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A Survey of Energy-Aware Routing and MAC Layer Protocols in MANETS: Trends and Challenges

Ahlam Hashim Mohsin[1], Kamalrulnizam Abu Bakar[2], Adebanjo Adekiigbe[3], Kayhan Zrar Ghafoor[4]

Dept. of Computer Sys. & Comm.,Universiti Teknologi Malaysia, Skudai.

Email: [1]dream_hashim800@yahoo.com, [2]kamarul@fsksm.utm.my, [3]aadekiigbe2@live.utm.my, [4]kayhan@ieee.org

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Abstract

One of the major issues in current routing and MAC layers protocols for mobile ad hoc networks (MANETs) is the high energy resources consumed for process of route discovery and collision avoidance respectively. Proper use of location information and dynamically adjustment of intermediate nodes' retransmission probabilities adopted by a number of algorithms contribute to a reduction in the number of retransmissions and consequently reduce bandwidth and power consumption, but this feat was achieved at a price on network reachability. Many other efforts were made to achieve greater power conservation by many authors. This paper reviewed some current literatures that were proposed to improve the energy conservation in MANET at both MAC and routing layers, it also highlight the performance demands required of these protocols to assist researcher in MANET energy conservation as a good starting point for developing energy conservation algorithm.

Keywords: MANET, Energy, Conservation, Routing, MAC, Power.

1. Introduction

A mobile ad hoc network (MANET) is a self-configuring infrastructureless network of low-power mobile devices connected by wireless links. In such an environment, due to the limited radio range of the wireless link, it may be necessary for one node to enlist the aid of other nodes in forwarding data to a destination node not within the radio transmission range of the source. Thus, each node operates not only as a host but also as a router [1, 2]. The primary challenge in building a MANET is equipping each device to continuously maintain the information required for proper data forwarding. Each device in a MANET is free to move independently in any direction, and will therefore change its links to other devices frequently. Moreover, nodes mobility results in a continuous change in network topology and, thereafter, routes connecting the nodes within the network are continuously changing [3, 4]. In such dynamically changing environment, the routing process is not trivial and efficient and reliable routing protocols are required for determining new routes or maintaining known routes. Routing protocols are responsible for efficiently establishing a reliable route between nodes so that data can be delivered between nodes in a timely manner. The efficiency of the routing protocols can dramatically affect the performance of the entire network in terms of bandwidth utilization, power consumption, and delay; therefore, the process of establishing a reliable and efficient route should be done with minimum complexity, delay, overhead, and bandwidth and power consumption [5].

Energy conservation is a precious resource for battery-driven nodes in the network. Management of energy resources has significant impact on the adhoc network. Therefore, by handling the early drain of the battery node, controlling the transmission power of a node and put low power consumption strategies together into the protocols, by keeping these managements can prolong network life time [6, 7, 8, 9, 10, 11]. Energy conservation in mobile ad hoc network has been studied by many research scholars through the employment of various routing techniques. The center point of many of the protocols proposed is the reduction on the number of retransmissions for the route request (RREQ) messages to save bandwidth [12, 13, 14, 15], contention and duplicate reception that resulted in reduced node energy consumption, however, the scalability of the network is negatively affected by reducing the network reachability. [16] conducted a review of energy efficient and secure multicast routing protocols, but the studies was not able to concretize the reasons why most of these protocols were unable to totally address the issue of energy consumption reduction in an holistic manner. This study will try to bring out the effect of the high energy consumption on the overall performance of the network by pointing out the impact of the battery drain on the performance demands such as overheads, throughputs, delay and latency in an ad hoc mobile network. The aim of this paper is to contribute to the research trend in the energy efficiency management in an infrastructureless ad hoc mobile network and to assist researchers in identifying base protocols to achieve power reduction design objectives. The remaining parts of this paper follow the pattern highlighted as discussed here: Section 2 summarizes protocol solutions at various levels of network layer, section 3 presents a survey of energy efficient routing protocols for MANETs. Section 4 highlights the performance comparison of these energy-efficient routing protocols, section 5 discusses some MAC based power conserving protocols and section 6 concludes the paper and present our future research trends in MANET.

2. Related Works

Many authors have provided ample evidence and literature backing on the various energy efficient protocols for MANETs. Many related literatures were review by [38] with various categorization of the level of contributions into the energy conservation. Some authors targeted the design of low-power protocols within the physical layer such designs can be found in [47, 48, 49, 50], others addressed the energy efficiency issues with energy efficient protocols within the data link layer where MAC layer protocols were properly addressed to minimize energy consumption within the networks [51, 52]. In some cases, authors preferred the power conserving protocols within the Data Link layer [53, 54, 55, 56], while some addresses it from the network [57, 58, 59] and transport layers [60, 61] power aware protocols within the network layer. In Figure 1, these contributions were summarily depicted based on the level at which the energy conservation can be addressed. Many of these protocols were able to solve some problems; research is still ongoing to maximize the energy conservation at various levels. The interest in this paper is to examine recent energy savings protocols that are employed in both at the MAC and routing levels of MANETs.

