of WOBAN into sleep state. We will not consider putting OLT into sleep state as it connects the WOBAN to the rest of the Internet. However, for protection purposes, in a PON segment, it is possible to have several OLTs in a ring setup. In that case, a low-load OLT can be put into sleep state while reroutingits traffic through other OLTs. In this paper, we reduce ONU power consumption in WOBAN by putting low-load ONUs to sleep.

2) How to Put an ONU to Sleep State: Current IEEE 802.3 ah/802.3av standards do not define any low-power state for an ONU [3]. However, proposals have been made to IEEE 802.3av team to include low-power states for an ONU so that it can go to sleep during idle periods [6]. Typical power consumption by an ONU during active state is approx to 10 W [4]. It is also forecasted that, during sleep state, power consumed by an ONU is less than 1 W [6]. Available ONUs in the market include a TX DISABLE input which disables the transceiver of an ONU [4]. Disabling the transceiver can reduce ONU power consumption several fold.

In WOBAN, the OLT can manage a centralized sleeping mechanism to put low-load ONUs to sleep. The mechanism works as given in Algorithm 1. An OLT maintains two watermarks for the traffic load at ONUs—low and high watermark.

Algorithm 1 Coordinated ONU Shut-Down Algorithm

Input: WOBAN topology, Low Watermark (LW), and High Watermark (HW).

Output: Set of ONUs that can be shut down.

• Initialization: Initialize LW and HW.

• Measurement: At different hours of the day, OLT quantifies traffic load at different ONUs by measuring the length of corresponding input queues (maintained by the OLT).

• Decision: € ONUs,

—If load < LW, shut down ONU.

—else if load > HW, keep ONU active and turn on another inactive ONU.

—else keep ONU active.

C. Energy-Aware Routing

We have several routing protocols proposed for WOBAN like architectures. Two of them are – (a) Delay Aware Routing Algorithm (DARA) [3], (b) Capacity and Delay Aware Routing (CaDAR) [3]. These routing algorithms are Link State (LS) protocols where a node periodically transmits

its link-state information to the network by Link-State Advertisement (LSA). Upon receiving the LSAs from all the nodes, each node finds a map of the network and can build a routing table to route load to other nodes in the mesh network. LS protocols generally vary on how they assign link weights in the LSA. For example, DARA uses predicted link delay metric to assign link weights. Based on link weight assignment, these protocols try to achieve several performance objectives. One such objective is load balancing which balances the traffic load in all parts of the network [3].

The routing algorithm tries to route traffic through the ONUs which are already used so that probabilities of other ONUs being idle increase. In that case, we can put zero-load ONUs to sleep. Furthermore, we may find some other ONUs with very low load (ONUs with loads under low watermark). By being more selective, we can put these ONUs to sleep and let the wireless mesh reroute the traffic through these ONUs. When traffic load increases, putting ONUs in sleep state can be activated to handle increased traffic.

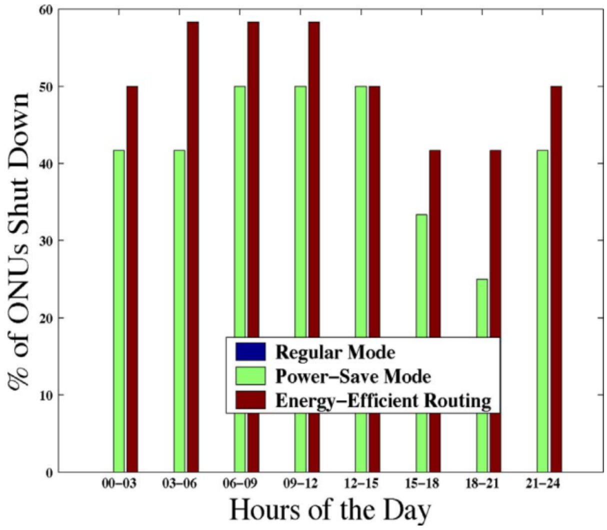

Fig. 3. Power savings in energy-aware WOBAN.

Fig. 3 shows the power savings during different periods of the day. apparently, there is no energy saving in the regular mode. Interestingly, on an average, we can put 50% of the ONUs to sleep state in this scenario by using the other two setups. One may argue that if we can put 50% of the ONUs to sleep, *why do* we deploy them in the first place? The answer is here, at high load, when all the routers are active, we will not be able to put any ONU to sleep. The power-saving opportunity lies somewhere else—specifically in the traffic profile. When one portion of the network is at high load, the other parts may be in low load. We can save energy by putting ONUs of those low-load portions to sleep.

