Bandwidth Aware Slot Allocation in Hybrid MAC

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***Abstract*— Hybrid Medium Access Control (MAC) protocols combine the strength of random and schedule based MAC schemes. From random MAC schemes, Hybrid MAC protocols borrow flexibility and ease of operation while also incorporating the scalability and high capacity performance of schedule based schemes.**

A number of hybrid approaches exist. The most effective of those, as shown in [1], can dynamically adapt to the contention level in the medium. They achieve this adaptability by combining TDMA (schedule-based) and CSMA (random-based). Whereas the combination of TDMA and CSMA enhance contentions resolution, the existing solutions do not allocate slots in proportion to the bandwidth requirements of the individual nodes. This affects the performance adversely. In this paper we propose an algorithm to optimize slot allocations during the schedule-based phase of the Hybrid MAC protocol. Through simulations, we evaluate the performance of our algorithm in both single-hop and multihop networks. Our results show an improvement of upto 40% in some cases.

I. INTRODUCTION

Recent advancements in wireless networking have necessitated further research in the development of MAC schemes suitable for new technologies such as wireless mesh networks (WMN). It is desirable that new MAC schemes should be capable of ad-hoc operations, i.e., it should be able to operate in absence of network infrastructure, requiring them to be capable of dynamically self-forming, self-configuring, self-healing and self-organizing. The new MAC should also be able to support high bandwidth requirements and local QoS guarantees, and conserve power for energy constrained nodes.

It has been shown in previous works [1] that for such operational scenarios hybrid schemes outperform random-based and schedule-based schemes. In case of random-based schemes, throughput drops significantly with increase in traffic intensity, the number of nodes, and/or hops in the network. Random-based schemes can not guarantee contention-free transmission. The probability of packet loss, for a single hop, increases with increase in the number of nodes attempting to transmit simultaneously. This probability cumulates across multiple hops. Schedule-based schemes provide for contention-free transmission slots to each of the nodes. The schedule comprising of these transmission slots is based on the network traffic and topology. To derive and propagate the schedule, traffic and topology information needs to be collected, which involves overheads. Thus, coping with frequent changes in network conditions results in high overheads, leading to poor performance of schedule-based schemes.

In infrastructure networks, it is imperative that the underlying MAC schemes should be able to provide high bandwidth and support QoS requirements. To increase bandwidth through higher degree of spatial reuse of the medium, shorter transmission ranges and network with high node density are employed, making random-based schemes unsuitable. The infrastructure network acts as traffic conduit for a number of access points (AP)[1]. The number of users connected to an AP varies with time. In one of the studies [2], it has been shown that the number of active cards (users) per AP varies from a peak value of 91 to an average value of 7. This indicates that traffic generated at the AP, which is proportional to the number of users, varies highly, rendering schedule-based schemes unsuitable for the given scenario. Thus, hybrid schemes, that combine the flexibility of random-based schemes and performance capacity of scheduled-based schemes, seem to be most suitable for the given scenario.

II. RELATED WORKS

Prior research efforts in multi hop wireless ad hoc networks and related fields have resulted in a number of interesting solutions. We list some of the more popular ones and briefly present the ones relevant to this paper. On the basis of access strategy employed, MAC protocols can be categorized into three categories- random access or contention-based, schedule-based and hybrid (Table I). Further, they may employ various techniques to achieve higher throughput (e.g., multi channel, directional antenna and power control), QoS capability and power conservation. From among the various MAC protocols given in the Table I, IEEE 802.11 [11], CATA (Collision Avoidance Time Allocation) [12], ADAPT [10] and Z-MAC (Zebra-MAC) [3] are the protocols of special interest to us.

IEEE 802.11 is the standard MAC protocol for wireless LANs [11]. Even though IEEE 802.11 is not designed for multi-hop ad-hoc networks, its simple design and easy operation makes it a popular candidate for multi-hop wireless networks. It has adopted most of the useful techniques, such as RTS/CTS message exchanges (for avoiding hidden-terminal problem), etc. from other random-access schemes. It comprises

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[1] User end devices, such as laptops, are connected to APs, which act as gateways connecting them to external networks.