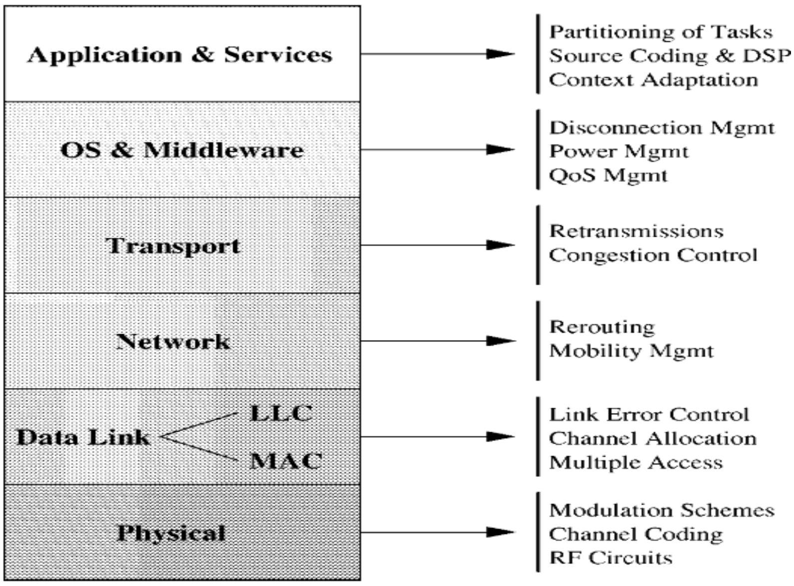

Figure 1. Protocol stack of Generic Wireless Network and corresponding areas of energy efficient research [38].

3. **Energy Conservation Routing Protocols**

MANETs energy conservation research has gained a tremendous focus from researchers by minimizing the active communication energy required to transmit or receive packets through transmission control or load distribution and also the energy consumption can be minimized by making inactive mobile nodes sleep or power down through inactive energy conservation approach. Some other school of thoughts believed that the dual approach can be hybridized to achieve efficient power conservation. The remaining part of this section takes a closer look at some protocols, discusses the objectives and methods adopted in saving power for MANET.

3.1 Location-based Power Conservation Scheme for Mobile Ad Hoc Network

Location-based power conservation scheme (LBPC) was proposed by [17]. They proposed an algorithm that reduces power consumption in MANET. The protocol uses the location information provided by inbuilt GPS to extract information such as average distance of the first hop neighbors and random distance between the nearest and farthest first hop neighbors for the adjustment of the transmission range. Based on the results of the simulation performed on the two types of flooding algorithms, it was shown to have a power conservation ratio that varied from 10-50%. This is a significant amount of energy conservation, and the power conserved was as a result of the various adjustments done to the network transmission range. However, the transmission range that equates the average distance of the neighbors provide higher energy conservation ratio but with low other performance parameters (such as throughput, end-to-end delay).

LBPC protocol finds the Euclid distance (r) between a node and all other nodes within the network. The deployment criteria are employed to determine the power conservation ratio (P_c) that causes additional computational complexities. These computational complexities impose extra energy usage on the all nodes in the network. The protocol only works well without extra overheads being added in MANET that uses location aware routing (LAR) algorithms where each node is already in the known of its location without necessarily computing the Euclid distance of other nodes within the network. Though, the results recorded from the simulation proved to be encouraging especially when the node density is increasing, because this also improves node connectivity and reduction in transmission range. Nevertheless, the limitation imposed by the computational complexities of the non-LAR compatible algorithm has eroded the gains recorded in LBPC scheme.

3.2 *SPAN: Energy Efficient Coordination Algorithm for Topology Maintenance*

This protocol codenamed SPAN [18] adopted distributed synchronization technique for multi hop ad hoc 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 and rotates them in time. The back-off delay for a node is a function of the number of 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 [19].

3.3 Energy-Efficient Location Aided Routing (EELAR)

Energy Efficient Location Aided Routing (EELAR) Protocol [31] was proposed to make significant reduction in the energy consumption of the mobile node power through the limiting new route discovery to a smaller zone. This assisted the network to have significantly reduced control packet overheads. The base algorithm for this proposal was Location Aided Routing (LAR) [32]. The proposal uses a reference wireless base station while the network's circular area centered at the base station is divided into six equal sub-areas. Packets are only flooded to the sub-area of the destination nodes instead of flooding control packets to the whole network area during route discovery, hence, the base station stores locations of the mobile nodes in a position table. The results from the simulations showed that EELAR protocol makes an improvement in control packet overhead and delivery ratio compared to Ad hoc On Demand Vector, Location Aided Routing and Dynamic source routing protocols.

