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Green Wireless Mesh Networks

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***Abstract*—In the last few years, Telecom operators, Internet Service Providers and public organizations reported statistics of network energy requirements and the related carbon footprint, showing an alarming and growing trend. With this increasing demand for energy in these field related with the increase in carbon dioxide levels in the environment produced by wireless devices in the idle mode, it became necessary to develop to develop the technology that reduce energy consumption. In this context, Wireless Mesh Networks (WMNs) are commonly considered the most suitable architecture because of their versatility that allows flexible configurations. This paper focuses mainly on different studies that propose number of protocols in different types of wireless networks. Several approaches are presented and discussions on the details related to energy management WMN are also presented. The classification of different techniques of the largest existing approaches spent on energy conservation is treated.**

Keywords-WMN, Power control; Connected Active Subset; Asynchronous Wake-up; Synchronized Wake-up.

I. INTRODUCTION

Energy consumption nowadays is one of the major concerns faced by governments worldwide, because of its significant environmental footprint and the eventual exhaustion. In a near future, the major traditional energy sources will be substituted by an alternative source adapting a sustainable energy source such as wind generation or solar. Green Networking consists of a rethinking of the way networks are built and operated so that not to be in charge only about costs and performance are taken into account but also their energy consumption and carbon footprint. A major role in the "greening" effort into globally reducing energy consumption will be the role of wireless networking technologies.

A well-known advanced type of wireless access is the so-called Wireless Mesh Networks (WMNs) that supply wireless connectivity through much cheaper and more flexible backhaul infrastructure compared with wired solutions. Wireless Mesh Network (WMN) [1], [2] is an emerging new technology which is being adopted as the wireless internetworking solution for the near future. Characteristics of WMN such as rapid deployment and self configuration make WMN suitable for transient on-demand network deployment scenarios such as disaster recovery, hard-to-wire buildings, conventional networks and friendly terrains. The architecture of WMNs can be classified into three types [2]: **Infrastructure/Backbone WMNs**, this architecture, where mesh routers form an infrastructure for clients. **Client WMNs**, Client meshing provides peer-to-peer networks among client devices. **Hybrid WMNs**, this architecture is the combination of infrastructure and client meshing, as shown in Fig. 1. Mesh clients can access the network through mesh routers as well as directly meshing with other mesh clients. While the infrastructure provides connectivity to other networks such as the Internet, Wi-Fi, WiMAX, cellular, and sensor networks, the routing capabilities of clients provide improved connectivity and coverage inside WMNs.

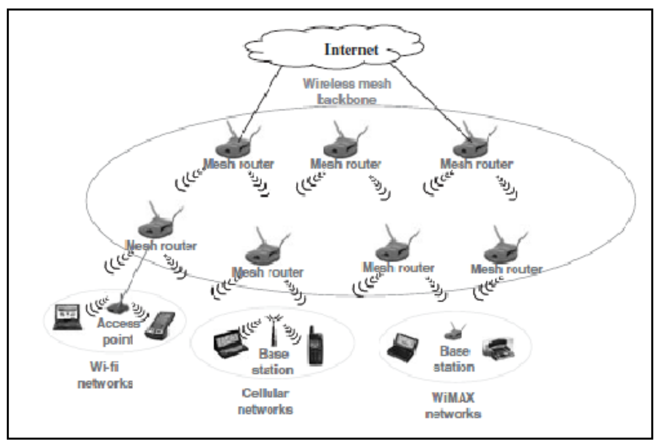

Figure 1. Network architecture of Wireless Mesh Network

There has been a great deal of research performed with the consideration of energy efficiency in wireless ad hoc networks as well as in sensor networks where it could be considered even more important due to more limited resources. Power management for wireless networks from a perspective that has recently begun to receive attention is targeting the conservation of energy for operating and environmental reasons [3].

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In general, this work seems to fall into two main categories. The first technique attempts to control the amount of power used to transmit a packet such that only the power required to get the packet to a specific destination is used. The second category involves the design of distributed protocols which allow the nodes of the network to be placed in a sleep mode. The sleep mode category is further divided into three types of approaches: connected active subset, asynchronous wake up, and synchronized wake up. Each of these strategies has advantages and disadvantages.

The remainder of this paper is organized as follows. Section II introduces power consumption model. Section III describes work dealing power control techniques and the sleep mode category is addressed in section IV. Finally, section V summarizes and concludes the paper.