Base for Comparison	Random Access Protocols	Scheduled Access Protocols	Hybrid Access Protocols
Definition	There is no predetermined medium access schedule. When data is required to be transmitted the medium is randomly accessed.	Medium is accessed according to a pre determined schedule. The schedule is determined such that no two nodes access the medium simultaneously.	Combines random and Scheduled charecteristics
Overheads	Due to collisions, does not perform well in high traffic and dense network topologies	Overhead in exchanging control messages to determine schedules. Does not perform well in dynamic scenarios wherein schedules need to be updated frequently. [3] suggests stand-alone TDMA (Time Division Multiple Access not practical.	Can perform better than random access based protocols in high traffic conditions and adapts to dynamic conditions better than schedule based schemes.
Flexibility	Highly flexible	No	The degree of flexibility depends on the scheme
Performance Capacity	Can not give high throughput	Achieve high throughput performance	High performance, but depends on the scheme.
Examples	ALOHA [4][5], MACA[6], IEEE 802.11[11], etc.	STDMA[7], FPRP[8], CATA [12], etc.	MITION [9], ADAPT [10], Z-MAC[3], request-TDMA/CDMA[13], etc.

TABLE I

COMPARISON OF RANDOM, SCHEDULED AND HYBRID MEDIUM ACCESS APPROACHES

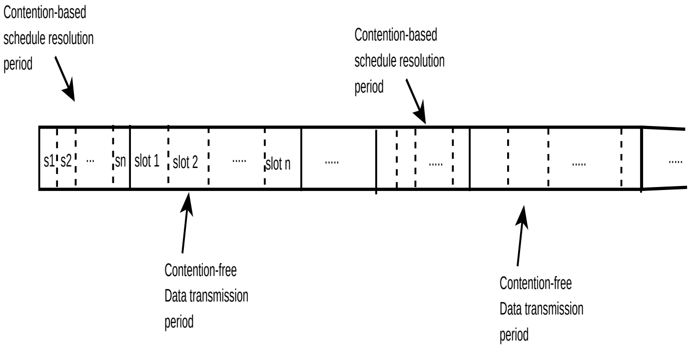

Fig. 1. Schedule-based scheme augmented with random-based scheme's flexibility

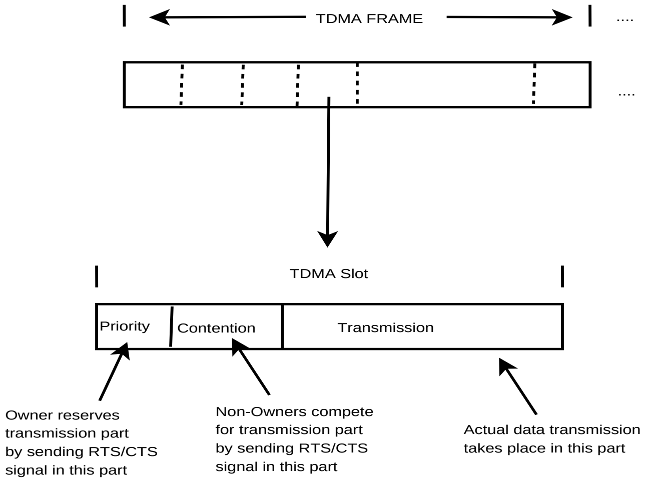

Fig. 2. ADAPT [10]: The structure of the TDMA Frame and time-slot

of two access mechanisms: Distributed Coordination Function (DCF) and Point Coordination Function (PCF). DCF provides support for asynchronous contention-based medium access, by employing Carrier Sense Multiple Access and Contention Avoidance (CSMA/CA). CSMA/CA is implemented through physical and virtual carrier sensing (Network Allocation Vector or NAV) and Ready To Send-Clear To Send (RTS/CTS) signal exchanges. PCF provides support for scheduled medium access. The network comprises of an Access Point (AP), which coordinates PCF based medium access of other CF-pollable nodes.

