Toaward Energy Saving In Wireless Mesh Networks

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Abstract—**Wireless Mesh Networks (WMNs), a recently emerged type of access network offering wireless connectivity with the use of cheap and low transmission power devices. WMNs can also be applied to Spontaneous (Emergency/ Disaster) Networking with dynamically self-organized and self-configured communication infrastructures, with a high degree of cooperation between many individual wireless stations. In this paper, we propose a green approach for power management in WMN to improve energy efficiency and network utilization. We suggest energy-aware design and energy-aware routing protocol to study the performance of WMN over dynamic traffic profiles. The combination of this two Algorithms point that, with suitable design parameters (number of shutdown MRs and hop offset), we can efficiently reduce energy consumption in WMN without significantly impacting the network performance.**

Keywords-WMN; Energy Saving; Power Management; Routing; Sleep State.

I. Introduction

Reducing energy consumption has become an effect for the industry, economic and environmental reasons. While this desire strongly influences on the electronics designers, the sector of information and communications technology (ICT), and more particularly to the field of networks, is also concerned [1]. Green computing aims to reduce the environmental footprint, economic and social information and communication technology (ICT). Green networking solution provides global environmental network architectures to improve energy efficiency, performance and reduce the cost savings, it also allows companies to gain competitive advantage and maintain a sustainable environment. The recent studies have estimated that the accounts of the ICT industry represent approximately 2% of global CO_2 emissions, even overcoming the carbon footprint of aviation. In detail, with a focus on telecommunications networks, these are estimated to produce about 0.6% of global CO_2 emissions [2].

To solve this problem, it is essential that we aim to improve and sustain performance of ICT and minimize their energy consumption and carbon footprint. An overall solution to energy-efficient ICT should take into consideration the whole lifetime of the equipments going from manufacturing to exploitation to their end life and recycling [3].

The network devices connected to the Internet has a significant impact of energy costs. It has been considered that the access networks consume approximately 70% of energy costs of global telecommunications networks and this percentage should increase over the next decade [4]. The Figure.1 indicated that local area networks, through hubs and switches, are responsible for about 80% of the total Internet consumption at that time. This is mainly because the wireless access networks (WANs) are generally dimensioned to meet the demands in terms of peak traffic constraints, resulting in over-provisioning in low-demand periods wasting a significant amount of power. In this respect, trying to minimize the energy consumption of deployed access elements is an important goal.

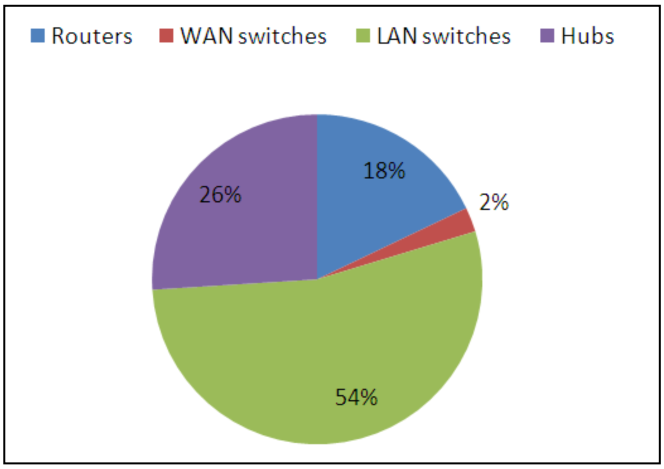

Figure 1. Contribution of different device types to the network energy consumption [5].

The objective of our work is to associate the flexibility of wireless mesh networks (WMN) with the need to optimize the energy consumption obtaining benefit of low demand periods and dynamic reconfigurations that are possible in WMNs. Some introductions on WNM are presented in section II and detailed discussion of the energy efficiency issues is beyond the scope of this paper.

This paper mainly focus on the power consumed by technology networking products, such as wireless access networks, communication protocols and routing protocols because these are the most widely utilized and deployed over the world as part of the Internet infrastructure. The key objective of the proposed work is to optimize network energy consumption by putting under-utilized MRs to sleep state and using the routing protocol which aims to use the already-used paths. The rest of the paper is organized as follows. In Section II, introduces wireless mesh network and their architecture. Section III, briefly reviews some related work on energy management in access networks that have been proposed to enable energy-efficient. Section IV; proposes an efficient algorithm to optimize network energy consumption by putting under-utilized MRs to sleep state. Section V, develops an energy-aware routing. Finally, we make some concluding remarks and future work in Section IV.