II. POWER CONSUMPTION MODEL

A view to investigate the power efficiency of several protocols, it is essential to first understand exactly how electricity is wasted by wireless network interface card (NIC) [4]. The wireless interface card is able to take four possible operating states, each of them consumes power at a rate determined. The lowest rate of energy consumption is the **state sleep**. While in the sleep state the wireless card is always consuming a minimal amount of energy, the radio which consumes generally more power is off. In this state, the card is unable to send or receive packets and does not know the activities that take place on the medium. Since only the radio is powered off, the card can switch the radio off and on quickly. If the card is completely off not only the radio, the reactivation time is much longer. The sleep state consumes 95% less energy to transmit continuously.

The wireless card can also be in an **idle state**, means that the radio is powered on, but it is not currently sending or receiving packets. The idle state consumes only 36% of energy less than the continuous transmission. On-demand routing protocols typically spend a most of time in this state, since they need to be continuously ready to receive route requests. While in the idle state card constantly monitors sensing the medium for a carrier signal which would lead him to enter the reception status. The card is in **transmiting or receives state** when it is actively sending or receiving. The power consumption in the sending or receiving state is not much more than the power consumption in the idle state, while the sleep state consumes significantly less power.

As a result, in order to achieve maximum power savings a protocol must utilize the sleep state as frequently as possible.

III. POWER CONTROL

The technique of power control intended to regulate the amount of power used to send a packet such that only the power needed for the packet to a destination specified is used.

Power control and Topology control protocols [5], [6], [7] and least energy path routing protocols [8], [10] both try to achieve energy saving by controlling the transmission power. The basic concept that drives these protocols is the long distance transmission need greater power than the short-range transmissions. Therefore, sending a packet by using several short range hops can consume less total power transmission than sending the packet directly to the destination.

To reduce energy lost, there are researches that addressed the power control, the topology control and least energy path routing protocols to promote energy conservation are pointed out in this Section with Table.I.

- Aron et al. [5] proposed calculating the minimum transmission power and need only an optimum value to maintain optimum connectivity and reducing interference and collisions that save energy and to achieve a good throughput.
- Aron et al. [6] developed a minimum-energy distributed topology control which ensures the reduction of the amount power consumed by each node during transmissions and without the loss of connectivity with the increasing in the lifetime of the network.
- Mudali et al. [7] presented a TC scheme for a WMN backbone comprising of commercially available Linksys WRT54GL routers. The proposed system is designed to keep network connectivity on the basis of data collection by a proactive routing protocol.
- Sheppard [8] saved the power by selecting the paths through a multi-hop ad hoc network that minimize the total transmit energy. This approach has been extended by Chang and Tassiulas [9] so as to maximize the overall lifetime of the network by distributing energy consumption fairly. In this protocol, nodes adapt their transmission power levels and choose routes to optimize performance.
- Bouyedou et al. [10] suggested a new mechanism which allows a tradeoff between energy efficiency and shortness path chosen for the transmission of data packets. Therefore, it try to minimize the energy consumption and, at the same time maintain a good end-to-end delay and throughput performance.

TABLE I. POWER CONTROL

Authors	Protocol	Network	Contribution	Involvement
Aron et al.[5]	LM-SPT (Local Minimum Shortest Path-Tree)	WMN 802.11s	Power control	increased throughput, increased network lifetime
Aron et al.[6]	Minimum-energy topology	hybrid WMN	Topology control	saving energy and extending the lifetime
Mudali et al.[7]	PlainTC	WMN backbone	Power control	maintain network connectivity
Sheppard [8]	Minimum-energy	multi-hop ad hoc	least energy path routing	maximize overall network

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	Routing			lifetime
Bouyedou et al.[10]	EMM-DSR (Extended Max-Min DSR)	ad hoc	least energy path routing	minimize the energy consumption and maintain a good end-to-end delayand throughput.

The primary disadvantage of these power control protocols that transmission power consumption usually represents a small fraction of total consumed system power in typical 802.11 radios. This is caused by both the high consumption of energy at rest, and the low transmission duty cycle of a typical node in multi-hop shared medium wireless networks. Therefore power control strategies are fundamentally limited to reducing the overall power consumption by a fraction of 36%. This kind of power saving strategy is much more useful when using significantly higher power radios where transmission power begins to dominate the total power consumption.

IV. The Sleep Mode

The sleep mode category consist of three kinds of approaches: connected active subset, asynchronous wake up, and synchronous wake up. Each of these strategies has advantages and disadvantages.