As pointed out in the earlier section, traffic (and/or network topology) dynamism renders stand alone TDMA unsuitable for practical purposes. The same has also been suggested in [3]. Pure schedule-based schemes need to be augmented with the flexibility of random-based schemes to make solutions based on them practicable. One of the effective ways to do this is to precede a group of contention-less scheduled transmission period by a short contention-oriented period wherein the transmission schedules are determined (Figure 1). During the contention-oriented period, nodes that need to reserve slots for data transmission contend by transmitting short control messages to reserve corresponding slots in the following contention-free transmission periods. Examples of schemes based on this approach are- FPRP [8] and CATA [12].

A number of approaches to combine the strengths of random and schedule based schemes have been developed. In schemes as MITION [9], the default transmission is random-based, however on collision a round of token passing (contention-free) transmission mode is initiated. Thus, whenever collision probability increases, the scheme shifts to schedule-based contention-free transmission characteristics. In Probabilistic TDMA (PTDMA) [14], the probability of collision is contained by programming nodes to transmit with different probability. Nodes are allocated transmission slots as in TDMA (schedule-based scheme) and slot owner transmits with probability p_o, while non-owners transmit with probability p_{no}. By regulating these values, chances of collision are reduced.

ADAPT [10] and Z-MAC [3] are two other schemes that employ approach similar to PTDMA, but are much simpler. In

ADAPT, time is divided into slots and each node is allocated a unique slot in a time frame of some length (as in TDMA). As shown in Figure 2, each slot is divided into three parts, namely-priority, contention and transmission. At the beginning of each slot, the owner node may acquire transmission part of the slot by initiating RTS/CTS message exchanges during priority-part. If the owner does not attempt to acquire the transmission-part during priority-part, other nodes may contend for it by initiating RTS/CTS message exchanges during contention-part. In effect, if the owner node has data to send, it can send it in contention-free manner (as in schedule-based schemes), while if it does not have data to send, other nodes may attempt to transmit in that slot in a random-based fashion. Thus, for higher traffic intensities, most of the times owner nodes will be transmitting data and thus the scheme displays performance capacity of schedule-based schemes and for lower traffic intensities, as mostly non-owner nodes will be transmitting the scheme displays characteristics of random-based schemes. This scheme gives better performance by adapting to the traffic conditions. Also, its ability to utilizes slots whose owner does not have data to send improves its performance. In [1] it has been shown that the overall performance of ADAPT is better than that of IEEE 802.11 and CATA. Thus establishing the approach taken by ADAPT as a superior one compared to random-based or schedule-based (augmented with flexibility of random-based).

Z-MAC [3] is another hybrid scheme that is based on the same approach as ADAPT. It has been optimized for multi-hop scenario and adapted to operate in sensor network environment. Like ADAPT, Z-MAC [3] operates in two modes- setup mode and transmission-mode. During setup mode, each of the nodes is assigned time-slot using (DRAND [15]),a distributed implementation of RAND (Random, [16]) . In DRAND, based on the probability which depends on the local topology, each node randomly initiates slot reservation process. The node allocates itself smallest whole number not yet reserved by any of its one-hop or two-hop neighbors. It advertises this information to its neighbor nodes by broadcasting it. In transmission-mode, the time is divided into transmission-slots. Nodes access the medium using CSMA approach. When a node needs to access the medium, it checks if it is the owner of the slot. The node backs-off using a smaller back-off window *[0,* T_0*]* if it is the owner of the slot, otherwise it may attempt to acquire the channel using a larger back-off window *[*T_0*,* T_{n0}*]*. The transmission is postponed for the number of *back-off slot(s)* as the randomly drawn value from the back-off window. A node will not attempt to gain access of the slot if it is a two-hop neighbor of the owner and it has been notified of congestion. Time synchronization is achieved by receivers passively synchronizing their clocks with that of senders, as well as with the help of clock synchronization control messages. Z-MAC uses STDMA scheduling to reduce collision probability of CSMA based scheme. Like ADAPT, by combining the strengths of schedule-based and contention-based approaches, Z-MAC delivers a robust scheme which even in worst case, performs as well as CSMA scheme.

