Efficient Power Saving MAC protocols for Mobile Ad Hoc Networks – A Review

Suma R
Department of Computer Science & Engineering
T. John Institute of Technology
Bangalore, India

Dr. Siddaraju
Department of Computer Science & Engineering
Dr. Ambdekar Institute of Technology
Bangalore, India

***Abstract*—A Mobile Adhoc Networks (MANETs) are collection of mobile nodes without any centralized infrastructure. Nodes in Mobile Adhoc Networks are typically battery operated. The power consumption in a mobile node must be minimized to maximize its lifetime, otherwise the battery may quickly run out of power, making the mobile nodes useless. Recent advances in the performance of Adhoc Networks, limited life of batteries in mobile devices poses a bottleneck in their development. Thus minimizing power consumption at Medium Access Control (MAC) Layer of Adhoc networks is an essential issue. The proposed power efficient protocols depends on the mobile nodes staying in sleep state most of the time, unless data have to be transmitted. This study focuses on the Synchronous and Asynchronous wake up approaches for power saving in the MAC layer.**

Keywords: MANET, Power Saving, MAC Layer, Sleep state, Wake up.

I. INTRODUCTION

MANET is a type of wireless mobile network. A mobile ad hoc network (MANET), sometimes called a mobile mesh network, is a self-configuring network of mobile devices connected by wireless links. They have been widely adopted in many application scenarios such as battle fields and other military environments, disaster areas and outdoor activities. Each device in a MANET is free to move independently in any direction, and will therefore change its links to other devices frequently. Each must forward traffic unrelated to its own use, and therefore be a router. The primary challenge in building a MANET is equipping each device to continuously maintain the information required to properly route traffic. Such networks may operate by themselves or may be connected to the larger Internet. MANETs are a kind of wireless ad hoc networks that usually has a routable networking environment on top of a Link Layer ad hoc network. They are also a type of mesh network, but many mesh networks are not mobile or not wireless. The growth of laptops and 802.11/Wi-Fi wireless networking have made MANETs a popular research topic since the mid- to late 1990s. Different protocols are used for the communication between the mobile nodes. There is no particular access points in this networks, instead the nodes itself transfer data between the communication nodes. Like any other networks there is also some algorithms used for the routing of information between nodes.

A. Challenges in Mobile Adhoc networks

Adhoc networks have to suffer many challenges at the time of routing. Dynamically changing topology and no centralized infrastructure are the biggest challenges in the design of Adhoc network. The position of nodes in Adhoc network continuously varies due to which we can't say that any particular protocol will give the best performance in each and every case topology varies very frequently so we have to select a protocol which dynamically adapts the ever changing topology very easily. Another challenge in MANET is limited bandwidth. If we compare it to the wired network then wireless network has less and more varying bandwidth, so bandwidth efficiency is also a major concern in Adhoc network routing protocols. Limited power supply is the biggest challenge of an Adhoc network so if we want to increase the network lifetime(time duration when the first node of the network runs out energy) as well as the node lifetime than we must have an efficient energy management protocol. So, an Adhoc routing protocol must meet all these challenges to give the average performance in every case.

This paper surveys and classifies numerous energy saving techniques in MANET at the MAC Layer. The main focus is on motivation, research challenges, recent development and modifications in this widely used field. Also we see how conventional routing protocols are modified to make them as energy efficient. We believe that survey can be a great source of information for researchers in adhoc networks. Here we discuss the latest development, industry effort and future direction for further research is identified. While it is still not clear whether any particular algorithm or a class of algorithms is the best for all scenarios, each protocol has definite advantages/disadvantages and is well suited for certain situations. However it is possible to combine and integrate the existing solutions to offer a more energy-efficient routing mechanism. Since energy efficiency is also a critical issue in other network layers, considerable efforts have been devoted to developing energy-aware MAC and transport protocols [1]. Each layer is supposed to operate in isolation in layered network architecture but, as some recent studies suggested, the cross-layer design is essential to maximize the energy performance [2].