II. WIRELESS MESH NETWORK

As various wireless networks evolve into the next generation to provide better services, a key technology, wireless mesh networks (WMNs) has emerged recently [6], which is a variant of Mobile Ad hoc Networks (MANET), and is an IEEE 802.11-based infrastructure network made up of Mesh Routers (MRs) and mesh clients (MCs), where mesh routers have a minimum mobility and form the backbone of WMNs. The integration of WMNs with other networks such as the Internet, cellular, IEEE 802.11, IEEE 802.15, IEEE 802.16, sensor networks, etc., can be achieved through the gateway and bridging functions in the mesh routers. Clients mesh may either be fixed or mobile, and can form a client mesh network between themselves and with mesh routers [7]. WMNs are expected to address the limitations and to significantly enhance the performance of Ad hoc networks, wireless LANs (WLANs), wireless personal area networks (WPAN) and wireless metropolitan area networks (WMAN). They are subjected making rapid progress, inspiring many deployments, extending the coverage area and increasing available bandwidth.

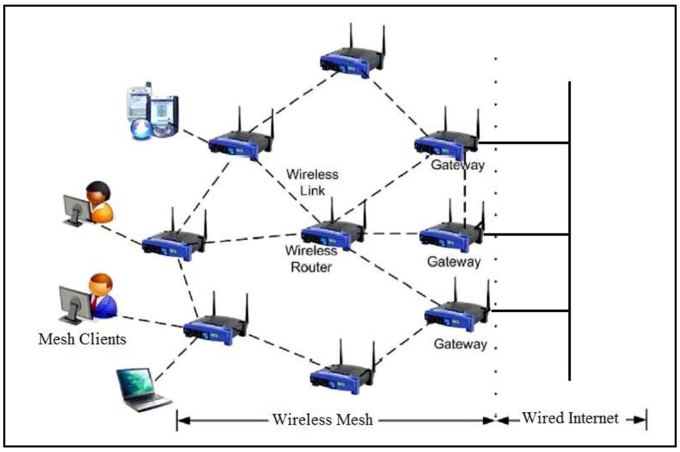

Figure 2. Wireless Mesh Network architecture

In WMN Figure. 2, multiple wireless routers form the WMN backbone. A selected set of these routers are called gateways. The WMN backbone is essentially a multi-hop with several wireless routers and a few gateways. These gateways are connected to the internet. End-users (both mobile and stationary) connect to WMN through the wireless routers. In WMN, when an end-user wants to send a packet, it sends the packet to its nearest wireless router. The wireless router can deliver the packet(s) to any of the gateways.

Traditionally, networking systems are designed and dimensioned according to principles that are inherently in opposition with green networking objectives: namely, over-provisioning and redundancy. Due to the lack of QoS support from the Internet architecture, over-provisioning is a common practice: networks are dimensioned to sustain peak hour traffic, with extra capacity to allow for unexpected events. As a result, during low traffic periods, over-provisioned networks are also over-energy-consuming.

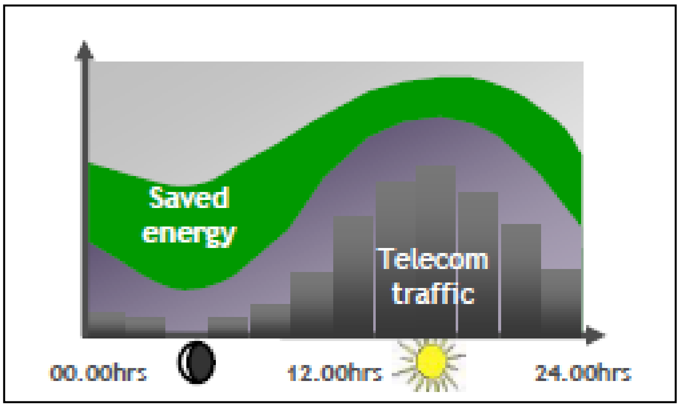

Figure 3. Energy saved during a day by turning off unnecessary nodes

However, WMNs infrastructure devices are always active. Thus, during lower traffic periods the energy consumption is the same as in busy hours, while it would be possible to save a large amount of power by turning off unnecessary nodes as shown in Figure.3. Concerning this issue, an energy-aware approach for such kind of networks was tackled in Section III.