III. PROPOSED WORK

Both ADAPT and Z-MAC, use TDMA slot allocation to reduce collision probability. Their overall performance is better than that of most of the other schemes based on other approaches. ADAPT and ZMAC, however, have scope for further improvement in their performances. The TDMA slot allocation carried out in the beginning during setup phase, does not take bandwidth requirements of individual nodes into account. Thus a very busy server and a client node with no data to send may be allocated same number of slots. This results in inefficient utilization of bandwidth. In the slot duration of the node with minimal bandwidth requirement, mostly other nodes will be transmitting. When nodes other than the owner node transmit, there is wastage of priority-part duration (in case of ADAPT), or due to larger back-off slot value (in case of ZMAC). The existence of discrepancy in bandwidth requirement of different nodes is also hinted in a previous study [2], where it has been given that the number of users per hour for different sites varies from about 50 to about 350. The difference in the number of users associated with different APs is a clear indicator of the different amount of bandwidth requirement of the APs. In our simulations, we have observed that in worst cases, the above stated factor affects the performance by over 40%. Hence, we propose that TDMA slot allocations should be done in proportion to the bandwidth requirement of the node and its neighborhood topology. In the following subsection (III-A), we propose an algorithm to optimize slot allocations. In the next subsection (III-B) we discuss the transmission frame size and time-slot duration. Transmission frame size determines the number of slots after which the current slot may be used again.

A. Bandwidth Requirement Aware Slot Allocation Algorithm

The proposed algorithm allocates slots to the nodes in proportion to their bandwidth requirement. The input to the algorithm is a list of connections comprising of information regarding the data-rate and path from source to destination. This information may be obtained from higher layers. A connection *i* is represented as:

$$C_i(r_i,(s_i,n_i1,n_i2,...,d_i))$$

The notations have been explained in Algorithm 1. The information regarding one-hop and two-hop neighboring nodes (i.e., local network topology) can be obtained using simple HELLO messages as in Z-MAC [3]. Bandwidth aware slot allocation is carried out by Algorithm 1. For each of the given connections, bandwidth requirement (r_i) values are normalized (to get R_i). The normalized values (R_i) are smallest integers proportional to the earlier bandwidth requirement values (r_i), i.e.

$R_i : R_j = r_i : r_j$
Where, i $\in$ {0 to N-1} and j $\in$ {0 to N-1}

The normalized values are used to allocate transmission slots

Algorithm 1 Bandwidth Requirement Aware Slot Allocation

Notations:

- $C_i(r_i, (s_i, n_i1, n_i2, ..., d_i))$: Representing connection i
- r_i : Data-rate of connection i
- s_i : Source of connection i
- d_i : Destination of connection i
- $(s_i, n_i1, n_i2, ..., d_i)$: Path of connection i
- N : Total number of connections
- HCF : Highest Common Factor

Begin

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1:  $R_{max} = 0$
2:  $H = HCF(r_0, ..., r_{N-1})$ { HCF of data-rates of all of the given connections}
3:  for i = 0 to $N - 1$ do
4:      $R_i = r_i/H$
5:      if $R_{max} < R_i$ then
6:          $R_{max} = R_i$
7:      end if
8:  end for
9:  for j = 0 to $R_{max} - 1$ do
10:     for i = 0 to $N - 1$ do
11:         if $R_i \leq 0$ then
12:             Skip the current iteration
13:         end if
14:         $R_i = R_i - 1$
15:         for each of the nodes in the path of connection i do
16:             Allocate smallest whole number, not yet been taken by any of its one-hop or two-hop neighbor nodes
17:         end for
18:     end for
19: end for
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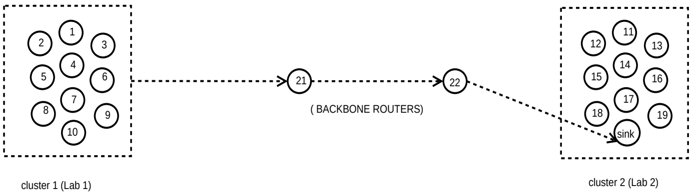

