Energy Aware Cross Layers Design for Wireless Mesh Networks

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Abstract—Wireless mesh networks (WMN) are considered such a highly promising technology and will become increasingly important in future generation wireless mobile networks. The wireless mesh networks (WMNs) consist of mesh clients and mesh routers that have minimal mobility and form the backbone of WMNs. They are providing network access for both mesh and conventional clients. In this paper, we consider energy management for wireless mesh networks from a point of view that started recently to attract the attention energy conservation for operational and the environment reasons which is known as the Green Networking. This paper considers the different routing protocols in the development of a protocol which will consider energy efficiency. The existing protocols are compared using the basic features of routing and the suggest protocol is design to overcome some of their shortcomings, specifically energy efficiency. We focus on cross layer design of routing protocols that is implemented in TDMA (Time Division Multiple Access) based MAC protocol wireless mesh networks.

Keywords-Wireless Mesh Network; Routing protocols; energy consumption; TDMA; NS 2.

I. INTRODUCTION

Wireless mesh networks (WMNs) are an emerging trend in wireless communication hopefully, more flexibility, reliability and the performance than the conventional wireless LANs (WLAN). Wireless mesh networking and mobile ad hoc networking use the same key concept communication between nodes over multiple wireless hops on a meshed network graph. Nevertheless, they highlight various aspects. Mobile ad hoc networks (MANET) have an academic background and concentrate on end users, mobility and ad hoc capabilities. WMNs have a background in business and focus mostly on static devices (often infrastructure), reliability, network capacity and practical deployment [1].

The architecture of WMNs can be classified into three main groups based on the functionality of the nodes [2]:

• **Infrastructure/Backbone WMNs**: This type of WMNs includes mesh routers forming an infrastructure for clients that connect to them.

• **Client WMNs**: client nodes constitute the actual network to perform routing and configuration functionalities as well as providing end user applications to customers. Hence, a mesh router is not required for these types of networks.

• **Hybrid WMNs**: This architecture is the combination of infrastructure and client WMNs architecture as shown in Figure. 1.

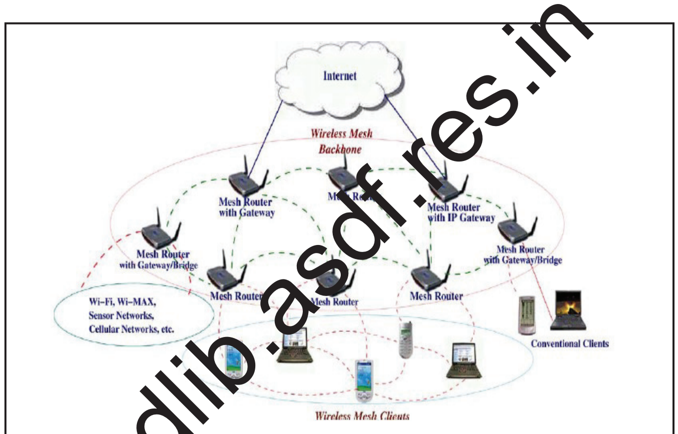

Figure 1. Hybrid WMNs [2].

In the majority of WMNs most of nodes are stationary or have a minimum mobility and do not rely on batteries. Therefore, the developing of routing algorithms is to enhance network throughput or performance independent transfers, instead of dealing with mobility or minimizing power consumption. However in this paper, we consider energy management for wireless mesh networks from a point of view that started recently to attract the attention means the conservation of energy for operational and the environment reasons which is known as the Green Networking comprised of the rethink how the networks are constructed and operated so that not only performance and costs are taken into account, but also their energy consumption and carbon footprint.

The basic functionality of multi-hop wireless ad hoc wireless networking, as well as wireless mesh networks is the routing capacity. The routing protocols anticipate the required paths via a WMN, such that the nodes may communicate in good or optimal paths of multiple wireless hops. From the moment that WMNs have common features with the ad hoc wireless networks, routing protocols developed for the MANET can be applied to WMNs [1].Such as Microsoft Mesh Networks [3] are designed on the basis of Dynamic Source Routing (DSR) [4], and for example [5] use ad hoc On-demand Distance Vector (AODV) routing [6] . Occasionally, the basic concepts of routing protocols that exist have been extended to meet the specific needs of wireless mesh networks, for example, with radio aware routing metrics in IEEE 802.11s WLAN mesh network standardization.