3.4 Predictive Energy-efficient Multicast Algorithm

The Predictive Energy-efficient Multicast Algorithm (PEMA) [20] take the advantage of the network statistical properties in resolving scalability and overhead issues caused by large scale MANETs as opposed to relying on route details or network topology. The running time of PEMA depends on the multicast group size instead of network size, hence, this resulted in PEMA to be fast enough for MANETs that consisting of 1000 or more nodes. The results of simulation shows that PEMA post appreciable power savings compared to other existing algorithms, it also attains good packet delivery ratio in mobile environments. What makes PEMA so different is its speed, it is extremely fast because its running time is independent of its network size and the routing decision does not rely on the information about network topology or route details [21].

3.5 Power-aware Routing Protocol

Power-aware routing (PAR) [21] maximizes the network life span and minimizes the energy utilization by selecting less congested and more stable route, during the source to destination route establishment process to transmit data packets, hence, providing energy efficient routes. The three parameters focused by PAR protocol are: Accumulated energy of a path, status of battery lifetime and type of data to be transmitted. These core metrics are the focus of PAR during route selection time, hence, less congested and more stable routes for data delivery are considered. Thus, network lifetime are increased if different routes for different type of data transfer are provided. The results from the simulation shows that PAR outperforms related protocols such as DSR [22] and AODV [23], with respects to diverse energy-related performance metrics even in high mobility scenarios. Nevertheless, PAR incur increased latency during data transfer, but it discovered route will last for a long time, and enormous energy saving.

3.6 Power Management in Mobile AdHoc Network

In the work presented by [24], they proposed a scheme which is concerned with power awareness during route discovery. This scheme deals with mobile ad hoc network having large number of nodes and handles a different data traffic levels. The scheme modified AODV protocol by assuming that battery has three states as shown below:

- If (battery status < 20%), then it is in danger state.
- If (20% < battery status < 50%), then it is in critical state and,
- If (battery status > 50%) it is in active state.

Where % age is the decay factor of battery.

The proposal by [24] has 3 phases: RREQ (Route Request) phase, RERR (Route Errors) phase and local repair phase. Power related function occurs with RERP (Rout Reply) only because in the beginning all the nodes will be in fresh mode so there is a full power to find the route and send the request message and also all the nodes which are not participating in route request go to sleep mode.

The simulation done to comparison between AODV and the new scheme (modified AODV) shows that a large number of nodes did not died till the end of simulation (in new AODV) while less number of nodes survived deaths in AODV.

3.7 A New Energy Level Efficiency Issues in MANET

The aim of the proposal by [25] was to find a new scheme that minimizes energy consumption during idle mode of the node. They identified four types of energy consumption by the node in a network as follows:

- Energy consumed during sending a packet

- Energy consumed during receiving a packet
- Energy consumed during idle mode
- Energy consumed during sleep mode which occurs when the wireless interface of the Mobile node is turned off.

Due to a lot of power being consumed by nodes even when in a sleep or idle mode, they now came up with a protocol conserve or reduce the wasted energy. In simulating the protocol with two famous protocols AODV [23] and DSR [22] and comparing their energy consumption, the results placed DSR as being a little bit better than ADOV especially in a high mobility conditions.

3.8 Triangular Energy-Saving Cache-Based Routing Protocol by Energy Sieving

Triangular energy-saving cache-based routing protocol by sieving (TESCES) was proposed by [26], it is a kind of energy aware and location aware grid based protocols in MANETs. It was based on two protocols: a fully energy aware and location aware protocol (FPALA) [27, 33] and an energy saving cache based routing protocol (ESCR) [28]. In this protocol the network is divided into grids depending on GPS. TESCES has three procedures:

- GLEES to elect leader node with maximum energy for each grid in the network, while some nodes join a grid leader election, other nodes will be in sleeping mode.
- CGLM for maintain grid leader and new grid leader is candidate from cache table directly.
- TESRD for saving routing discovery and chose path with minimum nodes.

Connection in this protocol will be between the leaders in the grid and only the grid leaders will be in active mode and the other nodes of the grid will be in sleeping mode. Each node has cache table contains node identification; grid coordinates of the node and energy of the node. Communication in this protocol is also divided into intra-grid mode, when nodes connect with each other directly in the same grid through the leader node and this mode is supported by the point coordination function (PCF) of IEEE 802.11, and another mode is inter-grid mode, when node can connect with another node in different grid through its leader node in multiple hops, and this mode is supported by distributed coordination function (DCF) of 802.11. When the leader of grid loses his energy or the energy of the leader node will be insufficient, another node from the same grid will wake up and replace as the new leader of the grid and enter to the active mode, this is done by CGLM procedure. In route discovery, TESRD procedure choses path with minimum hops, regardless of the energy consumption.