A. Connected Active Subset

The insight behind the connected active subset protocol, such as CDS [11] or SPAN [12] or GAF [13], was that when there are many nodes close together in a multi-hop wireless network, only a subset of these nodes needs to be active in order to keep network connectivity. These protocols oblige to keep only a small subset of nodes awake in the network to provide network connectivity, and then place the rest of the nodes in a sleep state for the large majority of the time. Frequently, the members of the active subset are rotated to distribute the energy consumption more equally between different network nodes and to enable changes in the network topology due to mobility. Examples of connected active subset are classified in the Table.II.

- Cardei et al. [11] used topology information or neighborhood to identify the set of nodes that form a connected dominant set (CDS) for the network when all nodes were either an element of the CDS or directly adjacent of at least one element. Nodes in the CDS are considered to be the backbone routing and stay active all the time in order to keep global connectivity. All other nodes can choose to sleep if necessary.
- Jamieson et al. [12] proposed that each node in the network using the Span protocol may make periodic local decisions on whether to sleep or to stay awake as a coordinator and take part in the transmission backbone topology.
- Heidemann et al. [13] offered an alternative technique which used knowledge of geographic positions of nodes to elect the coordinators. The geographical positions of the nodes are used to divide the full topology into fixed zones size. A single node in each zone must be awake and maybe the coordinator. All other nodes may choose to sleep if there is no packet to be transmitted.

TABLE II. Connected Active Subset

Authors	Protocol	Topology	Contribution
Cardei et al. [11]	CDS (connected dominating set)	Flat	Information of neighborhood
Jamieson et al. [12]	SPAN (An Energy-Efficient Coordination Algorithm)	Grid	Local decisions
Heidemann et al.[13]	GAF (Greographical Adaptive Fidelity)	Grid	Geographic positions

The primary advantage of the connected active subset strategy is that there has little impact on communication. Data are routed through nodes that are always on, and therefore suffer a slight delay.

The major disadvantage of the active subset strategy is that depend on node density for energy savings. Basic principle is that the nodes that sufficient only a small number of them are required at a given time. In networks with low density, almost no power can be saved using this strategy because nearly every node must remain active.

B. Asynchronous Wake-up

The whole idea behind the asynchronous wake-up strategy is that by using a carefully designed wake-up schedule, each node in the network shall be capable to sleep for some fraction of the time. In addition, reflecting the schedule, the node will be sure to be awake at the same time as any particular neighboring node in the network within a limited amount of time, without requiring any type of network clock synchronization. Examples of asynchronous wake- up are pointed out in the Table.III.

- Heinzelman et al. [14] proposed LEACH protocol which is scheduled MAC protocol with clustered topology. It is one of the hierarchical routing algorithms for WSN popular combines the effectiveness of energy consumption and quality of media access, and based on the division into clusters, in order to allow the use of the notion of data aggregation for best performance in terms of lifetime.
- Heidemann et al. [15] adopted an effective mechanism for solving the problems of loss of energy, which has been revised by periodical listening and sleeping. When a node is idle, it is

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more likely to be asleep instead of continuously listening to the channel. S-MAC reduces the listen time by letting the node go into periodic sleep mode.

- Fan et al. [16] have improved the performance of energy efficiency, throughput and delay in WMSN, they designed a Multi-hop TDMA Energy-efficient Sleeping MAC (MT-MAC) protocol. The main idea behind this protocol was to divide one frame into many slots for sensor nodes in WMSN to forward data packets, with TDMA scheduling method.

TABLE III. ASYNCHRONOUS WAKE-UP

Authors	Protocol	Network	Topology	Contribution
Heinzelman et al.[14]	LEACH	WSN	Clustered	TDMA, Low energy clustering
Heidemann et al. [15]	SMAC	WSN	Flat	Active/sleep schedules
Fan et al. [16]	MT-MAC	WMSN	Clustered	TDMA Energy-efficient Sleeping MAC

The primary advantage of this strategy is that little coordination is necessary between nodes. In addition, since each node uses the same wake-up schedule, the network is balanced in terms of equal energy use by different nodes. Also, the energy savings are independent from node density for efficient operation of networks of low density.

The asynchronous strategy has low protocol overhead and good energy efficiency, these come at the price of reduced communication quality and capabilities. Asynchronous strategy only ensures that two nodes will simultaneously within a limited period, this warranty does not apply to any number of nodes beyond two. This mean all packets traverse along a path will not able to know if all nodes in the path are power on at the same time, so the packet may be delayed by up to the bounded time for every hop it traverses. Similarly all of nodes neighbors will not be powered on at the same time, thus traditional broadcast are also impossible. The asynchronous strategy considerably decreases its real world practicality. Also, the asynchronous wakeup protocol makes extensively use of beacon packets therefore to detect when neighbors are awake. Given that, each node must send these beacons, the scalability of this strategy can be compromised in networks with high density.

