www.ijecs.in
International Journal Of Engineering And Computer Science ISSN:2319-7242
Volume 4 Issue 5 May 2015, Page No. 12176-12180

An Energy Efficient Multichannel Mac Provisioning In MANETS

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ABSTRACT-This paper proposes a TDMA-based multichannel medium access control (MAC) protocol for QoS provisioning in mobile ad hoc networks (MANETs) that enables nodes to transmit their packets in distributed channels. The IEEE 802.11 standard supports multichannel operation at the physical (PHY) layer but its MAC protocol is designed only for a single channel. The single channel MAC protocol does not work well in multichannel environment because of the multichannel hidden terminal problem. Our proposed protocol enables nodes to utilize multiple channels by switching channels dynamically, thus increasing network throughput. Although each node of this protocol is equipped with only a single transceiver but it solves the multichannel hidden terminal problem using temporal synchronization. The proposed energy efficient multichannel MAC (EM-MAC) protocol takes the advantage of both multiple channels and TDMA, and achieves aggressive power savings by allowing nodes that are not involved in communications to go into power saving "sleep mode". We consider the problem of providing QoS guarantee to nodes as well as to maintain the most efficient use of scarce bandwidth resources. Our scheme improves network throughput and lifetime significantly, especially when the network is highly congested. The simulation results show that our proposed scheme successfully exploits multiple channels and significantly improves network performance by providing QoS guarantee in MANETs.

Keywords: *Multichannel MAC, MANETs, frequency spectrum, TDMA, hidden terminal, energy efficiency, IEEE 802.11.*

I.INTRODUCTION

A key problem of wireless networks is medium access control (MAC) protocol, which deals with efficient resource sharing for multiple nodes during communications. A MAC protocol addresses how to resolve potential contentions and collisions when using the communications medium.

By exploiting multiple channels, we can achieve higher throughput compared with single channel communications, since the use of multiple channel can reduce the interference influence. Because of the multichannel hidden terminal problem, a single channel MAC protocol does not work well in a multichannel environment. To achieve high throughput with congested traffic, the design of multichannel MAC protocol is a good solution. In multichannel MAC protocol all the active nodes select their data channel on a default channel during control phase and then transmit their data packets on the selected channel during data communications phase. One of the important design issues of MAC protocol is how to utilize radio spectrum efficiently to resolve potential contentions and collisions among mobile nodes.

In ad hoc networks consisting of portable devices (at least in part), energy management is of prime importance because of the limited energy availability in the portable devices. With the increase in the number of mobile devices, and with communications being the major cause of energy consumption, the power savings of a MAC protocol become a pertinent issue. Therefore, it is desirable to build a network protocol that maximizes the time a device is in sleep mode, and also maximizes the number of wireless devices that can be in sleep mode.We use bandwidth as a main QoS parameter in this paper. This is because the bandwidth guarantee is one of the most critical requirements for real-time applications.

In this paper, we propose an energy efficient multichannel MAC protocol for QoS provisioning, which enables nodes to dynamically select not only channels but also timeslots, such that multiple communications can take place in the same region simultaneously, each in different channel. We consider a MANET that does not rely on infrastructure, so there is no central authority to perform channel management. The main idea is to divide system time into fixed-time beacon intervals, and have a small window at the start of each interval to indicate traffic and select channels and timeslots for use during the interval. Apart from the nodes that will be involved in data transmissions, all other nodes turn into sleep mode in the rest of the beacon interval. The proposed scheme can eliminate contention between nodes, decompose contending traffics over different channels and timeslots based on actual traffic demand, which guarantees QoS in MANETs.

II. RELATED WORK

A large number of multichannel MAC protocols and TDMA scheduling algorithms have been proposed in the literature. In our proposed EM-MAC protocol, we do not require any special hardware but only a single half-duplex radio transceiver. Multichannel MAC protocols that are closely related to the EM-MAC protocol are the ones that extend

IEEE 802.11 DCF and use certain kinds of control message for channel selection. Typical protocols in this group are multichannel MAC (MMAC),local coordination-based multichannel MAC (LCM MAC),cooperative asynchronous multichannel MAC (CAM-MAC),TDMA based multichannel MAC (TMMAC),and multichannel MAC with channel distribution (CD-MAC).

