An Energy Saving Scheme for Internet Provision in Rural Africa: LESS

Moshe Timothy MASONTA, Thomas OLWAL and Ntsibane NTLATLAPA
Tel: +27 12 841 2085, Fax: +27 12 841 4720, Email: {mmasonta,tolwal,nntlatlapa}@csir.co.za
Meraka Institute, CSIR, P.O. Box 395, Meiring Naude Rd, Pretoria, 0001, South Africa

Abstract: In the past decade, the access to telephone services has increased drastically due to the deployment of wireless technologies and liberalization of telecommunications markets. But Internet access in most African rural communities still remains a dream. In today's digital age, the lack of Internet access to the rural communities will disadvantage poor communities to keep up with the global developments. It has been reported that lack of sustainable and reliable electricity coupled with poverty are among the reasons for the growing digital divide gap. In this paper, we present a Low cost Energy Saving Scheme Medium Access Control (LESS-MAC) protocol for broadband wireless networks suitable for deployments in energy-constrained rural areas. Our results show that up to 60% of energy can be saved by implementing our proposed scheme compared to the current power saving mechanisms used in IEEE 802.11 (widely known as Wi-Fi) standard.

Keywords: Energy Efficiency, Internet, Community Network, Rural Areas.

1. Introduction

Energy efficiency is an important design criterion to be considered in wireless communication systems due to the limited battery lifetime of portable devices, high electricity cost, and the lack of electricity supply in most rural areas in Africa. Today, the majority of rural communities in Africa are still suffering from the lack of sustainable energy supply. In some areas, this problem is being addressed by alternative energy supply techniques, such as windmill, solar, dry-cell batteries and energy harvesting. Also affecting the rural communities is the lack of Information and Communication Technology (ICT), and Internet access in particular. It should be borne in mind that Internet access in rural areas is expected to improve the lifestyles of the community. Such access will address digital divide problems in schools, local libraries, e-Health centres, small scale businesses and public safety. As a result, it is essential to develop innovative methods to reduce the total energy needed to operate wireless communication systems or devices in rural areas.

Recent studies by the United Nations (UN) International Telecommunication Union (ITU) [1] published in 2007, has shown that worldwide fixed line penetration is less than 20%, cellular or mobile users have grown by 40%, while Internet users has seen a growth of 17% globally. According to the ITU study, about 80% of the global population are not enabled for Internet connection, and the majority of this population is found in the rural areas of the underdeveloped countries. In the quest to close the digital divide gap in rural areas, it is important for local governments to partner with rural entrepreneurs or Small, Micro and Medium Enterprises (SMMEs) in order to deploy cost effective wireless community networks.

The advancement in computer technologies have seen the integration of wireless radio interface or Network Interface Cards (NICs) in almost every personal computers and laptops, making them the most preferred wireless data communication terminals. It is argued that the total energy consumption by a wireless NIC is the sum of its transmit energy and transceiver circuit processing energy [2]. Transmit power refers to the power radiated by the antenna, and transceiver power refers to the power consumed by the transceiver circuit. The IEEE 802.11 [3] standardized the physical (PHY) layer and Medium Access Control (MAC) layer for Wireless Local Area Networks (WLANs). More energy in MAC is consumed through retransmissions. Retransmission occurs due to the collisions that takes place at the MAC layer. Though impossible to completely eliminate retransmissions, it is important to eliminate collisions at the MAC layer when considering the design of energy efficient protocols.

The IEEE 802.11 or Wi-Fi standard provides a Power Saving Mechanism (PSM) for Distributed Coordinated Function (DCF) for WLANs, which is called IEEE 802.11 Independent Basic Service Set (IBSS) PSM [3]. The basic idea of the IEEE 802.11 IBSS PSM is to reduce the idle time as much as possible. At the start of each beacon interval, all nodes stay awake for an Ad-hoc Traffic Indication Message (ATIM) window, the size of which is static in IEEE 802.11 PSM. When a node has packets destined for another node, it may transmit an ATIM to the intended receiver during the ATIM window. Upon receiving ATIM, the intended receiver shall reply by an ATIM-ACK. The re-transmission of ATIM follows the normal DCF access procedure. Following the end of the current ATIM window, any node neither having sent an ATIM nor having received an ATIM containing its own address during the ATIM window shall enter the doze state. Any node which has received an ATIM or sent an ATIM containing its own address during the ATIM window shall remain in the awake state until the end of the next ATIM window.