The remainder of the paper is organized as follows. Section II presents general considerations of MAC protocols. Power saving mechanisms in mobile adhoc networks has been discussed in Section III. Later Section IV focuses on research reviews of power saving MAC protocols categorized into Synchronous and Asynchronous protocols. Finally, Section V draws conclusion and recommendations for future research.

II. CHARACTERISTICS OF MAC LAYER PROTOCOLS

Medium Access Control (MAC) schemes have most important role in the system performance, the system capacity and the hardware complexity. The main responsibility of MAC protocol in adhoc networks is the allocation for the common channel for transmission of packets. A successful MAC scheme needs to take the full advantage of the traffic and network characteristics to fulfill the requirements of adhoc networks.

MAC is considered a part of the data link layer (DLL) in the Open Systems Interconnection (OSI) reference model [3]. The DLL also covers error and flow control on a link basis.

The MAC layer interfaces directly with the network medium, it interfaces with the physical layer and is responsible for providing reliability to upper layers. Retransmissions should be eliminated as much as possible because this led to increase collisions within MAC layer. Retransmissions mean more unnecessary energy consumption and may cause unbounded delays.
MAC protocols can be divided into three categories contention-based, conflict-free and hybrid schemes. Contention-based in this category protocols try to prevent collisions once occur. In conflict-free there is no conflict, i.e. no transmission can overlap with another transmission. This category suitable for fixed networks with centralized control. Hybrid schemes use a contention-based to get the resources for the transmission and then use conflict-free for dynamically allocated resources [4]. In this classification, it is imperative to note that the most important characteristics of an efficient MAC protocol according to [5] are as stated below.

- Predictability of delay
- Adaptability
- Energy Efficiency
- Reliability
- Scalability

III. POWER SAVING MECHANISMS

Nodes in MANET are typically battery operated. Energy is scarce resource that can be quickly depleted by communication. Management of energy resources has significant impact on the adhoc network. Hence handling the early drain of the battery node, controlling the transmission power of a node and put low power consumption strategies together into protocols, by keeping these managements can prolong network lifetime [6,7, 8,9,10,11].

One of the most critical issues in mobile adhoc networks is energy conservation. Since nodes are usually operated on batteries, a prudent power saving mechanism (PSM) is required to guarantee a certain amount of device lifetime.

The power consumption of a battery in mobile node must be minimized to maximize its lifetime [12, 13] otherwise; the battery may quickly run out of power, making the mobile node useless. Energy consumed by a node includes when transmitting packets, receiving packets, and when the device is idle. In general, power requirements during packet transmission and reception are higher as compared to when the device is idle. However, power consumption of an idle device is not necessarily negligible. For instance, in case of the IEEE 802.11 protocol, an idle device continually senses the wireless channel to detect the channel state, as well as to detect the start of the transmission of a new packet by another host. Thus, even when a host is "idle" it is busy performing useful tasks, which can consume nontrivial amount of energy. To allow mobile nodes to conserve energy, an additional mode is often designed to allow the node to "sleep". During the sleep mode, the mobile node may not transmit or receive any packets, or even sense the channel state. The power consumption in the sleep state is significantly smaller than in other states. The term "power save" is used here is to refer to the mechanisms that allow a mobile nodes to enter the sleep state. But a disadvantage here is that a sleeping wireless device cannot communicate with any other device. Therefore, the power saving mechanisms also needs to incorporate the ability to "wake-up" a sleeping device.

The reduction of power consumption by MANETs has been studied widely. Existing power saving MAC protocols can be classified into two categories-synchronous wake-up approaches [6][14-17] and asynchronous wake-up approaches [19-24].

In synchronous wake up approaches all nodes must execute a clock synchronization mechanism. Asynchronous wake up approaches require no such synchronization mechanism. However, the neighbor discovery time is the most important issue in asynchronous wake up approaches. They must adjust the overlap of node's wake up time with that of its neighbors.