Even if the functions of routing protocols are plausible, they are always facing challenges in terms of energy efficiency. So there is requiring for a routing protocol which will be energy efficient as well as scalable. This paper reviews different routing protocols focusing on the request of energy efficiency. The routing protocols are compared using the basic features of routing and the proposed protocol is designed to overcome some of their shortcomings, specifically energy efficiency.

The rest of the paper is structured as follows: Section II explores the existing routing protocols. Section III discusses different routing protocols focusing on the request of energy efficiency. Section IV presents the model of a Time Division Multiple Access (TDMA) protocol to schedule flows of traffic in slots. Section V concludes the paper and finally Section VI present future works.

II. ROUTING PROTOCOLS

Generally, there are two families of routing protocols [7]: routing protocols called proactive, anticipating the demand for packet routing and reactive routing protocols that respond to the request. Between these two families, a new approach is emerging: it is the protocols called "hybrid" which are inspired by both proactive and reactive protocols. The presentation of the following routing protocols is far from being exhaustive. There are many others, but this selection covers most standard protocols and is studied. In preoccupations of brevity, a global vision of protocols is given, with the essential features, but only used to for comparison as a support or base for the rest.

A. Ad hoc On-demand Distance Vector Routing Protocol (AODV)

AODV [6], is a highly popular routing protocol for MANET. It is a reactive routing protocol. The itineraries are set up on demand, and only active channels are maintained. This protocol implements various operations to achieve and maintain routing: local connectivity management, discovery of routes and maintenance of routes. AODV uses a simple request-response (RREQs - RREP) mechanism for route discovery. It can use hello messages on connectivity and signal link breaks in active routes with error messages. Each of this routing information has a delay associated with it, and a sequence number. The use of sequence numbers to detect outdated data, so that only the information of the most common path used is available. It guarantees freedom of routing loops and avoids problems known from classical distance vector protocols, such as ''counting to infinity''. Whenever a node wants to send packets to destination it broadcasts RREQs, the source node uses a search technique in the ring expansion. When a destination or an intermediate node using a route error (RERR) is sent to the source node affected. When the source node receives (RERR), it can revive route if the route is still needed. Neighborhood information is obtained from emission of Hello packet. This helps to reduce the overhead of routing, but introduces a certain initial latency because of the configuration of the route on demand. There are several implementations available, for instance, SEE-AODV [8] which is salable and more energy efficient than existing Ad hoc on Demand Distance (AODV) routing protocol in wireless mesh networks. Another example, The PO-AODV [9] stands for the Power Optimized Ad hoc On demand Distance Vector routing protocol which considers the remaining energy of the nodes on the path for finding the optimal path from source to destination.

B. Ad hoc On-demand Multipath Distance Vector Routing Protocol (AOMDV)

Multipath variant of AODV called AOMDV [10]. Here, multiple disjoint paths are maintained for each destination. When the primary path fails an alternate path is available instantaneously. This eliminates the route rediscovery overhead. The main idea in AOMDV is to compute multiple paths during route discovery. It consists of two components: A route update rule to establish and maintain node and a distributed protocol to find link-disjoint paths. In AOMDV each RREQ, respectively RREP arriving at a node potentially defines an alternate path to the source or destination.

When a node S floods a RREQ packet in the network, each RREQ arriving at node I via a different neighbor of S, or S itself, defines a node disjoint path from I to S. In AOMDV this is used at the intermediate nodes. Duplicate copies of a RREQ are not immediately discarded. Each packet is examined to see if it provides a node-disjoint path to the source. For node disjoint paths all RREQs need to arrive via different neighbors of the source. At the destination a slightly different approach is used, the paths determined there are link disjoint, not node-disjoint. In order to do this, the destination replies up to k copies of the RREQ. The RREQs only need to arrive via unique neighbors.