Fig. 3. Simulation setup for multi-hop wireless network

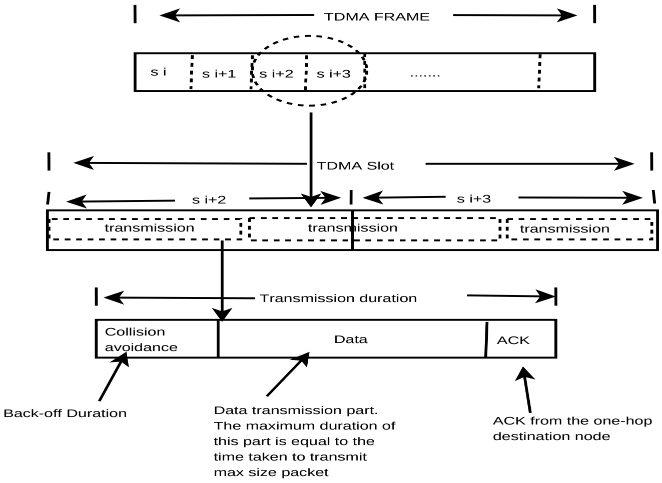

Fig. 4. TDMA frame, slot and transmission duration structure of bandwidth aware hybrid MAC. It is same as that of Z-MAC [3]

to the nodes in proportion to the bandwidth requirements of the connections passing through them. Each of the connections are allocated transmission slots for data transmission. One by one, each of the node in the connection path is allocated smallest whole number value, which has not yet been allocated to any of its one-hop or two-hop neighbors. For a given connection i, this step is repeated R$_i$ times. This ensures that slot allocations have taken place in proportion to the bandwidth requirement.

Example: Let the topology be as shown in Figure 3, and the input list of connection to the algorithm is as follows:-
$C_0(20000, (n1, n21, n22, sink))$
$C_1(40000, (n2, n21, n22, sink))$
$C_2(60000, (n3, n21, n22, sink))$

Slot Allocation: The algorithm, in lines 1 to 8, calculates normalized bandwidth rates and determines the maximum normalized rate value. In this case, the calculated values are: $R_0 = 1$, $R_1 = 2$ and $R_2 = R_{max} = 3$. In lines 9 to 19, the normalized values are used to allocate slots to the nodes in proportion to the bandwidth requirements of the connections passing through them. For carrying connection C_0, the carrier nodes are allocated one slot each, as R_0 is equal to 1. Similarly nodes in the path of connection C_1 and C_2, participating nodes are allocated two and three slots each respectively (as R_1= 2 and R_2 = 3). Thus, according to Algorithm 1, we get following slot allocations:-
n1 slot(0), n2 slot(3, 9), n3 slot (6, 12, 15), n21 slot(1, 4, 7, 10, 13, 16) and n22 slot(2, 5, 8, 11, 14, 17)

We can see that the number of slots allocated to each node are in proportion to their bandwidth requirement.

To generate transmission schedule, we propose that before the start of transmission phase, we run the proposed algorithm, which will generate transmission schedule as per the bandwidth requirement of the nodes. A distributed version of this algorithm can be easily implemented with the help of token passing scheme.