In [4], a power saving MAC protocol for WLANs is proposed. While this work addressed energy efficiency in WLAN MAC, it focused on multi-radio multi-channel scenario instead of a single radio MAC protocol. Jung [5] have considered two approaches to address the energy problem in a wireless interface: 1) is to use power saving mode – by enabling a node to power off its wireless NIC whenever there is no data to transmit or receive, and 2) is to use a technique that varies transmission power to reduce energy consumption. While [5] focuses on improving throughput and energy saving, he does not however address the implementation issue. We propose a Low cost Energy Saving Scheme Medium Access Control (LESS-MAC) protocol for single channel radio, which offers significant energy savings, improved throughput and low-cost, which makes it most suitable for rural areas deployment.

The rest of the paper is organized as follows: Section 2 presents the objectives of the project. The methodology is presented in Section 3, while Section 4 describes the technology implemented in this project. In Section 5, the development of our proposed LESS-MAC protocol is discussed. Section 6 presents the results, and Section 7 discusses the business benefits. And Section 8 concludes the paper.

2. Objectives

The high demand for broadband communication coupled with the need to reduce the digital divide gap in rural areas cannot be addressed without solving the energy problem in wireless networks. The objectives of this project are as follows:

1. Developing energy saving MAC protocol for Wi-Fi technology.
2. Proposing a low cost wireless community network model for rural areas.

3. Methodology

In order to achieve the objectives of this project, the following methods where used:

- Conduct the secondary literature review on related work.

- Designing the protocol
- Computer simulations of the proposed LESS-MAC protocol
- Comparison the existing energy saving MAC schemes with the proposed energy saving scheme and present the numerical results.

4. Technology Description

Our proposed technology is a Low-cost Energy Saving Scheme Medium Access Control (LESS-MAC) protocol for WLAN in IEEE 802.11. In this section we give the description of the proposed LESS-MAC protocol.

4.1 – Proposed LESS-MAC

The proposed LESS-MAC time is divided into identical beacon intervals as shown in Figure 1. At the beginning of each beacon-interval, both nodes A and B switch to the channel and remain awake for an ATIM window. During the ATIM window, node A performs traffic indication and negotiates channel to transmit data with node B. Once node B receives an ATIM, it will reply with ATIM-ACK, and both nodes A and B will remain awake during the entire beacon interval. Two phases are identified in each beacon interval. Phase I serves as the estimation of the number of active links, also called the ATIM window. Phase II serves as data exchange.