C. Destination- Sequenced Distance-Vector (DSDV)

Destination-Sequenced Distance-Vector (DSDV) [11], is a proactive routing algorithm. It is based on distance vector algorithm which allows limiting the exchange of control messages topology only neighbors of node. The DSDV protocol uses the diffusion properties to transmit routing information. Indeed, the great advantage of the broadcast is a frame sent by a station is heard by all its neighbors. Periodically, each station broadcasts its entire routing table followed by a number to date information. This number is called the sequence number. From two sequence numbers, it is possible to determine what information is the most recent. The routing table of a node contains information related to each route. Upon reception of this information, neighbors update their routing table following a specific pattern. Any entry of the routing table is updated only if the information received is more recent or if it is the same age but has a smaller number of nodes. Eventually, the DSDV protocol provides for each destination, the route that has the smallest number of nodes. To be a full routing protocol, the DSDV protocol must maintain the status of the paths. For this, nodes detect the link failures. Each node transmits periodically its routing information to all its neighbors. A node detecting a break, will broadcast a packet containing all the destinations that can be reached through this link. Any node receiving such a packet propagates immediately to inform the faster the topology change. One problem with this algorithm is that it reacts too slowly to bad news.

III. COMPARATIVE ANALYSIS

The following sections discuss some characteristics of the studied protocols that could affect energy consumption.

Indeed, some significant differences, a point of view of energy consumption between the proactive and reactive behavior of routing algorithms studied can be identified to facilitate the understanding of the simulation results:

- *Usage of bandwidth*: the choice between on demand or reactive routing protocol in terms of consumption of energy, the fact that one must consume energy to update periodically route table and in the other case, it must consume energy only to discover that a route where communication must be established. In protocols proactive routing, many route discovered by standing broadcasts control packets roads will never be used and the bandwidth consumed for these discovery is wasted. Clearly, the reactive protocols have an advantage on this point (but probably not in delay for the routing).
- *Management of invalid or congested routes* : AODV seems better able to monitor more finely invalid paths since it uses the timer expirations route those serving regular routes considered too ancient and force for new discoveries of routes (sometimes unnecessarily). In addition, these messages "Hello" are used to verify the validity of links (but these control packets that evoke moreover entirely those used in the protocols pro-active energy-consuming, even for a link that not used then).

The previous elements can be summarized with the following table:

TABLE I. COMPARISONS OF THE CHARACTERISTICS OF THE ROUTING PROTOCOLS

	AODV	DSDV	AOMDV
Routing categories	Reactive routing	Proactive routing	Reactive routing
Route maintained in	Routing table	Routing table	Routing table
Discovery of necessary route	Yes	No	Yes
Necessary periodic update	No	Yes	No
Update from	No update	All the neighbors	No update
Uses "Hello" message	Yes (actifs neighbors)	Yes	Yes
Route inserted into the header of the packet	No	No	No
Uses timer route	Yes	No	Yes
Multiple route available	No	No	Yes

So each approach has its own advantages and disadvantages that we can evaluate via simulations to understand exactly how they work in relation to energy use.

A. Modeling Scenarios in NS2

NS-2 [12] is an open source discrete event simulation tool to explore the performance of wired and wireless networks in terms of underlying protocol stacks, routing algorithms, network traffic, etc. The main functionality of NS-2 is to establish a network of nodes that are able to communicate with each other by transmitting or receiving data packets over the network, and subsequently to generate traces of network traffic for further analysis. To achieve this, NS-2 contains a great diversity of network related components that can be flexibly assembled by a descriptive language called Tool Command Language (Tcl) specific to certain networking configurations to allow different simulation scenarios.

B. The Energy Model Used In NS-2

The NS-2 extension includes an energy model that informs any node about its instantaneous energy level. To use his model, we must define three parameters: the initial energy (*InitialEnergy)*, the transmission power (*txPower)* and reception power (*rxPower*). These two last values, Multiplied by the duration of transmission or reception of a packet, give respectively the quantity of energy necessary for the transmission or the reception of a packet. In our simulation study, we have fixed these parameters to the following values:

TABLE II. PARAMETER FOR ENERGY MODEL

Parameter	Value
Network Interface	WirelessPhy
MAC Type	802 11
Channel	WirelessChannel
Propagation	TwoRayGround
Antenna	OmniAntenna
Queue	DropTail/PriQueue
Initial Energy	100 joule
Reception Power	35.28 mW
Transmission Power	31.32 mW