IV. REVIEW OF POWER SAVING PROTOCOLS

1) Synchronous Power-Saving Protocols

A synchronous power-saving protocol saves power by determining intervals during which nodes should wake up and listen to traffic. Such protocols are engineered so that the sleep-wake patterns minimize the impact on throughput and latency of the network. Since all the nodes of a network are synchronized, a common clock rate and period exist. In addition, nodes must share arbitrary phase information to maintain a globally synchronized sleep-wake cycle.

IEEE 802.11 PSM

The most well known synchronous wake up power saving protocol is the IEEE 802.11 standard [14] which was originally designed for single-hop adhoc networks. As shown in Figure 1, time is divided into beacon intervals. In the power saving mechanism (PSM) of the IEEE 802.11 standard, all nodes are synchronized by transmitting beacon frames to one-hop neighbors at the beginning of the beacon interval. After the beacon frame has been sent, the node sends an Adhoc Traffic Indication Map (ATIM) frame to inform other nodes that has packets that are waiting to be transmitted during the ATIM window. Upon receiving an ATM-ACK frame from the destination node, a node obtains the right of transmission and begins to transmit data immediately after the ATIM window ends. Both sender and destination nodes are awake during the transmission period. Otherwise, at the end of ATIM window, a node enters the power-saving state.

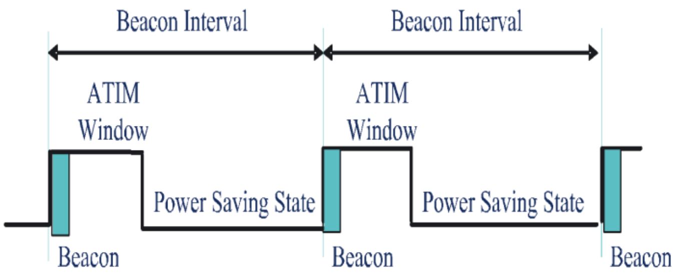

Figure 1. Power-saving mode of IEEE 802.11 standard

IEEE 802.11 PSM has been extended to multi-hop MANETs [6], to activate paths, minimize delay and conserve energy. However, the proposed synchronization strategy, routing strategy and power management capability depend on extra support from MAC layer. Additionally, the potential problem of network partitioning has not been addressed.

On Demand Power Saving Management

In On Demand Power Saving Management (ODPM) [6], in which a node switches between the AM and PS mode based on communication events and event-induced time-out values. For example, when a node receives an RREP packet, it is better to stay in AM for an extended period of the time (RREP time out) because it will most probably need to forward data packets in the near future. However, this scheme asks for each node to switch between the AM and PS frequently, which may incur non-negligible overhead. Moreover, each node needs to know and maintain the power management mode of its neighbors. This may not be trivial as it requires either an additional energy cost or an extended packet delay if the information is not accurate. Also, its performance greatly depends on time-out values, which need fine tuning with the underlying routing protocol as well as traffic conditions. For example, consider that a node stays in AM for five consecutive beacon intervals upon receiving a data packet (Data time-out). If data traffic is infrequent, say once every six beacon intervals, the node stays in AM for five intervals without receiving any further data packets and switches to low power sleep state. It receives the next data packet while operating in the PS mode, and thus decides again to stay awaken for another five intervals. Packet delay is not improved but it consumes more energy than an unmodified 802.11 PSM. Each node makes an AM-node (backbone) decision based on the number of neighbors; i.e., the backbone probability (P) is inversely proportional to the number of neighbors (say, n). This is based on the observation that having more neighbors usually means more redundancy in terms of connectivity. The backbone probability is then adjusted based on the average number of neighbors of its neighbors.

Traffic Informed Topology Adaptive Network

Traffic –Informed Topology-Adaptive Network (TITAN) [25] is another probabilistic algorithm that improves over ODPM. It favors AM nodes when selecting routing paths at the network layer. It can be easily accomplished when PS nodes delay forwarding RREQ packets. Discovered routes could be a long way around compared to the shortest ones, but they utilize more AM nodes for delivering traffic. PS nodes would sleep for a longer duration than in ODPM and save more energy. The backbone decision (AM node) depends on the number of neighbors as well as the number of neighboring AM nodes.