C. *Synchronized Wake-up*

Synchronized wake-up approaches work by obtaining and maintaining network vast clock synchronization and allowing decisions in the network to be made at specific time intervals [4]. This kind of approach is capable to conserve the largest quantity of energy, primary in idle networks, since all of the nodes in the network can turn off their radios over long periods of time. This is able to occur regardless of network properties such as density. Examples of synchronized wake- up are pointed out in the Table.IV.

The most well known synchronized power saving strategy is the 802.11 Power Save Mode (PSM) [17]. Other researchers have provided this protocol with many features which have extended it.

- The 802.11 standard defines a Power-Saving Mode (PSM) [17], which aimed to reducing the energy consumption of mobile devices. The proposed of the 802.11 PSM is to let the wireless interface of a mobile host in the active mode only for the time necessary to exchanging data, and turned into the sleep mode whenever it becomes idle. PSM defines two different power management modes that the mobile device can operate in one of them: active mode and Power Saving Mode (PSM).
- SOFA protocol [18] helped PSM clients to save energy by enabling them to sleep more, hence to increase battery lives. If a client has buffered packets at the AP in a beacon period, and that client decides to receive it, it has to remain awake from the beginning of the beacon period till the last packet scheduled for it in the beacon period is delivered. SOFA manages to reduce such energy waste and maximizes the total sleep time of all clients.
- Virtualization of NICs [19], this method is based on the power save mode feature available in 802.11 networks. A station is capable to connect to more than one infrastructure mode network at the same time, without the need to repeat the association procedure with every network switch. Through the usage of PSM before every network switch, the station stays associated with both APs all time. This approach allowed path activation, which reduced the packet delay. However their synchronization strategy needed MAC layer implementation in order to achieve the sub-millisecond accuracy required by the 802.11 PSM.
- The Pulse protocol [4] is also a synchronized wake-up approach. Therefore, it enabled the dissemination and permitted all the nodes in the network to power off their radios when the network is idle. This approach used path activation to eliminate per hop delay, but deferred from the existing synchronized protocols in that the time scale is much wider, and that a proactive routing proprieties was provided at the same time to the energy saving functionality. The larger time scale of the Pulse protocol enabled it to operate with much steed time synchronization (on the order of 10 milliseconds) which can be implemented without MAC layer integration.

TABLE IV. SYNCHRONIZED WAKE-UP

Protocol	Network	Topology	Contribution
PSM	802.11	Flat	Active/sleep period

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SOFA	802.11	Flat	A round-robin scheduling and sleep/wakeup
Virtualization of NICs	802.11	Flat	NIC virtualization
The pulse	multi-hop wireless infrastructure	Tree	powering off their radios when the network is idle.

The principal advantage of this kind of approach is that since nodes are always active at the same time, network broadcasts are still possible. These enable ad hoc routing protocols to operate, which depend on broadcast for efficiency.

The most power saving protocols generally do not take this approach due to the difficulty in establishing network-wide synchronization.

V. CONCULSION

Variety of available methods of conserving energy suggested by various studies but energy is still a challenge for wireless mesh network by environmental perspective. On the basis of several studies which have been carried out by different researchers. In this paper, we summarized certain of the research outcomes that have been reported in the literature on methodologies for energy saving in wireless mesh network. Even though lot of these power saving approaches seem promising, it that are still plenty of challenges which must be addressed in wireless mesh networks. Therefore, more research is necessary to treat these kinds of situations.

The Pulse protocol which was reported previously is an energy efficient protocol for ad hoc infrastructure access. An extensive set of simulations have demonstrated that this protocol is effective at both routing and conserving energy. Their results indicate that the Pulse protocol is appropriate for multi-hop infrastructure access, particularly when high performance, scalability, and energy efficiency are simultaneously desired. As WMNs share many common features with ad hoc networks. Thus, this protocol for ad hoc networks can usually be applied to WMNs. The Pulse protocol [4] is a synchronized wake-up approach. However, it is very difficult to establish the network-wide synchronization, since there is no base station to perform centralized control. The IEEE 802.11 Standard has defined a Timing Synchronization Function (IEEE 802.11 TSF). Mobile nodes generate a beacon with its system time and periodically send a beacon. Nodes can be synchronized by the time information in the beacon.

Since there is an active flow from the source node to the destination node, each node sends a reservation packet up the tree to the pulse source in response to the pulse flood. Nodes that have forwarded a reservation stay on. The rest of the nodes in the network may turn off until the next pulse. Nodes that overheard a reservation (or are adjacent to the pulse source) may perform fast activation. Node which can perform fast activation since it was able to overhear forward the source's reservation packet. Node which did not overhear any reservation packets would need to wait for the next pulse period to activate.