MMAC assumes *C* channels are available for use. Each node maintains a data structure called the preferable channel list (PCL) which records the usage of channels inside the transmission range of the node. PCL also indicates which channel is preferable for the node to use. Based on this information, the channels are categorized into three states: high preference, medium preference, and low preference. During the ad hoc traffic indication messages (ATIM) window, every node must listen to the default channel for periodic beaconing and to transmit ATIM packets. During the ATIM window, every node listens to the same default channel to decide which channel to use for data communications. After the ATIM window, nodes that have successfully decided channels send data packets using 802.11 DCF to avoid congestion. Its performance can be obviously degraded because of the random channel selection. Furthermore, MMAC protocol leads the problem of wasting multiple channels bandwidth greatly.

Two new MAC protocols for multichannel operation in wireless ad hoc and mesh networks have been proposed in. The first protocol, extended receiver directed transmission protocol (XRDT), is based on the receiver directed transmission (RDT), a multichannel solution, which uses a notion of quiescent channel. XRDT solves the problems faced by RDT, such as multichannel hidden terminal and deafness, by using an additional busy tone interface and few additional protocol operations. A novel single interface solution, called local coordination-based multichannel MAC (LCM MAC) is also developed. LCM MAC performs coordinated channel selection and channel switching to provide multichannel support.

An energy efficient multichannel MAC protocol, called TMMAC is proposed in . In TMMAC, system time is divided into fixed periods, which consists of an ATIM window followed by a communication window. The ATIM window size is dynamically adjusted based on different traffic patterns to achieve higher throughput and lower energy consumption. During the ATIM window, each node decides not only which channels to use, but also which timeslots to use for data communications. Then each node adopts the selected channel for each timeslot to transmit or receive data packets.

A multichannel MAC protocol for MANET that enables nodes to transmit packets in distributed channels is proposed in . In this protocol, the ATIM window is divided into two windows: the deciding channel window (DCW), and the exchanging packet window (EPW). Source and destination nodes can negotiate with each other in deciding a channel that can be used to compete for the final data channel in the DCW. In the EPW, source and destination nodes can compete to obtain a channel to transmit packets. This mechanism can distribute pair source and destination nodes to compete for a data channel. Hence, because of this, collisions can be avoided greatly and throughput can be increased. Our work is different from them, we consider TDMA-based slotted scheme in communication window instead of contention-based scheme.

A multi-channel MAC protocol for single-hop scenario is presented in . An analytical model is proposed to calculate the network throughput that are designed to schedule multiple packets to be transmitted on different data channels simultaneously, having a dedicated control channel. Based on the analytical model, a scheme by tuning the initial contention window size is proposed to maximize the network throughput. The proposed scheme can find an optimum initial window size to maximize the total network throughput. The proposed protocol allows better channel utilization by reducing the number and the size of control packets. Though this protocol performs better in dedicated control channel protocols for single-hop scenario but it does not investigate the performance in multi-hop cases.

III. SYSTEM MODEL

We consider a multi-hop MANET, where no central entity exists to coordinate medium access and channel allocation. Each node is equipped with a single half-duplex transceiver. The spectrum bandwidth is divided into multiple orthogonal channels. Consider the spectrum consisting of *C* non-overlapping channels, each with bandwidth B_c (c = 0, 1, 2 C -1). A transceiver can be tuned to different channels, but can only use one channel at a time.

We assume that each transceiver always transmits at a fixed transmission power and hence, their transmission range R_c and interference range I_c , which is typically 2 to 3 times of transmission range , are fixed for a particular channelϵ c. We use a communications graph $G(V, E)$, to model the network, where each node v V corresponds to a mobile node in the network and E $\epsilon$is the set of communications links each connecting a pair of nodes. There is a link $l = (u, v)$ E between nodes u and v, if two nodes are in the transmission range. A communication link $l = (u, v)$ denotes that u can transmit directly to v if there are no other interfering transmissions. Due to the broadcast nature of the wireless links, transmission along a link may interfere with other link transmissions when transmitted on the same channel.

IV. Energy Efficient Multichannel MAC Protocol

The structure of the proposed EM-MAC protocol is depicted in **Fig. 1.** We assume that system time is divided into fixed-length beacon intervals and each beacon interval consists of an ATIM window, and a communication widow. The ATIM window, which is divided into the beacon and the control window, is contention-based and uses the same mechanism as in the IEEE 802.11 DCF. A TDMA scheme is used in the communication window.