SPAN

SPAN [15] adopted distributed synchronization technique for multi-hop adhoc wireless networks which minimizes power consumption without markedly reducing the connectivity of the network. The “stay-awake and sleep” cycle of the nodes is coordinated by SPAN and also performs multi-hop packet routing within the ad hoc network, while other nodes remain in power saving mode and occasionally check if they should remain awaken and become a coordinator. The election of coordinators are adaptively done by SPAN through the process of allowing each node to use a random back-off delay to decide whether to become a coordinator in the network an rotates them in time. The back-off delay for a node is a function of the number of the other nodes in the neighborhood and the amount of energy left in these nodes. The procedure adopted in SPAN does not only safeguard network connectivity, it also conserves capacity, decreases latency and provides considerable power savings. The quantity of power saving provided by SPAN increases only a little as node density decreases. In the current execution of SPAN, the power saving features is used, since the nodes practically wake up and listen for traffic advertisements. Although SPAN guarantees efficient energy consumption and low delay latency in dense networks, it has limitations. One is that coordinators must remain active at all times, broadcasting HELLO messages to maintain the backbone, increasing the overhead. The other is its synchronization overhead.

p-MANET

p-MANET protocol proposed by [26] is an energy efficient protocol for multi-hop mobile adhoc networks. It is supposed to be a new foundation MAC layer power saving protocol. The aims of this protocols are decrease energy consumption and transmission latency, and to realize efficient power saving. IEEE 802.11 is a power saving strategy designed for the single hop environment, making it unsuitable for MANET which has multi-hop as one of its features. p-MANET has two power management nodes: listen and power saving mode. In listen mode mobile node awakes and may receive data. In power saving mode, mobile node sleeps in most of the time except for sending data or beacon messages to neighbor nodes. Each node has global hash function and MAC address to regulate when to enter the listen mode. So the source can know the mode of destination from global hash function, if it's in listen interval then source will send the packets efficiently. To reduce latency in the network, a next hop candidate would be a neighbor with least remaining time to wake up or a neighbor that is awake in listen mode. Energy saving thus achieved by p-MANET is much higher compared to Quorum-based protocol [20] under various scenarios, the neighbor discovery time of p-MANET is also significantly reduced.

Special Purpose Methods

Special purpose methods for reducing power consumption of MANETs have been proposed [16,17]. A node can power down during its natural silent periods [16]: when a node does not expect to transmit, receive or relay packets, it can power off its network interface. Traffic aware PSM (TA-PSM) [17] also achieves good performance with light traffic load. TA-PSM allows the node directly to enter the doze state when it does not need to transmit or receive packets, even if beacon or ATIM frame has to be sent. Instead of entering the idle state of IEEE 802.11 PSM, the node enters a doze state to save more power. However, such approaches depend on the monitoring of traffic at each node to guarantee transmission throughput and low transmission latency. Hence, these approaches may not be suitable for heavy traffic scenarios.

The neighborhood aware approach has been proposed in [17, 18]. Power saving mechanisms (NA-PSM) [18] and the neighborhood and traffic aware power saving mechanism (NTA-PSM)were proposed to reduce the number of exchanged announcement frames to increase throughput and reduce both power consumption and transmission delay. A NA-PSM node knows the state of neighbors and uses few ATIM announcement frames to increase bandwidth and carry more packets. However, the NA-PSM node has to stay in active mode throughout the beacon interval, even when the transmission or reception is complete. NTA-PSM and allows each node to enter sleep mode when the transmission or reception is complete.

2) Asynchronous Power Saving Protocols

Several asynchronous wake up approaches have been proposed [19-24]. In contrast to the synchronous class of protocols, asynchronous power-saving protocols are characterized by independently scheduled sleep-wake patterns. Each node has no idea of the wake up time of its neighbor nodes, a live routing path to the destination node is not always available. To improve the availability of the routing path, we must design carefully both the power saving mechanism and the neighbor discovery mechanism of the asynchronous wake up approach. The scheduling rules are defined such that neighboring nodes awake intervals eventually overlap and retransmission rules are defined such that neighbors can eventually exchange traffic.