III. RELATED WORK

Face the fact that the cost of power continues to rise, and the necessity for providing broadband in rural areas, green network has become one of the most important research areas of industry ICT. To address this difficult challenge, effective communication power appeared to be a promising solution.

The wireless networking community has developed several techniques for wireless technologies with high energy efficiency. In the literature, different approaches have been proposed to reduce the power consumption in different kinds of access networks [8, 9]. A survey of energy-efficient protocols for wireless mesh networks can be found within [10]. Here, we concentrate on efforts aimed to enhance energy efficiency in access networks.

In this paper, we are facing the challenge of reducing the energy consumption in backbone networks through an approach in sleep mode. The intuition has already been reported in the literature, starting from the seminal work of Gupta et al. [11]. Particularly the approaches from the traffic engineering [12], that proposed to minimize the energy in a time varying context by selecting dynamically a subset of mesh routers to switch on considering coverage issues of the service area, traffic routing, as well as capacity limitations both on the access segment and the wireless backhaul links, to routing protocols [13] with it Optimal Green Routing and Link Scheduling, called O-GRLS, and efficient algorithm based on Ant Colony, called Ant Colony Green Routing and Link Scheduling (AC-GRLS), and novel architectures [14], the authors proposed a comparison between a sleeping-mode and a rate switch algorithm, both applied at a network infrastructure level. In [15], the authors proposed a novel distributed algorithm, called GRiDA, to put into sleep mode links in an IP-based network.

These studies deal with the reduction of energy consumption of the network by switching off elements, such as routers and links, and major savings can be achieved when the sleep mode States are exploited. Despite all these efforts, there remain major challenges to deploy energy efficiency in the access networks.

IV. ENERGY-AWARE DESIGN

WMN represents hierarchical access architecture with routers as the original traffic aggregation points. Gateways are the highest aggregation point to access the access network with the rest of the Internet.

A. Energy Savings in WMN:

Various aspects of WMN should be considered for its energy-aware design. Present conception of WMN, deployment and management approaches provide fault tolerance, reliability and robustness along with a high degree of performance. Thanks to the mesh backbone, where the traffic can be rerouted through alternative paths in the case of failures such as the failure of a wireless router or gateway. At a specified moment, it is possible to find multiple WMN topologies which can meet the capacity requirements and reliability objectives. This is possible through the densely interconnected wireless mesh that has many redundant paths to send the traffic. The flexibility offered by the WMN can be exploited to allow energy savings.

A further significant feature of the access network is its traffic profile. The traffic load on the access network arriving directly from clients, and it is well known that there are daily fluctuations of this load. During WMN (as well as other network) deployment, the common practice is deploying network equipments so that they may support the peak traffic load. Consequently, during low load hours, some parts of the network can be underutilized.

So, to design WMN topologies with reduced power consumption, we must take to consideration the following points: First, WMN topology may anticipate multiple redundant paths for a packet to reach its destination; and the traffic load fluctuation during different hours of the day. Consequently, we can selectively put some nodes to sleep state during low load hours, thereby reducing network wide power consumption.

B. How to Put a MR to Sleep State:

A general problem that we are considering aims to manage the mesh nodes in order to conserve energy when some of the nodes in the network are not required and can be deactivated. Energy efficiency is therefore calculated to be the number of nodes that may be turned off without compromising the network performance.This model of energy conservation is called ON-OFF model, was first introduced by Restrepo et al. [16] and reused in the context of wireless networks in [17, 18]. Capone et al. [12] presented the basic planning model introduced in [19] and described how the model is modified to achieve a formulation of optimal planning who does not take into consideration the time variations of the application and the dynamics of coverage which are necessary for the effective operation systems of energy management. From an operational point of view, this may be easily integrated in centralized network management platforms currently used for carrier grade WMNs and to the centralized and remote control of all devices and their configuration