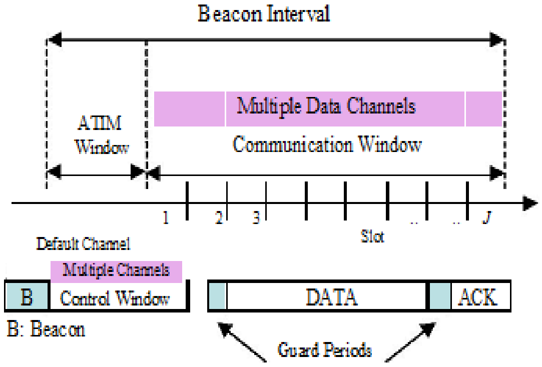


Fig. 1. Structure of the proposed EM-MAC protocol.

Although the EM MAC scheme has some similarities with both MMAC and TMMAC but our protocol is fundamentally different from them because the control information is not based on common control channel (CCC). Assume that default channel is channel 0. All nodes broadcast their beacons on channel 0, which is also used for global synchronization. In the beacon period, all nodes listen to channel 0 and wait for a backoff time to broadcast their beacon packets.

A channel-timeslot pair (*c*, *t*) is defined as the "communication segment". In the control window, the pair source and destination compete for selection of communication segment to transmit data packets. After competing in the control window, the winning pair source and destination will be able to use the communication segment in the communication window. In MANETs, the number of nodes is usually greater than the number of channels. Therefore, there are many pairs of sources and destinations that compete for the communication segments in the control window. Thus, for increasing the channel utilization and to decrease the control packet collisions in the control window, instead of using only channel 0 all multiple channels are used in our EM-MAC protocol for selecting communication segments. From **Fig.2**, it can be observed that the channel utilization of the EM-MAC protocol is higher than that of the MMAC protocol.

According to our MAC structure, the duration of each slot is given by×

$$D_{slot} = D_{data} + D_{ACK} + 2D_{guard}$$

In the communication window, nodes can send or receive packets or go to sleep mode to save power.

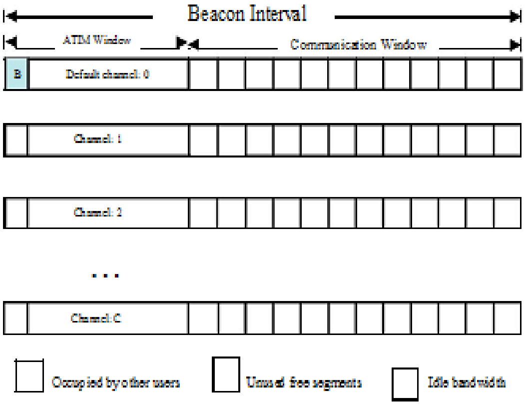


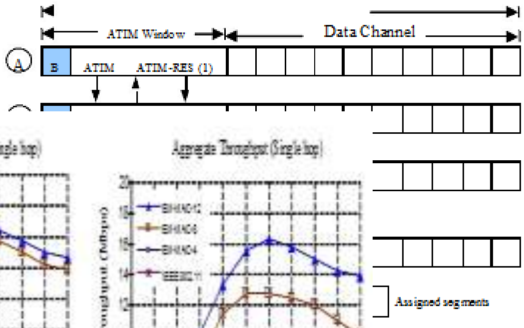
Fig. 2. Channel utilization of EM-MAC protocol.

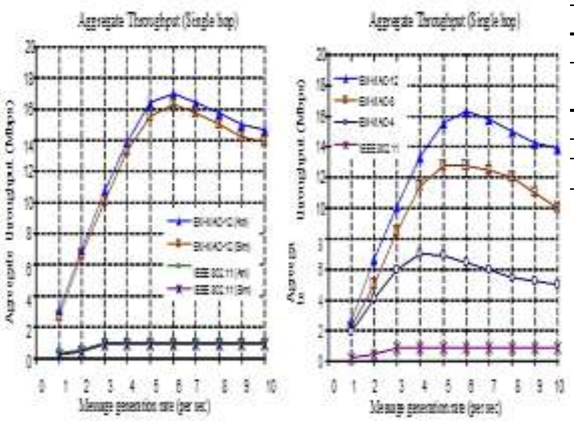
To assure collision-free communications, all neighborhood nodes of the intended receiver except the intended transmitter should remain silent on the particular channel during a given timeslot.