B. Transmission Frame Size and Time-Slot Duration

After carrying out slot allocations, a few other issues need to be addressed before the slot allocations can be used as transmission schedules to efficiently use the channel. The main issue is that of determining suitable TDMA frame size for each

of the nodes. *TDMA frame size* determines after how many slot(s), can the current slot be used again in a contention-free fashion by the owner node. We use the *Time frame rule (TF rule)* as in Z-MAC [3] to determine TDMA frame size. According to the TF rule, if S_{max} is the maximum allocated slot number in the two hop neighborhood of a node, then the frame size of the node is equal to 2^a, such that:
$2^{a-1} \leq S_{max} < 2^a$
By having the size of time frame as a power of a constant (which in this case is 2), synchronization of time schedules of different sized time frames (being used by different nodes), over a number of iterations, is achieved.

The *TDMA-slot duration* is constant for a given scenario. It is calculated as the maximum time taken to transmit the packet (to the one-hop neighbor node) plus time taken to receive acknowledgement from the destination node, if the transmission was successful. This calculation is similar to that of Z-MAC [3], with the exception that the back-off slot size values have been changed[2]. The TDMA-frame and slot, and transmission duration structure (Figure 4) is same as that of Z-MAC. As shown in the figure, time is divided into TDMA-frames, which is further sub divided into TDMA-slots. Each TDMA-slot may involve zero or more transmissions (represented by transmission-duration in the figure 4). The transmission duration is of variable length, and is itself comprised of three parts- collision avoidance, data and ack. The duration of collision avoidance part varies between 0 to T_{no} back-off slot time depending upon the back off drawn by the transmitting node. The data duration part depends on the length of data to be transmitted. The duration of ACK part is the time taken to receive ACK from the one-hop far destination node, after the transmitting node has finished transmitting data.

IV. PERFORMANCE COMPARISON OF Z-MAC AND BANDWIDTH AWARE HYBRID MAC

A. Simulation Setup

Previous studies [1], [3] have already established effectiveness of the approach on which ADAPT and Z-MAC are based. The aim of these simulations is to show that bandwidth requirement aware slot allocation can significantly improve the performances of such schemes. As the implementation of Z-MAC over ns2 [17] is readily available from [18], we have chosen it as the standard to compare the performances and ns2 as the discrete event simulator. The various default setting values of the parameters are as shown in the table II. All the values with the exception of communication range and contention slot-size are default values that came with the Z-MAC implementation download. The value used for communication range had to be modified to bring it into agreement with the default value being used by DRAND [15], slot allocation algorithm of Z-MAC. The contention slot-size value has been modified to make it same as that of IEEE 802.11, the previous default value used in Z-MAC was more suitable for low bandwidth sensor network environments. These modified values will not affect the generality of our results.

The following one-hop and multi-hop network setups have been used.

1) One-Hop benchmark : The one-hop benchmark comprises of twenty one nodes, where all nodes are at one-hop distance from each other. One of the nodes is a sink, to which all other nodes send data. The reason we have employed such a set-up, where there is only one sink, is that it makes the process of simulation simpler without the trade off of generality. Also the original Z-MAC [3] has employed similar setup. Unless otherwise stated (both for one-hop and multi-hop scenarios), transmitting nodes are in saturation state, i.e., they always have data to send.

2) Multiple-Hop benchmark : For multiple-hop scenario, we choose a very simple set up to demonstrate the effectiveness of the proposed modification to the existing approach. The topology comprises of two clusters separated by three hop distance (Figure 3). Two nodes each at one hop distance from each other and with the nearest cluster, form the path between the two clusters. The second cluster comprises of a sink node to which all the transmissions are directed. The real life equivalent of this set up can be thought of as two computer laboratories, lab1(cluster 1) and lab2(cluster 2), in some university, connected via backbone routers node-21 and node-22. Lab1 is a general public area open for use by all students. Lab2 is a computer center comprising of servers and a single gateway (sink) to the Internet. The servers may be accessed from outside the campus via gateway. Similarly students can access Internet through the gateway. In the simulation results, we vary number of active users to see its affect on the channel utilization and average access delay. When five users are said to be active, nodes-1 to 5 are transmitting. Similarly, when n nodes are transmitting, it means node-1, node-2,..., node-n nodes are transmitting.