An advantage of asynchronous protocols over their synchronous counterparts is that the former has less of an impact on network latency. If a node has a large number of neighboring nodes, it can afford to spend more time in sleep mode without any detrimental effect on latency, since there will always be a few neighboring nodes which will be awake to handle any routing requests originally directed to the sleeping node.

Guidelines for designing Asynchronous power saving protocols:

More Beacons: To prevent the inaccurate –neighbor problem, a mobile host in PS mode should insist more on sending beacons. Specifically, a PS host should not inhabit its beacon in the ATIM window even it it has heard others beacons. This allows others to be aware of its existence. For this reason, protocols will allow multiple beacons in a ATIM window.

Overlapping Awake Intervals: Asynchronous protocols do not count on clock synchronization, to resolve this problem, the wake up patterns of two PS hosts must overlap with each other no matter how much time their clocks drift away.

Wake-up Prediction: When a host hears another PS host's beacon, it should be able to derive that PS host's wake-up pattern based on their time difference. This will allow the former to send buffered packets to the latter in the future. Note that such prediction is not equal to clock synchronization since the former does not try to adjust its clock. Based on these there are several asynchronous protocols each with a different wake-up pattern for PS hosts. For each PS host, it divides its time axis into a number of fixed length intervals called beacon intervals. In each beacon interval, there are three windows called active window, beacon window and Multi-hop Traffic Indication Map (MTIM) window. During active window, the PS host should turn on its receiver to listen to any packet and take proper actions as usual. The beacon window is for the PS hosts to send its beacon, while the MTIM window is for other hosts to send their MTIM frames to the PS host. MTIM frames serve similar purpose as ATIM frames in IEEE 802.11 here MTIM is used emphasize that the network is a multihop MANET. Excluding these three windows, a PS host with no packet to send or receive may go to sleep mode.

Both the basic energy-conservation algorithm (BECA) and the adoptive fidelity energy-conversation algorithm (AFECA) [19] minimize the power consumption of transmitters during idle time while introducing latency into to the system. In BECA, nodes are in one of the three states-active, listen, and sleep. Each node alternates between the sleep and listen states if its traffic is low. A node enters the active state when it receives or transmits a large number of packets and then enters the sleep state when it has been idle for a while. BECA also integrates power-saving and routing mechanisms: when establishing a routing path, only the nodes along the routing path remain in the active state; other nodes enter the idle or sleep state.

AFECA

Adaptive Fidelity Energy Conserving Algorithm (AFECA) [19] is an established asynchronous power saving algorithm in MANETs. This protocol is a reactive protocol, and often used in conjunction with AODV. . The AFECA improves the performance of BECA by applying knowledge of node deployment density and increasing the sleep time when neighbor nodes are available In AFECA, each node maintains a count of the number of nodes within radio range. A node switches between sleeping and listening, with randomized sleep times proportional to the number of nearby nodes. The AFECA algorithm keeps the number of listening nodes consistent, and more energy can be saved as the density of nodes increases. The number of nodes is chosen so that there is a high probability that the listening nodes form a connected graph, so that ad hoc forwarding works. However, nodes using AFECA do not know if they should stay awake in order to forward traffic, so the algorithm often forces them to stay awake even though they could be sleeping. However, AFECA has two weaknesses that make it less able to reduce power consumption. First, numerous broadcast messages are required to carry information about neighbors. Second, the use of AFECA to establish and maintain routing paths introduces long latency because only a few nodes are in the active state to handle routing request and response packets.