In WMN, the centralized network management platform can manage a centralize sleeping mechanism and maintain two different traffic profiles for the traffic load at MRs low traffic (idle) and high traffic (Busy). During different hours of the day, the centralized network management platform will observe the traffic load at different MRs by measuring the length of corresponding input queues. If a MR is operating under low traffic, MR can put sleep and the wireless mesh backbone will reroute the affected traffic due to MR shut-down to alternate paths. Otherwise put back sleeping MRs into active state when traffic load increases above high traffic in the currently active MRs.

V. ENERGY-AWARE ROUTING

Due to dynamic and Ad hoc topology in Wireless mesh networks the routing problem emerges as a challenging task in such networks [20]. Routing protocols provide the necessary paths through a WMN, so that the nodes can communicate on good or optimal paths over multiple wireless hops [21]. The routing protocols have to take into account the difficult radio environment with its frequently changing conditions and should support a reliable and efficient communication over the mesh network.

A routing metric is mainly a value assigned to each route or path, and utilized by the routing algorithm to select one, or more, out of a subset of routes discovered by the routing protocol. Such values generally reflect the cost of using a particular route with respect to some optimization objective, and could take into account both application and network performance indicators.

Only a few protocols have been developed specifically for WMNs. Several approaches have been considered. MIT designed new protocols tailored for WMNs for example Hybrid Wireless Mesh Protocol (HWMP) which is the default routing protocol for WLAN mesh networking, mesh routers of Firetide Networks [22] are based on topology broadcast based on reverse-path forwarding (TBRPF) protocol [23], Microsoft mesh networks [24] are built based on dynamic source routing (DSR) [25], and many other companies are using ad hoc on-demand distance vector (AODV) routing [26]. Since WMNs share common features with wireless ad hoc networks, the routing protocols developed for MANETs can be applied to

WMNs. Other works have focused on enhancing existing routing protocols with new routing metrics more appropriate for WMNs. Sometimes, the core concepts of existing routing protocols are extended to meet the special requirements of wireless mesh networks, such as that we need to do in this work.

Several routing protocols have been proposed for wireless network like GRiDA [15] and OLSR [27]. These algorithms are link-state (LS) protocols which are based on Shortest Path First (SPF) algorithm to find the best path to a destination also known as Dijkstra algorithm, since it is conceptualized by Dijkstra. In Shortest Path First (SPF) algorithm, whenever a link's state changes, a routing update called a Link-State Advertisement (LSA) is exchanged between routers. When a router receives an LSA routing update, the link-state algorithm is used to recalculate the shortest path to affected destinations. LS protocols generally vary on how they assign link weights in the LSA. Link-state routing always try to maintain full networks topology by updating itself incrementally whenever a change happen in network. Each router constructs a map of the complete network.

Another approach that achieves a good performance load balancing that tries to use fairly all parts of the network. However it can result in an under-utilization of some segments of the network during times of low load. Over the times of low load, the traffic may be covered by using a small number of devices in the network. Our routing algorithm is an energy-aware LS protocol which aims to reduce the network wide energy consumption by putting underutilized nodes (mainly MRs) of the network to sleep. For routing the traffic, the goal will be **to use the already-used paths**. Thereby, MRs with no load can be put to sleep state. In addition, we can find some other MRs with very low load. Being more aggressive, we can set these MRs to sleep state and allow the wireless mesh reroute their traffic across other active MRs. When traffic load increases, sleeping MRs can be activated to carry the increased traffic.

To achieve this, we can modify the LS routing algorithm in WMN so that link weights are assigned to satisfy our energy objective. So, we use residual capacity as the link weight. When traffic flows through a link, its next link weight will be the remaining capacity on that link. To route traffic from source to destination, we find the lowest residual capacity path. A formal description of the different steps of our Algorithm will be explained in the following

•**The first step the initialization**: each MRs establishes a relationship an adjacency with each of its neighbors and for each link we attribute an initial capacity as residual capacity.