We have assigned to each node an initial energy of 100 joules which will be decreased as the node transmits or receives packets. If the energy level of a node reaches zero, it is seen as a dead node, i.e. it is no longer able to take part in communications. It is known that the energy consumption of a node is mainly due to the transmission and the reception of data or controlling packets (such as RREQ, RREP, RERR, HELLO). To measure this amount of energy consumed during the transmission process (noted *txEnergy*), we should multiply the transmission power (*txPower*) by the time needed to transmit a packet:

txEnergy* = *txPower* x (*packetsize/bandwidth)

And for a received packet:

***rxEnergy* = *rxPower* x (*packetsize/bandwidth*)**

In this study, we used the network simulator NS-2.35 to compare the three routing protocols (AODV, AOMDV and DSDV). The wireless mesh network consists of 2 GW (Gateways), 6 MR (Mesh Routers) and 2 Mesh Clients (Mobile nodes) which are distributed a 500m X 500m area as basic scenario. The initial energy of each node is taken as 100 J with transmission and receiving power consumption. The simulation model with parameters is listed in table 1. The data packet size is of 512 bytes. Traffic model used is CBR (Constant Bit Rate). CBR Model generates traffic at a constant rate of 4 packets per second.

C. Results and analysis

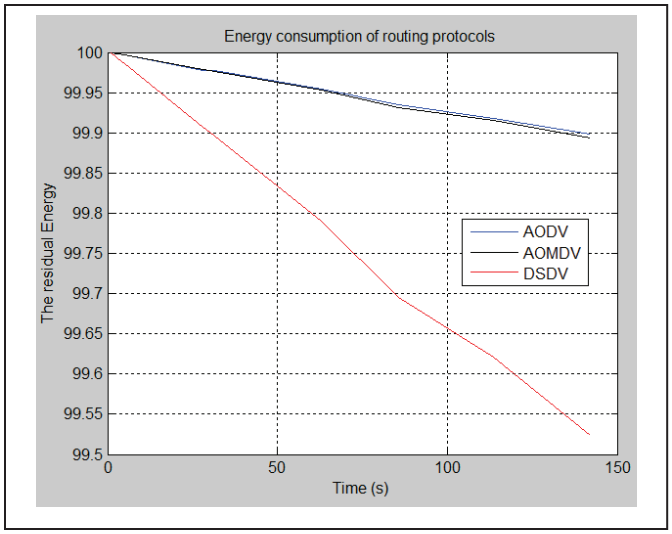

Figure 2. Energy consumption of routing protocols

In Figure 2, we can see that the residual energy of routing protocols AODV, AOMDV and DSDV decreases as time increases. However, there is a difference among proactive and reactive routing protocols. In the proactive routing protocol all nodes updated each other on the same network and make update their tables away to maintain a consistent approach and view network updates, that result in an energy consumption but with the reactive protocol when a node requires a route to its destination, it initiates a route discovery process within the network. The process is completed once a route is found or all possible permutations of the route had been examined. Simulation results show that the AODV and AOMDV routing protocol consumes less energy than the DSDV routing protocol.

IV. ROUTING PROTOCOLS OVER A DISTRIBUTED TDMA MAC PROTOCOL

In this section we propose a Time Division Multiple Access (TDMA) protocol to schedule flows of traffic in slots. Scheduling the flows can reduce energy waste.

A. Methodology

A Time Division Multiple Access (TDMA) Medium Access Control (MAC) protocol [13] that coordinates the delivery of data to receivers based on the gateways control.

There exist three phases in this TDMA: up-link phase in which nodes transmit data to the base station, down-link phase in which the base station transmits data to the nodes, and reservation phase in which nodes request new connections. The base station dictates a frame structure within its range. A frame made up a number of data and a traffic control. Nodes with scheduled traffic are indicated in a list, which allows nodes without traffic to rapidly reduce power. The traffic control is transmitted by the base station and contains information about the subsequent data, including when the next traffic control will be transmitted. Nodes explicitly request transmission from the base station, in a distributed manner, during the reservation phase. In our approach, the gateway performs the slot assignment based on its routing decisions.

To further improve the energy efficiency, according to wireless mesh network, this paper design energy-aware TDMA routing protocols based MAC layer whose slot assignment is managed by the gateway. The gateway informs each node about slots in which it should listen to other nodes' transmission and about the slots, which the node can use for its own transmission. The advantages of using a TDMA MAC layer are:

- TDMA protocol builds clock synchronization to refresh the energy model and send rerouting decision from the gateway to the nodes.
- The collision between the nodes can be avoided, because each node has its own assigned time slots.