Fig. 4 shows that the excess wireless energy consumption is still very less (at given WOBAN configuration) compared to energy savings by shutting down ONUs in the optical part of WOBAN.

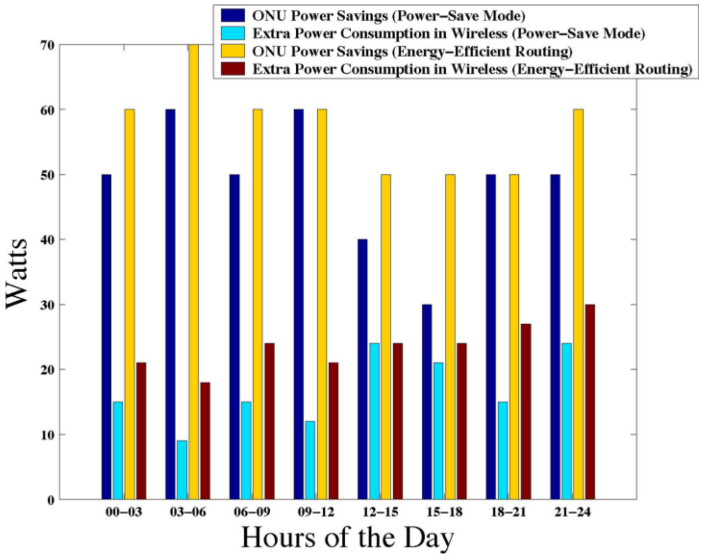

Fig. 4 .Power savings versus extra wireless power.

IV CONCLUSION

In this paper, we showed how energy consumption of providing broadband access in hybrid wired-wireless access architecture (WOBAN) can be efficiently reduced by efficient design and energy-aware routing. The energy saving in the optical part of WOBAN also does not increase the energy usage in the wireless part. These energy-aware design techniques applied on WOBAN can be generalized so that they are also applicable to other access networks such as PON variants. Future work on this topic may include: 1) studying the performance of green WOBAN with detailed analysis of packet loss rate, jitter, delay versus hop length, hop length versus energy cost, etc., and 2) energy-aware routing algorithm considering the wireless properties such as channel condition, rate, and modulation method, etc.

REFERENCES

[1] P. Leisching and M. Pickavet, "Energy footprint of ICT: Forecasts and network solutions," presented at the OFC/NFOEC, San Diego, CA, Mar. 2009.

[2] C. Lange and A. Gladisch, "On the energy consumption of FTTH access networks," presented at the OFC/NFOEC, San Diego, CA , Mar. 2009.

[3] S. Sarkar, P. Chowdhury, S. Dixit, and B. Mukherjee, "Broadband access networks: Technologies and deployment," in *Hybrid Wireless-Optical Broadband Access Network (WOBAN)*. New York: Springer-Verlag, 2009, ch..

[4] NEC GE-PON Data Sheets, 2009 [Online]. Available: http://www. nec.co.jp

[5] G. Kramer, private communication Mar. 2009.

[6] J. Mandin, "EPON powersaving via sleep mode," presented at the IEEE P802.3av 10GEPON Task Force Meeting, Sep. 2008 [Online]. Available: www.ieee802.org/3/av/public/2008-09/3av-0809-mandin-4.pdf

[7] J. Chabarek, J. Sommers, P. Barford, C. Estan, D. Tsiang, and S. Wright, "Power awareness in network design and routing," *IEEE INFOCOM'08*, Phoenix, Arizona, pp. 1130–1138, 2008.

[8] J. Baliga, R. Ayre, W. V. Sorin, K. Hinton, and R. S. Tucker, "Energy consumption in access networks," presented at the OFC/NFOEC, San Diego, CA, Feb. 2008.

[9] M. Allman, K. Christensen, B. Nordman, and V. Paxson, "Enabling an energy-efficient future internet through selectively connected end systems," *ACM SIGCOMM HotNets '07*, Atlanta, Georgia, Nov. 2007.

[10] S. Sarkar, S. Dixit, and B. Mukherjee, "Hybrid Wireless-Optical Broadband Access Network (WOBAN): A review of relevant challenges," *Journal of Lightwave Technology (JLT)*, vol. 25, no. 11, pp. 3329–3340, Nov. 2007.

[11] C. Jones, K. Sivalingam, P. Agrawal, and J. Chen, "A survey of energy efficient network protocols for wireless networks,"*Wireless Netw.*, vol. 7, no. 4, pp. 343

Meetu Singh M.tech Scholar in Rajasthan College of Engineering for Women.
Vandana Sharma M.tech Scholar in Rajasthan College of Engineering for Women.
Shrishti Sharma M.tech Scholar in Rajasthan College of Engineering for Women.