Based on the collected neighbor information and its own information each node updates the status of its communication segments as occupied or free. Status of the communication segments on a link is determined by finding the intersection of the status of both end nodes of the link.

IV.(i). SOLUTION OF MULTICHANNEL HIDDEN TERMINAL PROBLEM

Suppose that in **Fig. 3** node *A* has packets for *B* and thus *A* sends an ATIM packet to *B* during the ATIM window, a list of free communication segments of *A* included in the packet. On receiving the ATIM request from *A*, *B* decides which segments to use during the beacon interval, based on its free communication segments and free communication segments of *A*.After selecting the communication segments, *B* sends an ATIM-ACK packet to *A*, specifying the channel and timeslots it has chosen. When *A* receives the ATIM-ACK packet, *A* will see if it can also select the same channel-timeslot specified in the ATIM-ACK packet. If it can, it will send an ATIM-RES packet to *B*, with selected channel-timeslots of *A* specified in the packet. If *A* cannot select the channel-timeslots which *B* has chosen, it does not send an ATIM-RES packet to *B*.





The process of communication segment assignment and data exchange in EM-MAC is illustrated in **Fig. 3** and shows how multichannel

Fig.3. Solution of multichannel hidden terminal problem using EM-MAC protocol.

hidden terminal problem can be solved by using our EM-MAC protocol. During the ATIM window, *A* sends ATIM to *B* and *B* replies with ATIM-ACK indicating to use channel 1 and timeslots as per QoS requirement. This ATIM-ACK is overheard by *C*, so channel 1 will not be selected by *C*. When *D* sends ATIM to *C*, *C* selects channel 2 and required timeslots. So, after the ATIM window, the two communications (between *A* and *B* & between *C* and *D*) can take place simultaneously in the communication window.

V. ANALYTICAL MODEL

To estimate the capacity of EM-MAC protocol, in this section, we present an analytical model to compute the saturated throughput and delay for both EM-MAC and single channel MAC in IEEE 802.11 DCF in WLANs based on Markov chain model presented in. Although multi-hop networks are more complicated than WLANs, the analytical study based on WLANs offer better understanding of the performance of EM-MAC. **Table 1** shows the definitions of the system parameters used in this analysis. We have developed the analytical model based on the Markov chain model for IEEE 802.11e enhanced distributed channel access (EDCA). In order to compute the saturated throughput and delay for multichannel networks, we adopt the analytical model developed in based on the IEEE DCF MAC mechanism. When we consider the relation between packet size and saturated throughput, we shall attempt to find the ptimal trade-off between them.

Fig.4. Performance Evaluation Model

VI. PERFORMANCE EVALUATION

The effectiveness of the proposed EM-MAC protocol is validated through computer simulation. This section describes the simulation environment and the experimental results. To evaluate EM-MAC protocol, we have developed a packet-level discrete-event simulator written in C++ programming language,
which implements the features of the protocol stack described in this paper. The result of our approach is compared with IEEE 802.11 DCF , MMAC , TMMAC , and CD-MAC .

The simulated network is composed of 100 nodes deployed randomly within a 500 m × 500 m square region. The transmission and interference range of each node is approximately 150 m and 300 m respectively. The two-ray-ground reflection model is used as propagation model. We set an× initial energy of 100×Joules per node and the transmitting energy of each× node: *ETx* = (1.65 packet size in bits)/2 10^6 Jules, and the receiving energy: *ERx* = (1.15 packet sizein bits)/2 $\times 10^6$ Jules . Nodes move randomly according to the random waypoint mobility model. In all simulations, nodes choose a speed uniformly distributed between 0.5 and 3 m/s, which regard as the range of human walking speeds in an indoor environment. To provide a highly dynamic scenario, we set the pause time to zero seconds on all simulations.

Assume that beacon interval for the MAC scheme is set to 42 ms where the communication window is 34 ms. The number of timeslots in the communication window is set to 8 and each slot duration is 4.25 ms, which is calculated for a 1000 bytes packet to be sent through the channel of data rate 2 Mbps. The length of the ATIM window$_{\mu}$ is 8 ms where 2.5 ms is assigned for beacon period. Channel switching delay is set to 80 s. Among them, one channel is CCC and the others are data channels. Statically chosen shortest path routing is used to show the performance in multi-hop scenario. We initiate route request (RREQ) between randomly selected but disjoint source-destination pairs.