•**The second step Link State Flooding:** After the adjacencies are established, the MRs may begin sending out Link State Advertisement (LSAs). As the term flooding implies, the advertisements are sent to every neighbor. In turn, each received LSA is copied and forwarded to every neighbor except the one that sent the LSA and it advertise periodically the residual capacity as link weight and time stamp.

•**The third step Link Weight Assignment:** For each link, update the link weight found from the Link State Advertisement (LSA) by adding Hop Offset (HO) the purpose of this term is to reduce average path length.

•**Finally the Path Computation step:** After each MRs calculates its own path and find the lowest residual capacity path between source and destination finally update the residual capacity of links on the selected path.

For example, let us consider the small network in Figure. 4. The link metrics are their residual capacities. To send traffic from Source to Destination, energy-aware routing algorithm will route traffic through the path S-A-B-C-D, which has the lowest residual capacity (1+2+1+2+=6).

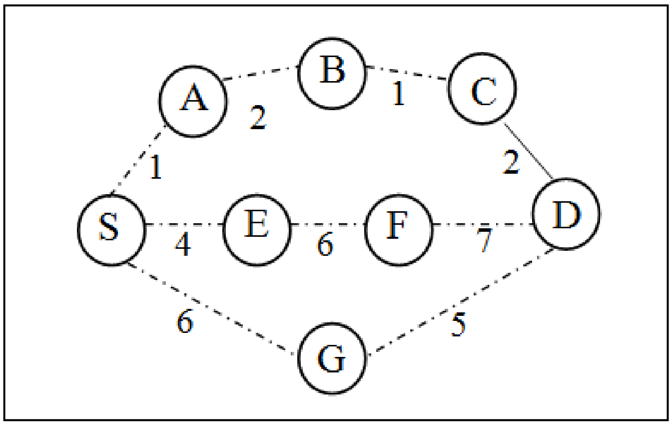

Figure 4. Residual capacity as link weights.

This approach, however, has its shortcomings as shown in Figure.4. The algorithm selects the path with four hops although that is not the shortest path while using other metrics (such as hop length or delay). This will increase the average path length and path delay in the network. To deal with this problem, we can introduce a term called **hop offset** the purpose of this term is to reduce average path length. If we have a hop offset **m,** we add **m** to the path cost for each hop, i.e., for a path of **n** hops, the cost of the path will be:

Residual capacity of the path + **n** x **m**

For example, as in Fig. 3, for a hop offset 1, the path costs are: 6 + 4 x 1= 10, 17 + 3 x 1= 20, and 11 + 2 x 1= 13 for paths S-A-B-C-D, S-E-F-D, and S-G-D respectively. The path which will be select is S-A-B-C-D. But, for a hop offset 3, S-G-D will be the chosen path in our algorithm. Selecting the optimal hop offset depends on how much delay the network connections can tolerate.

There is another important item to consider. We should select hop offset in such a way that average path length does not increase un-proportionately from regular shortest-path routing. If average path length increases too much, that means more wireless hops per path, i.e., more wireless transmissions and receptions. Each wireless transmission/reception requires power. So, out of proportion average path length may diminish the power savings that we gain from putting MRs to sleep. This energy-efficient routing can be adopted in any LS routing algorithm with residual capacity as link weight.

VI. CONLUSION

Energy consumption has become an important issue for the industry, economic and environmental. To solve this problem, it is essential that we aim to improve and sustain performance of ICT and minimize their energy consumption and carbon footprint. In this paper, we propose a green approach for power management in WMN to improve energy efficiency and network utilization. We suggest energy-aware design and energy-aware routing protocol to study the performance of WMN over dynamic traffic profiles. The key objective of the proposed work is to aid the design of efficient algorithms to optimize network energy consumption by putting under-utilized MRs to sleep state and allows to easily determining which MRs to switch off, and therefore the energy-aware routing which aims to use the already-used paths. Thereby, MRs with no load can be put to sleep state and reduce average path length and path delay. The future work will focus, on the optimization of the numbers of sleeping MRs. Developing a mathematical model which will act as a specification of the problem and as a guideline for energy-aware WMN design. The model will investigate the power consumption in WMN over dynamic traffic profiles. Along with analyze of the impact of energy-aware design on the performance of WMN.

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