Additional problems can happen with the existence of communication errors: a packet that contains the slot assignment can be dropped. Whether a node that does not learn the decision of the gateway turns off itself and no collisions can happen. However, we prefer to make up another alternative that a node preserves its previous state, if it does not get a packet routing from the gateway in the predetermined time slot, leading in potential collisions. However, the probability of collision is limited for the reasons acquired in [14].

There are some inconvenient of a TDMA protocol against a random access protocol, such as IEEE 802.11 [15]. First, the scheduling must be made by predicting the arrival of future traffic, delaying packets until the scheduling can be done or asking traffic to track a predictable pattern. Also, TDMA requires synchronization to divide the time in slots over the entire network.

B. Integration issues and performance evaluation

In this evaluation, we used the network simulator NS-2 to compare the three routing protocols (AODV, AOMDV and DSDV) using the design of energy-aware TDMA routing protocols based MAC layer. The network contains 2 GW (Gateways), 6 MR (Mesh Routers) and 2 Mesh Clients (Mobile nodes) distributed in a 500m X 500m area as basic scenario. Traffic model used is CBR; the packet size is 512 bytes packet rate is 4 packets per second. In NS 2, two MAC layer protocols are implemented, which are 802.11 and TDMA. In this section we briefly discuss TDMA MAC protocol.

Unlike contention based MAC protocol (802.11, for example), a TDMA MAC protocol allocates different time slots for nodes to send and receive packets. The superset of these time slots is called a TDMA frame which contains preamble besides the data transmission slots as shown in Figure.3. Within the preamble, every node has a dedicated sub-slot and uses it to broadcast the destination node id of outgoing packet. Other nodes listen in the preamble and record the time slots to receive packets. Each node has a data transmission slot to send packets [16].

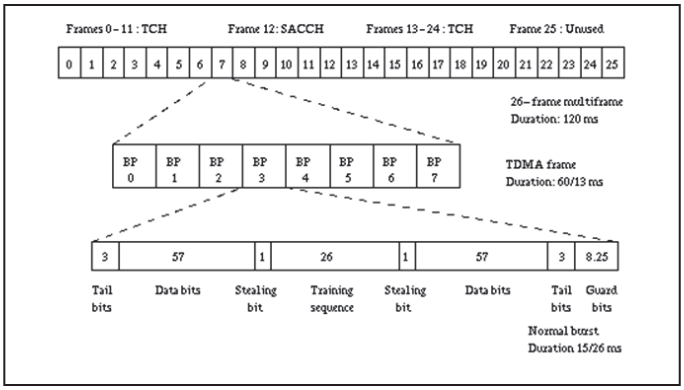

Figure 3. An example of TDMA frame structure

To avoid unnecessary power consumption, each node turns its radio on and off explicitly by invoking node **API set_node_sleep().**

The radio only needs to be on when: in the preamble phase (takes one slot time) and there is a packet to send and receive. The preamble is implemented as a central data structure **TDMA_preamble**, which is accessible to all the nodes. At the beginning of a frame, each node writes the destination node id into its sub-slot in preamble if it has a packet to send. Following preamble phase, each node sends packet in its data transmission slot and checks the preamble to determine if there is a packet to receive in other slots.