The result of the TESCES protocol simulation was evaluated and compared with FPALA and ESCR protocols. The results indicate that TESCES protocol elongate ESCR and FPALA by 67% and 84% respectively while in energy consumption, TESCES eliminates 31% and 40% of ESCR and FPALA respectively. For residual ratio of nodes, TESCES increases

11% of ESCR and 19% of FPALA. Moreover, all these metrics may be better in TESCES when the number of nodes is increased.

3.9 Modified AdHoc On-Demand Distance Vector (AODVM)

This protocol is proposed by [29] to minimizing remaining energy. The protocol used AODV [23] routing discovery protocol as a base with one difference, AODVM choses optimal path taking into account the network lifetime and performance, in other words, considering survival energy of nodes and hop count. To achieve this, Minimum Remaining Energy (Min-RE) field is added to the RREQ message to determine energy value. This field has default value (-1) when the source node send new RREQ message. On the path to the destination, each intermediate hop increase its hop count and check Min-RE field to determine whether it is less than energy of the node, if this is true, it then swap between the values, otherwise Min-RE is unchanged.

Destination collects all RREQ messages from different routes and then use following equation to calculate and determine the optimum path with minimum energy.

$$\alpha = {(Min - RE)}/{HopCount} \tag{1}$$

Here *Min-RE* is the minimum residual energy on the route and *HopCount* is the number of hop in the route path between source and destination. Simulation results showed that AODVM increased network lifetime and enhanced energy conservation.

3.10 Efficient Energy Management For Mobile Ad Hoc Networks

An algorithm to modify DSR [22] protocol by reducing the overhead by minimizing the number of route reply packets and the header size of DSR data packets was proposed by [30]. Additionally, an algorithm for energy management is integrated with new DSR to decrease required energy when transmitting the data packets. In DSR protocol, destination send RREP messages using all available paths (flooding) and this caused high consumption of network resources, waste of energy and unnecessary congestion. In modified DSR [30] algorithm, destination chooses the path through which the first RREQ message arrived to destination, and send the RREP message through the same path while ignoring the other paths, and this path also will be chosen by source to send the data packets because this is the fastest path. This leads to decrease the end-to-end delay, reduce control packets generated and maximize packet delivery ratio. The modified DSR, also overcome overheads drawback of existing DSR, by reducing the header of data packet. Header of data packet now includes only source and destination address, while previously it includes source and destination address as well as all intermediate nodes address between source and destination.

4. Performance Comparism of the Energy Conservation Routing Protocols

The performance demand of various protocols reviewed thus far has really pitched the added advantages and drawbacks of these protocols against each other. In as much as all these protocols strived to reduce power consumption either at node level or on the network in general, all proposed solutions have a kind of trade-off that let go to have conspicuous energy saving. To bring out this performance trade-off, this paper presents in a tabular form as depicted in Table I, the observed performance metrics based on the simulation results posted by the various algorithms under review. We consider the following as major performance demands for all the protocols: the number of routes established during route discovery, the message overheads (i.e. the cost of performing the data packet transmission and reception by different nodes), average energy conserved, data packet delivery ratio, the network throughput, the end-to-end data packet delay, computational complexity of the algorithm and finally, the network life which has a direct relationship with energy conservation.

Table 1: Energy Management Protocols Performance Comparison

Protocol name	Multiple routes	Message overhead	Energy efficiency	Packet delivery ratio	Throughput	End-to-End delay	Network life	Computation complexity
LBPC	NO	LOW	MOD.	AVE.	AVE.	AVE.	MOD.	YES
SPAN	YES	LOW	HIGH	AVE.	AVE.	HIGH	HIGH	NO
EELAR	YES	LOW	HIGH	HIGH	AVE.	LOW	HIGH	NO
PEMA	YES	MOD.	HIGH	AVE.	HIGH	LOW	HIGH	NO
PAR	NO	MOD.	HIGH	LOW	AVE.	HIGH	HIGH	YES
NEW AODV	YES	LOW	HIGH	AVE.	AVE.	LOW	HIGH	NO
Q-PAR	YES	LOW	HIGH	HIGH	HIGH	LOW	HIGH	YES
NELE	YES	LOW	HIGH	LOW	LOW	LOW	HIGH	YES
TESCES	YES	MOD.	HIGH	AVE.	AVE.	AVE.	HIGH	NO
AODVM	YES	MOD.	HIGH	HIGH	HIGH	LOW	HIGH	YES
MDSR	YES	LOW	HIGH	HIGH	HIGH	LOW	HIGH	YES

AVE-Average, MOD-Moderate

5. Other Energy Savings Techniques in MANET at the MAC Layer

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

MAC is considered a part of the data link layer (DLL) in the Open Systems Interconnection (OSI) reference model [37], as shown in Figure 1. 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.

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MAC protocols can be divided into three categories *contention-based, conflict-free* and *hybrid* schemes as shown in Table 2.