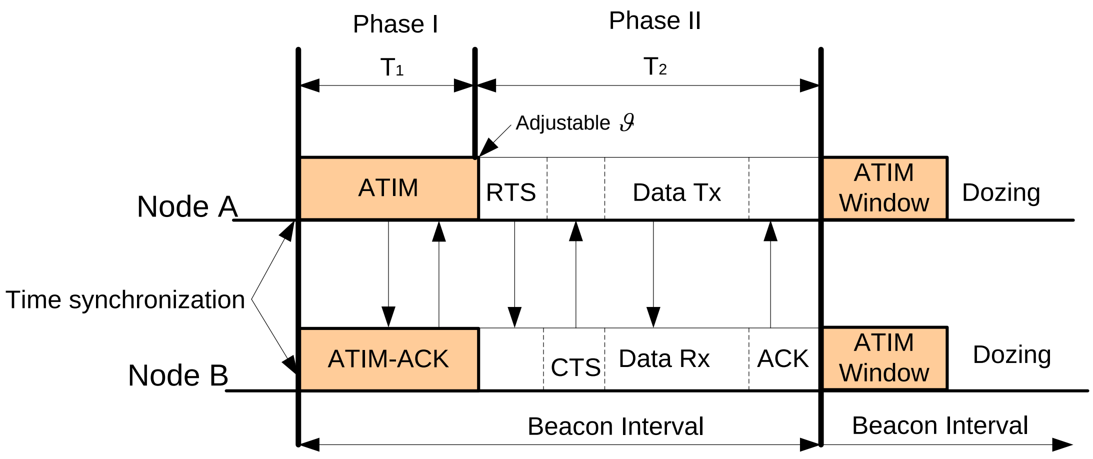

Figure 1: Proposed LESS-MAC Timing Structure

- Phase I: in this phase, each node must stay awake for a fixed time interval (i.e. ATIM window). Every sending node of an active link randomly selects one mini-slot to transmit busy signal. If no active link is observed at the end of Phase I, both nodes enter into doze state directly and remain in doze state until next beacon interval. ATIM exchange follows the backoff based carrier sense multiple access (CSMA) protocol.
- Phase II: Once ATIM exchange between a node-pair succeeds, the winning node-pair will select a channel for data exchange according to channel quality and expected traffic load. After Phase I, a node that have already exchanged ATIMs continue to be awake until it have completed data exchange. Other nodes which neither transmitted now received ATIM go to doze until the next beacon interval. During data exchange Phase II, backoff based CSMA is also used for Request to Send/Clear to Send (RTS/CTS) handshake. Since the number of intended transmission nodes in each channel could be known to each node after channel negotiation, each active node can also optimize the medium-access probability (or contention window size) to resolve RTS/CTS collision. As a result, RTS/CTS is not only used for collision resolution, but also for channel

probing. A node-pair can choose appropriate transmission rate or transmission power to exchange data after successful RTS/CTS.

4.2 – Benefits of the Proposed LESS-MAC

The ability to adjust the ATIM window to the smallest size means that up to 60% of energy saving can be achieved by our proposed LESS-MAC protocol. Compared to the standardized IEEE 802.11 IBSS PSM, our proposed LESS-MAC protocol brings the following benefits:

- *Energy* – the longer the data exchange period (Phase II), the longer the sleeping or dozing time of the nodes. The longer the dozing time, more energy is saved since the sleeping nodes consumes little or no energy at all. As a result, or proposed LESS-MAC protocol is more energy efficient than the standardized IEEE 802.11 PSM protocol.
- *Cost* – with regards to the implementation cost, one does not need to add more hardware on the conventional IEEE 802.11 device. All that is required is to simply improve the performance of the cheaply available off-the-shelf devices.
- *Throughput* – our proposed protocol has the ability to adjust the ATIM window size (Phase I) to the smallest size. By perform the adjustments; the data exchange (Phase II) period will be long enough, which translates to higher data throughput.

5. Developments

At this stage, our proposed LESS-MAC protocol is at the design stage. Practical simulations and analysis of the protocol will follow later.

6. Results

In our results we compare our proposed LESS-MAC protocol with the standard IEEE 802.11 PSM. Similar to [5], our results shows that the sleep (doze) mode option results into more energy savings, and the dynamic ATIM window leads to optimal throughput. We found ns-2 to be the most suitable tool to use for our simulation. Our simulation setup is as shown in Figure 1.

Our parameters for analysis and simulation are as follows: In the simulation scenario, node A was placed 200 m away from node B. Transmission rate for both control and messages and data packets is 2 Mbs. Each flow in the network transmits constant bit rate (CBR) traffic. The data packets length was varied between 512 (minimum) and 1024 (maximum) bytes. Packets were exchanged from node A to B and vice versa. The beacon-interval was set to 100 ms. The standardized ATIM window for 802.11 PSM is fixed at 20 ms. The maximum ATIM window size ($T_{1\max}$) was set to 20 ms. An adjusting parameter (ϑ) is adjustable between 1.2 and 1.5. We varied the data packet length for both instances, and also varied the ATIM window of our proposed LESS-MAC. The average energy lost in transmitting packets and the successful packets transmitted (aggregate throughput) and were recorded. The results, under the stable state, are summarized in Table 1 and Table 2.