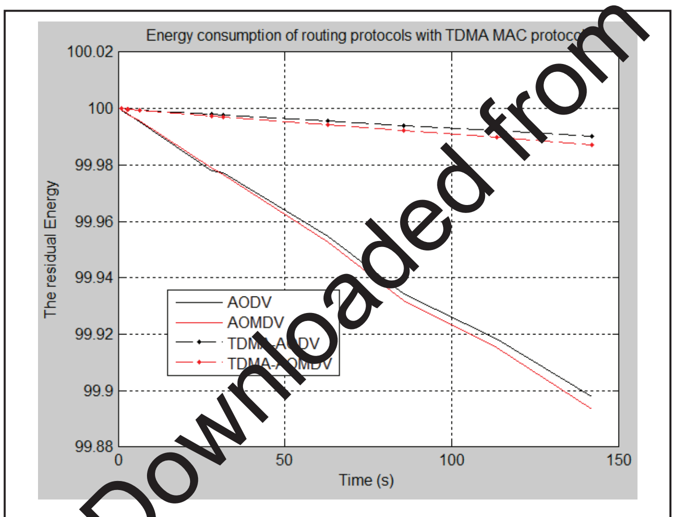

Figure 4. Energy consumption of routing protocols with TDMA MAC protocol

Figure 4, depicts a comparison between the routing protocols based 802.11 MAC protocols (called AODV, AOMDV) and energy-aware routing protocols TDMA based MAC protocol so called TDMA-AODV and TDMA-AOMDV function of time simulation. We can say that the TDMA-AODV approach provides more interesting results in residual energy ration which consume less energy than the AODV based 802.11 MAC. TDMA based protocols are more energy efficient, and the energy consumed is proportional to the length of the transmission cycle while the latency is proportional to the size of the network.

The TDMA-AODV seems to be a more promising solution, which has the natural advantages of having no contention introduced overhead and collisions. Moreover, TDMA can guarantee a deterministic delay bound.

Due to its benefits of reduced collisions, scalability and bounded latency, TDMA is widely considered in wireless networks. TDMA partitions time into many fixed slots and nodes transmit data in their assigned slots, thereby avoiding collisions.

V. CONCLUSION

In this paper, we introduced a novel approach for energy aware routing based on TDMA MAC protocol for wireless mesh networks. First, we reviewed the existing routing protocols and we compared them with the characteristics of energy consumption. AODV routing protocol consumes less energy compared with AOMDV and DSDV. After, we focus on the design of routing protocols that are implemented in TDMA based MAC cross-layer wireless mesh networks. Owing to its advantages of reducing collisions, TDMA-based protocols are more energy efficient. However, TDMA-AODV approach provides more interesting results in residual energy ration compared with the AODV based 802.11 MAC. TDMA based protocols are more energy efficient, and the energy consumed is proportional to the length of the transmission cycle while the latency is proportional to the size of the network. TDMA-AODV seems to be a promising solution.

VI. FUTURE WORK

Reducing energy consumption has become an effect for the industry, for economic, environmental and marketing reasons. 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 network devices connected to the Internet, form the access which 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 [17]. Traditionally, networking systems are designed and dimensioned according to principles that are inherently in opposition with green networking objectives: namely, over-provisioning and redundancy. On the one hand, 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. In this respect, trying to minimize the energy consumption of deployed access elements (that is to say, base stations, routers and access points) is an important goal.

The objective of our future 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.

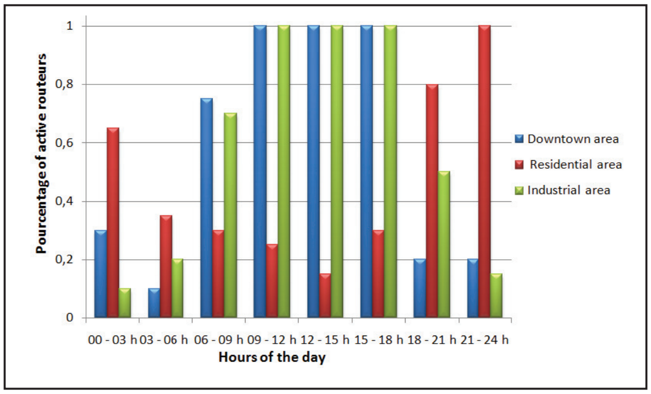

Figure 5. Traffic profile Vs active routers during a day.

Our future plan includes extending the energy model to improve network utilization by techniques such as shutting down underutilized network elements and energy-aware routing. Since we want to optimize the energy consumption during the day in such a way as to make the consumption follow the demand as much as possible, it is important to assume a realistic traffic profile as shown in figure.5. During low-load hours, traffic can be supported using a small number of devices in the network. Our future study will have the objective of reducing the network energy consumption by putting underutilized nodes (mainly MRs and MAPs) of the network to sleep and routing traffic using the already-used route and thus with zero-load MRs can be put to sleep. We can put these MRs to sleep and let the wireless mesh reroute their traffic through other active MRs. When traffic load increases, sleeping MRs can be activated to carry the increased traffic.

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