Table 2. Classification of MAC schemes [39]

Contention-based	Conflict-free	Hybrid
ALOHA: transmit whenever ready.	FDMA: allocate frequency channels.	PRMA, D-TDMA: contention-based for obtaining channels, and when channels are dedicated, use them conflict-free.
Slotted ALOHA: transmit at the beginning of a time slot.	TDMA: allocate frequency and time slot combinations.	
CSMA: sense the carrier before transmission.	FH-CDMA: frequency hop over several frequency channels.	
CSMA/CD: stop transmission when a collision is detected and try again.		
CSMA/CA: avoid collisions by notifying hidden terminals.	DS-CDMA: spread the data into a larger spectrum.	

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 [39]. In this classification, it imperative to note that the most important characteristics of an efficient MAC protocol according to [40] are as stated below:

• Predictability of delay

- Adaptability
- Energy efficiency
- Reliability
- Scalability

In this section some proposals on MAC protocols with interest in power management are briefly described.

5.1 p-MANET: Efficient Power Saving Protocol for Multi-Hop Mobile Ad Hoc Networks

p-MANET protocol was proposed by [34] and 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 (PSM) 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 modes: listen and power saving (PS) 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.

The simulation results of the protocol showed that about 10% to 70% energy saving can be achieved by p-MANET compared to Quorum-based protocol [35] under various scenarios. The improvement of survival time of p-MANET over that of the Quorum-based protocol ranges from 8.3% to 71%. Simulation results also shows that the neighbor discovery time of p-MANET is also significantly reduced.

5.2 Multiple Spreading Codes based MAC Protocol for Wireless Networks

In [36], authors propose an interference limited MAC protocol based on code division multiple accesses CDMA to increase the throughput and the energy conservation of MANETs.

Usually, IEEE 802.11 MAC protocol uses the same pseudo noise (PN) code for spreading all the transmitted signals. This mean no concurrent transmissions occurs in the neighborhood of a receiver. In this protocol multiple spreading codes are used to get simultaneous interference-limited transmissions in the neighborhood of a receiver. Generally, node knows location of its next neighborhood for transmissions from the overheard control packets (RTS and CTS). There are two frequency channels, control and data channel, and the

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node can use these channels to send and receive data simultaneously. So the channel allocation is similar to frequency division multiplexing in which a node can receive from different frequency channels simultaneously irrespective of the signal power. Different spreading codes are used to divide data channel into multiple channels. In this system each node must has two transceivers, one for data channel and the second for control channel. This is very necessary because the nodes use RTS-CTS packet exchange for route reservation. Each node has also two tables, transmission table and distance table, which are using during energy calculation.

The simulation of the proposed protocol shows that increase network throughput by 80% and this incensement was due to the increase in number of concurrent transmissions.

5.3 An efficient MAC protocol with cooperative retransmission in mobile ad hoc networks

In [41], the authors propose cooperative MAC protocol to increase transmission reliability and reduce delay time in mobile ad hoc networks. In traditional wireless MAC protocols, nodes that are not the intended receiver will discard the overhead data frames; yet, cooperation among these nodes is considered important in improving system performance [42]. In the proposed protocol, stuffing nodes between sender and receiver are used if the route between the sender and the receiver becomes unreliable. Moreover, the receiver may also stop forwarding the received data if the data is received by the next-hop receiver on the route to the final destination node. The RTS and DATA used in this protocol are modified to include the sender id, receiver id, and next-hop receiver id.

This protocol includes also two procedures to enhance transmission reliability and efficiency. These two procedures are: route enhancement and the second is route bypass.

The simulation of the proposed protocol shows that increase transmission reliability and decrease delay time compared with previous works.

5.4 TAMMAC: An Adaptive Multi-Channel MAC Protocol for MANETs

In [43], the authors present a new single transceiver MAC protocol, named Traffic Aware Multichannel Medium Access Control (TAMMAC). The protocol uses multiple channels with smart window increase and decrease rules to adjust the contention window size dynamically and properly. In this protocol each host uses only one transceiver for multi-channel transmission. There is one channel selected to be control channel for transmitting control messages, and the other channels will act as data channels to transmit the data messages. The time frame is divided into two subintervals; one subinterval will be uses for negotiation. This negotiation will be between two communicating hosts through the control channel to reserve an appropriate channel for data transmission. The second subinterval will be for data transmission interval. These subintervals can be dynamically adjusted according to network traffic condition to maximize the channel utilization. For channel negotiation, the protocol uses the reserved bits of RTS/CTS to save channel usage status and controlling information.

These new RTS/CTS messages are called MRTS (Multi-channel RTS) and MCTS (Multi-channel CTS). MRTS contains two extra fields, “Channel Info” field which is used to carry the information of channel negotiation, and “More Operations” field that is together with the “Channel Info” field define operations, such as channel selection, increasing/decreasing negotiation interval, etc.. The simulation of the proposed protocol shows that increase network throughput and decrease delay time compared with other protocols.