Table 1: Average Energy efficiency results

Protocol	Minimum Data Packet	Maximum Data Packet
802.11 PSM	10 Kbits/joule	80 Kbits/joule
LESS-MAC	25 Kbits/joule	145 Kbits/joule
Average Energy Savings	**60%**	**60%**

As shown in Table 1, our proposed scheme significantly improves energy efficiency. The energy efficiency gain is due to different reasons. *(1)* LESS-MAC protocol allows each link completing data exchange to enter the doze state. Whereas 802.11 PSM requires each node with exchanged ATIMs to stay in the awake state during the whole beacon-interval even after it has completed data exchange. *(2)* LESS-MAC adapts ATIM window size to be just enough for exchanging all ATIMs so that energy can be saved; else energy is wasted by staying in the idle state after all nodes complete ATIM exchanges.

Table 2: Aggregate Throughput results

Protocol	Minimum Data Packet	Maximum Data Packet
802.11 PSM	170 Kbps	240 Kbps
LESS-MAC	210 Kbps	280 Kbps
Average Throughput	**20%**	**20%**

With in Table 2, the aggregate throughput is increased by an average of about 20%. The size of ATIM window affects the throughput achieved by standard 802.11 PSM, while the proposed LESS-MAC yields a little bit higher throughput. One most important factor for the increased throughput is due to the fact that the 802.11 PSM nodes are allowed to transmit one ATIM frame for many pending packets for the same destination. Thus, as the data packet size increases, the ATIM window size becomes a significant factor for throughput.

In summary, the energy efficiency of LESS-MAC maintains relatively stable but varies slightly with traffic load, while in 802.11 PSM energy efficiency improves when traffic load increases. The reason for this is that for 802.11 PSM under the low traffic load case, the energy efficiency of ATIM window payload and that of data exchange improves when the traffic load increases since less energy per payload bit is wasted for being idle in ATIM window and in data exchange phase.

7. Business Benefits

The business benefits of our proposed LESS-MAC protocol may be realized in the next two to three years once the field trials and testing have been completed. Once ready to enter the market, it promises to offer great business benefits as explained below.

The regulatory regime in the Republic of South Africa (RSA) introduced an under serviced area license (USAL) [6] with the aim of providing telecommunication services in areas with a tele-density of less than 5%. These were earmarked for small and emerging entrepreneurs to enter the burgeoning and lucrative telecommunications market. There are 27 USAL areas identified in RSA. USAL licensees can benefit from LESS-MAC devices to setup Wi-Fi hotspots and Internet cafes in rural areas without worrying about the availability of electricity, since such devices can operate on battery power.

7.1 – First-Mile First Inch Concept

The First-Mile First Inch (FMFI) is a project [7] that was conceptualized by the Wireless Africa team at Meraka Institute in Pretoria. The project aim is to identify and develop models and technologies to overcome the problem of access to communication and information services in low-density rural areas. See Figure 2 for FMFI concept. This project presents an attractive model that put more emphasis on the end-user and encourages active participation of SMMEs in the development of the network. By deploying LESS-MAC devices within the FMFI networks, SMMEs can be able to offer cost effective wireless broadband services to rural areas. Business benefits can be realized by implementing LESS-

MAC enabled devices within the Wi-Fi devices in an FMFI setup. LESS-MAC enabled devices promises to bring down the cost of accessing Internet without compromising the throughput (high speed) for wireless broadband services in rural areas.