RandomCast

Rcast [27] implements randomized overhearing but not randomized rebroadcast. RandomCast [28] protocol employs both randomized overhearing and randomized rebroadcasting. It is designed to improve energy performance by controlling the desired level of overhearing and forwarding without significant impact on the network performance. The main advantage of this protocol is that the nodes are consistently operate in the PS mode. Here, the sender can specify the desired level of overhearing. The node in randomized overhearing that chose not to overhear will switch to a low power sleep state during the following data transmission period, saving substantial amount of energy compared to unconditional overhearing. In addition to energy consumption, overhearing brings in several undesirable consequences, it could aggravate the stale route problem, the main cause of which is node stability. This algorithm can applied to broadcast packets such as RREQ to allow randomized rebroadcast. This is to avoid redundant rebroadcasts of the same packet in the mobile networks. Rebroadcast decision must be made conservatively. This is because broadcast packet may not be delivered to all nodes in the network when randomized rebroadcast is used. The limitations of this protocol is delay in delivering packets, because nodes are not able to transmit or receive packets when they are in sleep state.

DBEE

In Demand Based Energy Efficient (DBEE) algorithm [29] is based on the RandomCast reduces the effect of overhearing by integrating with cross layer approach. The mobility of nodes results in stale routes, due to lack of route cache updation , for that cross layer frame work is implemented along with DBEE to improve route cache performance in Dynamic Source Routing(DSR). By using the cache timeout policy it is easy to prevent stale routes. The cache timeout of individual links are found by Receiving Signal Strength Indicator (RSSI) information. This method provides low delay, overhead, minimizes energy than RandomCast and 802.11 PSM.

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Quorum-based protocol

The quorum-based approach asynchronous power-saving protocol [21-23] assigns to each node a cycle pattern that specifies the wake up/sleep schedule. Tseng et al. [20, 21] presented a quorum-based asynchronous power-saving protocol. The design of quorum-based protocols is based on the concept of a quorum, such that a node only transmits in O(1/n) of the beacon intervals, reducing the power consumed for sending beacons. Accordingly, the quorum-based protocol solves the contention problem and improves the efficiency of power saving. This protocol guarantees that any two nodes have at least two entire BWs that are fully covered for some beacon intervals, using the quorums to identify the beacon intervals during which a host must wake up. However, efficient power saving by this approach requires many beacons to communicate with neighbors, potentially increasing the neighbor discovery overhead and the neighbor discovery time.

Hyper quorum system

Hyper quorum system (HQS) [23] is a fully adaptive quorum-based asynchronous power –saving protocol. An HQS node can select an arbitrary cycle length that fulfills the requirements of an application, such as packet delay and power constraint.

Other Asynchronous protocols

Zheng et al. [22] presented an asynchronous wake up mechanism is highly scalable to large networks, in which the wake up node wakes up for an entire beacon interval.

Chao et al. [24] proposed a new quorum-based asynchronous power-saving protocol, including Quorum-Based Energy Conservation (QEC) and Adoptive QEC (AQEC) in single-hop MANETs. This protocol maximizes the sleep time potentially to exceed one beacon interval if few transmissions are required. Nodes are woken up by the traffic load, rather than periodically. This power saving protocol thus not only conserves energy but also balances the delay latency. However, AQEC is designed for single-hop MANETs.

V. CONCLUSION AND FUTURE RESEARCH FOCUS

In this paper, we presented a survey of energy conservation protocols for mobile ad hoc network at MAC layer. In this article we first begin with various issues in MANETs and details of the causes for power drain in MANETs. Our primary concern is energy efficiency and has discussed various synchronous and asynchronous energy saving techniques at MAC layer adopted for reducing power consumption. Performance of the protocol varies according to the variation in the network parameters, as we know that in ad hoc network properties continuously vary. We conclude that no single protocols can deliver overall performance demands for MANET without having to trade-off other performance metrics to achieve high energy conservation. In many cases, it is complicated to compare them directly since each technique has a different objective with different assumptions and employs different means to achieve the objective. Therefore it is suggested to use many methods and if we are able to find the reason for different outcomes from each method, then we can have a better understanding of the problem. In the future, we intend to come up with a protocol that uses some purposely designed metrics to deliver perfect mix of the performance demands for MANETs, by satisfying most of these requirements would offer support for energy conservation, minimize storage and bandwidth consumption while also ensuring optimal paths and reduce network load.

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