5.5 FD-MAC: A Flow-Driven MAC Protocol for Mobile Ad Hoc Networks

Data collision is a significant issue in mobile ad hoc networks. Authors propose a new MAC protocol called flow-driven MAC (FD-MAC) for mobile ad hoc networks (MANETs) to solve this problem in [44]. FD-MAC depend on a slotted MAC protocol because it is an easier way to produce MAC protocol with a delay bound and also is more suitable way for a Wi-Fi Long Distance Network (WILD) [45]. FD-MAC includes random access and reservation-based access, and presents the notion of *data flow* and a flow-driven mechanism for resource reservation. Data flows are divided into two parts: first part is short-duration flows, also called mice flows (MFs), for which the FD-MAC uses a random access protocol. The second part is long-duration flows, also called elephant flows (EFs), for which the FD-MAC uses a flow-driven reservation-based access protocol. Data flow in FD-MAC is a chain of packets with five elements containing: source IP, destination IP, source port, destination port, and Type of Service (ToS). In slotted MAC, channel bandwidth is divided into a number of timeslots that can be used by network nodes through contention. In FD-MAC protocol each slot has six states these are:

- IDLE: The slot without any reservation by any node. A node can reserve a slot for sending and receiving data, and can transmit contention packets in this slot.
- CANSEND: A node is an exposed node and did not reserve this slot. The slot is reserved by one or more neighbors for transmitting data but not for receiving data. So, the node can send contention packets in this slot or can only reserve the slot to transmit data.
- CANRECV: A node is a hidden node and did not reserve this slot. The slot is reserved by one or more neighbors for receiving data but not for transmitting data. So, the node can reserve the slot to receive data but cannot send contention packets in this slot.
- FORBIDEN: one or more neighbors have reserved this slot to receive and to transmit data, and a node did not reserve this slot. So the node cannot send contention packets in this slot or reserve this slot.
- SENDING: A node has reserved this slot to transmit data. The node sends reservation packets in this slot and there is agreeing receiving node.
- RECVING: A node has reserved this slot to receive data. The node receives reservation packets in this slot and there is agreeing transmitting node.

Each head of the MAC packet has 12 bytes; the node can use these bytes or use Hello messages that are periodically exchanged among nodes to inform his neighbors of all states of all its slots. Every node uses this information to decide its slot states and to allocate its slot resources.

The simulation of the proposed protocol shows that increase network throughput compared with the MACA and Slotted ALOHA protocols, and performs better than IEEE 802.11 in terms of throughput and latency under medium and high traffic load.

5.6 A Faired Quality of Service Assured MAC protocol for Mobile Adhoc Network

In [46], a new MAC protocol is proposed which depend on IEEE 802.11 and handles the QoS, fairness and multihop capability. There are different types of traffics assigned with different priority levels. The authors involved in this protocol three types of traffics: voice traffic (constant bit rate) with priority level equal 2, video traffic (variable bit rate) with priority level equal 1, and datagram traffic with priority level equal 0. Each node has three queues q2, q1, and q0 for different priority classes. The highest priority queue is q2 which is check first, if q2 not empty then the packet is de-queued. The contention window is set for that prioritized traffic and then the CWsize multiplied by the scaling factor. Packet is belong to a flow, if the number of service obtained by the flow is less than the minimum service among other flows then the CWsize will be reduced and the node will contend for the channel with a less window size for the packet. If the number of service obtained by the flow is more than the minimum served flow the contention window size will be set more. The operations are repeated until all the queues are empty.

Simulation of this protocol shows that high prioritized traffics have larger throughput and transmission capability as compared to the low prioritized traffics.

5.7 Dynamic Channel Assignment with Power Control

In [62], dynamic channel assignment with power control (DCAPC) was proposed to address both power and multi channe1issues. This protocol has one control and N data channels. The sender, before sending RTS, checks to confirm whether a free data channel is available, and if it is available, it selects an available channel and sends a RTS signal on the control channel to the destination with maximum power. If the destination node is in agreement with the sender’s channel choice, it replies with CTS at a power level appropriate to reach the sender. The sender then reserves the channel. If the destination has a conflict with the sender’s channel choice, it sends its free channel list for the sender to choose a more appropriate channel. This protocol also optimizes power consumption at the node during transmission, by controlling the transmit power so that it is just enough to reach the intended receiver. The detailed behaviour of how each node continuously monitors, records, and updates the transmission power level it needs to reach each neighbor are specified. At the beginning, the nodes are not aware of the appropriate power levels; therefore, they transmit with maximum power. After the contact has been established with neighbor nodes, the appropriate power levels for communication are calculated and noted by the nodes. However, it is observed that when the number of channels is increased beyond a point, the effect of power control is less significant.