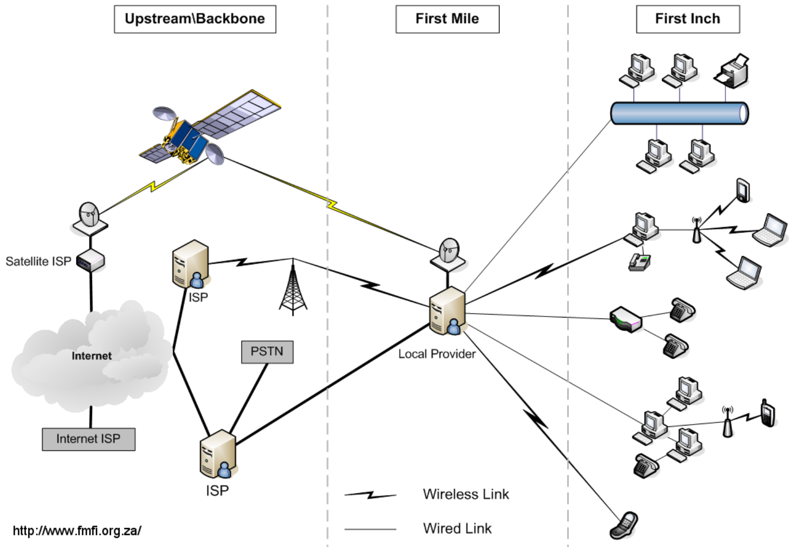

Figure 2: FMFI Concept [7]

7.2 – Time Scale for Availability

The proposed LESS-MAC protocol is still on the design stage. Further research work and testing is still needed before this solution can be realized in the market. We hope, however, that field testing on the existing FMFI network may be realized in the next two to three years.

8. Conclusions

Providing Internet access in rural communities requires a broadband network system which is energy efficient, cost effective, reliable and easy to deploy and maintain. In this paper we propose a Low-cost Energy Saving Scheme Medium Access Control (LESS-MAC) protocol for Wi-Fi deployment in rural areas. The main contribution of our work includes the ability of the proposed LESS-MAC protocol to reduce the collision probability and to reduce the waiting time in the awake state of a node. These capabilities translate to high throughput and energy efficient WLAN. The simple implementation of LESS-MAC requires minimal modification of conventional off-the-shelf Wi-Fi hardware devices. This translates to low cost technology transfer that may benefit local entrepreneurs' business.

Our proposed LESS-MAC protocol is still in the initial research stage. We are continuing with our research, and in future we anticipate at archiving the following:

- Implement LESS-MAC protocol in our massive mesh lab (at Meraka Institute).
- Test the LESS-MAC protocol on the existing FMFI project networks.
- Implement LESS-MAC on the off-the-shelf Wi-Fi hardware.
- Possible patenting of the product.
- Then the product will be ready to hit the market.

While the main objective of this work is to address energy and cost problems affecting rural Africa, we believe that greater collaboration opportunity with experienced European manufactures can be established to fast track the development of the end products. In conclusion, the cost and environmental impact of producing/supplying electricity requires future wireless communication systems to consider energy efficiency as one of a major design criterion.

References

[1] ITU, “Final Acts”, World Radio Communication Conference, Geneva, 2007.

[2] V. Rodoplu and T.H. Meng, “Minimum energy mobile wireless networks”, in *IEEE Journal on Selected Areas in Communications,* vol. 17, no. 8, August 1999, pp. 1333-1344.

[3] IEEE Std 802.11-2007, “Part II: wireless LAN medium access control and physical layer specifications”, *IEEE Computer Society,* June 2007.

[4] J. Wang, Y. Fang and D. Wu, “A power-saving multi-radio multi-channel MAC protocol for wireless local area networks”, in *Proceedings of IEEE INFOCOM 2006,* pp. 1 – 13

[5] E.-S. Jung, “Energy efficient in wireless networks”, PhD Thesis, Texas A&M University, August 2005.

[6] A. Gillwald, “A closing window of opportunity: under-serviced licensing in South Africa”, Research Article in *The Massachusetts Institute of Technology, Information Technologies and International Development,* Vol. 2, No. 4, pp. 1 – 19, 2005.

[7] First Mile First Inch (FMFI) project. Website: http://www.fmfi.org.za/wiki/index.php/First_Mile_First_Inch_Home_Page.