Future work will involve the development of this approach reported previously which seems to be an energy efficiency solution with further simulation results.

REFERENCES

[1] Akyildiz IF,Wang X and Wang W. "Wireless mesh networks: a survey". Computer Networks Journal (Elsevier) 47(4), 445–487, 2005.

[2] Akyildiz IF and Wang X. "A survey on wireless mesh networks". IEEE Communications Magazine 43(9), s23–s30, 2005.

[3] S. Nedevschi, L. Popa, G. Iannaccone, "Reducing Network Energy Consumption via Sleeping and Rate-Adaptation", Proceedings of the 5th USENIX Symposium on Networked Systems Design and Implementation (2008), pp. 323-336 .

[4] B. Awerbuch, D. Holmer, and H. Rubens, "The Pulse Protocol: Energy Efficient Infrastructure Access", IEEE INFOCOM, 2004.

[5] F.O. Aron, A. Kurien and Y. Hamam, " Topology Control Algorithm for Effective Power Efficiency and Throughput for Wireless Mesh Networks", Third International Conf. on Broadband Communications, Information Technology & Biomedical Applications, 2008.

[6] F. O. Aron, T. O. Olwal, A. Kurien, and M. O. Odhiambo, "A Distributed Topology Control Algorithm to Conserve Energy in Heterogeneous Wireless Mesh Networks", World Academy of Science, Engineering and Technology 40, 2008.

[7] P. Mudali, T.C. Nyandeni, N. Ntlatlapay, and M.O. Adigun, "Design and Implementation of a Topology Control Scheme for Wireless Mesh Networks", IEEE AFRICON 2009.

[8] T. Sheppard, "A channel access scheme for large dense packet radio networks", Proceedings of the ACM SIGCOMM, 1996.

[9] J. Chang and L. Tassiulas, "Energy conserving routing in wireless ad hoc Networks", Proceedings of the Fifth Annual ACM/IEEE International Conference on Mobile Computing and Network (MobiCom), Dallas,TX (August 1998).

[10] B. Bouyedou , M.FEHAM, F. Didi, H. Labiod,(2009) "Improvement of DSR Performances in Mobile Ad hoc Networks with Trade-off between Energy Efficiency and Path Shortness", IEEE International workshop on ITS for an Ubiquitous Roads UBIROADS 2009, Hammamet , Tunisia, June 2009.

[11] M. Cardei, M.X. Cheng, X. Cheng, Du D.-Z., (2002) "Connected Domination in Ad Hoc Wireless Networks", Proceedings of the Sixth International Conference on Computer Science and Informatics (CSI).

[12] B.Chen, K. Jamieson, H. Balakrishnan and R. Morris, (2002) "Span: An Energy-Efficient Coordination Algorithm for Topology Maintenance in Ad Hoc Wireless Networks", Kluwer Academic Publishers. Manufactured in The Netherlands, 2002.

[13] Y. Xu, J. Heidemann and D. Estrin, (2001), " Geography-informed energy conservation for ad hoc routing", Proceedings of the Seventh Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom), 2001.

[14] W.R. Heinzelman, A. Chandrakasan, and H. Balakrishnan. "Energy-Efficient Communication Protocol for Wireless Micro Sensor Networks". In IEEE Proceedings of the Hawaii international Conference on System Sciences (HICSS '00), 2002.

[15] W. Ye, J. Heidemann, D. Estrin, "An Energy- Efficient MAC Protocol for Wireless Sensor Networks", IEEE INFOCOM 2002.

[16] Q. Fan, J. Fan1, J. Li, and Xiaofang Wang; (2012), "A Multi-hop Energy-efficient Sleeping MAC Protocol based on TDMA Scheduling for Wireless Mesh Sensor Networks", JOURNAL OF NETWORKS, VOL. 7, NO. 9, SEPTEMBER 2012

Doi: 10.7321/jscse.v3.n3.112 e-ISSN: 2251-7545

[17] IEEE 802.11, Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, 1999.

[18] Z. Zeng, Y. Gao, and P. R. Kumar, SOFA: A Sleep-Optimal Fair-Attention scheduler for the Power-Saving Mode of WLANs, 31st International Conference on Distributed Computing Systems, 2011 IEEE.

[19] Y. Al-Hazmi and Hermann, "Virtualization of 802.11 Interfaces for Wireless Mesh Networks", Wireless On-Demand Network Systems and Services (WONS), 2011 Eighth International Conference on 26-28 Jan 2011.