5.8 Power Aware Medium Access Control with Signaling

Power Aware Medium Access Control with Signaling (PAMAS) [51] profits from the gains of a simple RTS/CTS handshake to get over the problem of power consumption due to the overhearing of irrelevant transmission and idle listening. Akin to DCAPC, power and multi-channel issues are also addressed by PAMAS. It has two channels – a common control channel and a common data channel respectively. The length of the upcoming transmission in both RTS and CTS is included in PAMA. If the nodes hear RTS or CTS on the control channel, they refrain from communicating since they are in the neighborhood of the sender and/or receiver. During the period of the transmission, as indicated in the handshake messages, the neighboring nodes go into a sleep mode. Therefore, PAMAS reduces power consumption for nodes operating in highly connected networks under sparse load conditions, where many idle nodes may be overhearing other nodes' transmissions.

5.9 Dynamic Power Saving Mechanism

Dynamic Power Saving Mechanism (DPSM) [63] scheme offers power conservation with dynamism of controlling the sleep and wake states of nodes. This protocol is a variant of the IEEE 802.11 scheme, which achieves longer node dozing times with the use of dynamically sized Ad hoc Traffic Indication Message (ATIM) windows. The IEEE 802.11 DCF mode has an in-built power saving mechanism. In the beginning of the beacon interval, all nodes stay awake for a fixed time called ATIM window, during which the status of packets ready for transmission to any receiver nodes is announced. These announcements are made through ATIM frames, and acknowledged with ATIM-ACK packets during the same beacon interval as illustrated in Figure 2

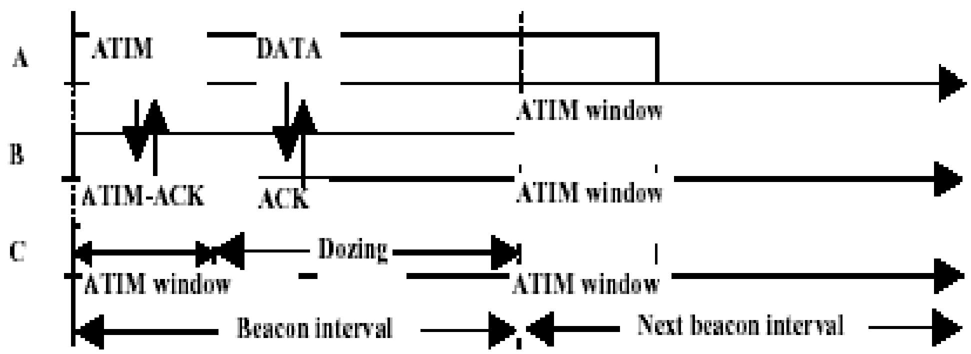

Figure 2: Power saving mechanism for DCF [64]

In the figure, Node A announces a buffered packet for B using an ATIM frame, then, Node B replies by sending an ATIM-ACK, and both A and B stay awake during the entire beacon interval. The actual data transmission from A to B is completed during the beacon interval. Since C does not have any packet to send or receive, therefore, C doze off after the ATIM window.

5.10 QoS-aware MAC protocol with power control

QoS-aware MAC protocol with power control (MPPC) was proposed by [64] for ad hoc a network, this protocol combines Modified MACA/PR and an idea of distance based power control. Because Modified MACA/PR (MMACA/PR) scheme enables bounded end-to-end delay for real-time flows, therefore this advantage was utilized in designing the MPPC.A power control mechanism that regulates the transmission power that a transmitting node uses was implemented. The appropriate transmission power is calculated based on the distance at which the recipient node is located, the initial request to set up a connection is made by the transmitter at the maximum power level by sending a RTS packet to the receiver. The receiver then calculates the suitable power level that is sufficient to carry out the communication between the two nodes legibly and includes this information in the CTS packet that it transmits to the transmitter in response to the RTS. Hereafter, the transmitter sets its transmission power at the desired level (as indicated in the CTS) and all communication thereafter is carried out at that power level.

All the nodes in the network maintain two reservation tables:

- Receive Reservation Table (RT)- This keeps track of the sessions in which the neighboring nodes are scheduled to receive timestamp and the power level in which they are transmitting.
- Transmit Reservation Table (TT)- This keeps track of the sessions in which the neighboring nodes are scheduled to transmit timestamp and the power level in which they are transmitting.