We impose the best effort traffic with message generation time exponentially distributed with mean value 1/{(message generation rate)/(number of nodes)} s. Average message length is geometrically distributed with mean value 4000 packets. We vary the message generation rate to vary the offered load to the network. Each data point in the plots is an average of 10 runs where each run uses a different random network topology. The simulation time of each run is set to 600 seconds.
The following performance metrics are used to evaluate the proposed EM-MAC protocol:

***Aggregate Throughput*:** Total bits received per second by the destinations.

***Average End-to-End Delay*:** Average latency incurred by the data packets between their generation time and their arrival time at the destinations.

***Energy Efficiency*:** The energy efficiency that is measured in data packets delivered to the destinations per Joule.

***Network Lifetime*:** The duration from the beginning of the simulation to the first time node runs out of energy.

The comparisons of the energy efficiency of the protocols are shown in **Fig.5**. The graph shape is identical with aggregate throughput. It is shown in the figure that received packets at the destinations per Joule increase up to the saturation level of the offered load and then slightly decrease till the end of simulation. Our proposed EM-MAC protocol shown more energy efficient compared to other protocols. The network lifetime is shown in **Fig.6**.Our proposed EM-MAC protocol handles battery energy in an efficient way thus prolonging the lifetime of individual nodes and overall network as well. When the offered load increases the network lifetime decreases because of the increasing of the number of routes.

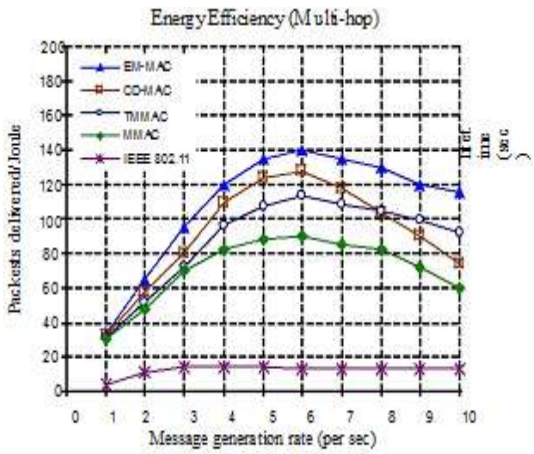


Fig. 5. Comparison of energy efficiency of EM-MAC with other protocols.

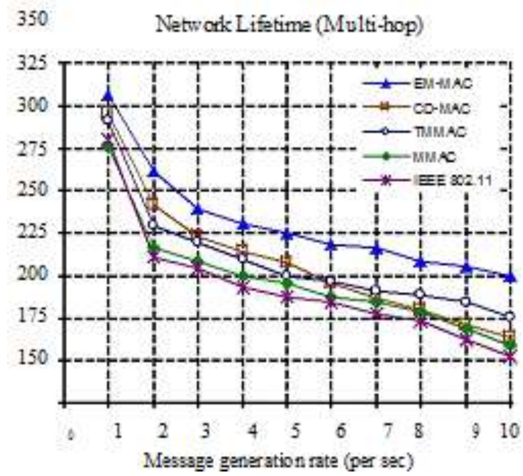


Fig. 6. Comparison of network lifetime of EM-MAC with other protocols.

VII. CONCLUSION

In this paper, we present the EM-MAC protocol, which is a multichannel MAC protocol using a single half-duplex transceiver for QoS provisioning in MANETs. Nodes that have packets to transmit, negotiate which channels and timeslots to use for data communications with their destinations during the ATIM window. This two-dimensional negotiation enables EM-MAC protocol to exploit the advantage of both multiple channels and TDMA in an energy efficient manner. Further, EM-MAC is able to support broadcast in an effective way.

Since EM-MAC only requires one transceiver per node, it can be implemented with hardware complexity comparable to IEEE 802.11. Also, power saving mechanism used in IEEE 802.11 can easily be integrated with EM-MAC for energy efficiency without further overhead. Simulation results show that EM-MAC successfully exploits multiple channels to improve aggregate network throughput and the average end-to-end packet delay. Extensive simulations confirm the efficiency of EM-MAC and demonstrate its capability to provide high throughput for robust single hop and multi-hop communications. EM-MAC can also be used for communications under unknown and dynamic traffic conditions, i.e. disaster recovery or military operations.

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