In an attempt to transmit RTS, the sender checks its two reservation tables for an empty session that is big enough to transmit RTS/CTS/DATA/ACK. If an empty session is available, it will send a RTS packet at the maximum power level and wait for a CTS packet. On receiving the RTS packet, the receiving nodes check its two reservation tables and then calculates the appropriate power level based on the distance factor, that is sufficient to carry out the communication between the two nodes and includes this information in the CTS packet and transmits back to the sender if it is in a session that can accommodate CTS/DATA/ACK transmissions. Should the case cannot receive CTS it will back off for a while and retransmit RTS. If the RTS/CTS handshake is successful, the transmitter sets its transmission power at the desired level (as indicated in the CTS) and sends the DATA packet. On receiving the DATA packet, the receiver sends back the ACK with the same power level. The simulation results point out that the performance of this scheme is largely invariant for light and moderately heavy loads. In heavily loaded networks, however, for performance measures such as throughput, average delay, the overall MPPC scheme with power control is seen to be the best. This scheme reduces exposed terminal problems, it provides different QoS requirements, increases the life of battery driven devices with power control, and reduces co-channel interference.

5.11 Energy Efficient-MAC Protocol

Energy Efficient MAC protocol was proposed by [65]. The design was based on the fact that most applications of ad hoc networks are data-driven, which means that the sole purpose of forming an ad hoc network is to collect and disperse data. Hence, keeping all network nodes awake is costly and unnecessary when some nodes do not have traffic to carry. This protocol conserves energy by turning off the radios of specific nodes in the network. The goal is to reduce energy consumption without significantly reducing network performance. EE-MAC is based on IEEE 802.11 and its power saving mode, and can provide useful information to the network layer for route discovery. The scheme select master nodes from all nodes within the network, the master nodes stay awake all the time and act as a virtual backbone to route packets in the ad hoc network. Other nodes, called slave nodes, remain in an energy-efficient mode and wake up periodically to check whether they have packets to receive. To crate fairness among all nodes, a rotation mechanism between masters and slaves nodes are used. EE-MAC uses some features of PSM, such as periodically waking up at the beginning of the beacon interval.

EE-MAC can provide knowledge and guidance to the route lookup process, because only master nodes can be selected along a routing path. On the other hand, EE-MAC requires a mechanism to awaken a sleeping node when packet delivery is imminent. This is usually handled by low-level mechanisms at the MAC or physical layers. In EE-MAC, if a node has been asleep for a while, packets addressed to it are not lost but are stored at one of its upstream nodes, usually a master. When the node awakens, the buffered data is sent to it (this is a PSM feature which is used in our protocol).

The design considered the following design criteria:

- The protocol must ensure enough master nodes are elected to build the backbone of the network so that every node has at least one master in its vicinity.
- The master node election algorithm is based on local information, which is a distributed approach. Each node only employs local information to determine whether it will become a master.

Due to the characteristics of distributed management in ad hoc networks and the two essential requirements, low overhead and fast convergence, the algorithm for finding a CDS should be localized. The election algorithm is given in the next section.

The performance of EE-MAC was evaluated using network simulator, and its performance was compared to IEEE 802.11 with and without power saving mode. The simulation results show that IEEE 802.11 performs better than EE-MAC in terms of packet delivery ratio and average packet delay. Nevertheless, EE-MAC outperforms IEEE 802.11 in energy efficiency and is much better than PSM in overall terms. The network load has a great impact on the behavior of EE-MAC. Under a light network load, EE-MAC is only slightly worse than IEEE 802.11, but as the network load increases, the difference in performance between EE-MAC and IEEE 802.11 increases because EE-MAC needs to rotate masters and slaves more frequently with high traffic and EE-MAC still uses the ATIM window. The results also show that the higher the node density, the better EE-MAC performs. It was summed up by the author that a mid-sized network with relatively high node density is the best environment to utilize EE-MAC.

The list of energy conserving MAC protocols are inexhaustible, Table 3 shows the some distinguishing features of some of the protocols discussed thus far.. A dash (-) used where there is no information about the protocol characteristics.

Table 3. Performance Comparison of MAC based Energy Conservation Protocols

MAC Protocol	Collision Avoidance	Reliability	Energy Conservation	Adaptability	Delay Predictability
p-MANET	Yes	-	More efficient than Quorum-based protocol	-	No
cooperative MAC protocol	Yes	Yes	Yes	-	No
TAMMAC	Yes	Yes	-	-	No
Multiple Spreading Codes	-	-	Yes	Yes	-
FD-MAC	Yes	-	-	-	No
Faired Quality of Service	-	-	-	-	No
Adaptive Multi-channel MAC Protocol	Yes	-	-	-	No

6. Conclusion and Future Research Focus

In this paper, we presented a survey of energy conservation protocols for mobile ad hoc network at both routing and MAC layer respectively. The article starts with the detailing of the causes for power drain in MANETs and various methods that have been adopted to reduce power consumption. We identified various performance demands of these protocols and showed the effect of optimizing energy consumption against these performance parameters through available proposals. We conclude that no single protocols can deliver the overall performance demands for MANET without having to trade-off other performance metrics to achieve high energy conservation. This conclusion is based on the simulation results of protocols under review. However, many of these simulations were performed in completely different conditions, in non-realistic scenarios and in some cases even with different simulators/implementations. 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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