B. Simulation Results

The simulations carried out with the available Z-MAC source code and its modified bandwidth requirement aware version for one-hop and multiple-hop network scenarios gave encouraging results. As already stated above in the previous section the simulations were carried out over discrete event simulator ns2 [17]. Following sub-sections discuss the observations regarding channel utilization and average access delay. Channel utilization gives a measure of the efficiency with which the MAC scheme utilizes the bandwidth. It is calculated as the fraction of the channel capacity which was utilized to successfully transmit data. Average access delay gives the average time taken to successfully transmit a packet across a single hop. Access delay value is calculated from the time sender node receives packet to send to the time it receives acknowledgement from the receiver node (at one-hop distance).

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[2] The back-off slot size value has been changed to 20 μ seconds, the same as that of IEEE 802.11. The value used in Z-MAC was more suitable for low bandwidth sensor networks environment

Parameters	Default values
Communication bandwidth	2 mbps
Communication Range	40 meters
T_o	8
T_{no}	32
Contention Slot-size	20 μ secs.
Transmission Slot-size	1.6 m secs.

TABLE II
DEFAULT SETTINGS OF VARIOUS PARAMETERS

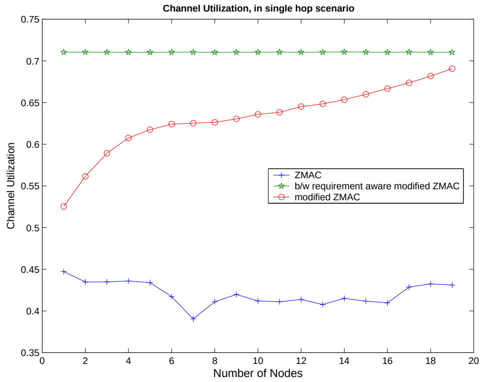

Fig. 5. Channel Utilization in one-hop scenario

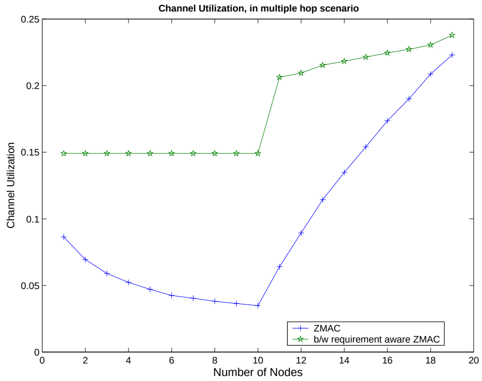

Fig. 6. Channel Utilization in multi-hop scenario

1) Channel Utilization : In this sub-section we compare channel utilization, in one-hop and multiple-hop scenarios, by Z-MAC and Bandwidth Aware Z-MAC (BAZ-MAC) wherein slot allocations are done in proportion to the bandwidth requirement. In case of one-hop scenario it can be seen in the figure 5 that the channel utilization achieved by Z-MAC is between 0.45 and 0.4. However, there was a restriction in the original version of Z-MAC downloaded from the web site [18]. The original version allowed only one packet to be transmitted in a single slot. The size of a slot is equal to the maximum time to transmit a packet, including maximum contention back off duration plus time to transmit the packet and receive acknowledgement. If the contention back off period incurred is lower than the maximum duration, which mostly is the case, the remaining time is wasted as only one packet is allowed to be transmitted in the slot. By removing this restriction, we found that the performance of the now modified Z-MAC improved substantially. It can be seen in Figure 5 that the channel utilization of modified Z-MAC varies between 0.52 and 0.68. The trend in this case is of steady increase of channel utilization with the increase in the number of transmitting nodes. The reason being that, with the increase in the number of transmitting nodes, number of nodes transmitting in their own slot increases which implies that the average back off duration is reduced as well as collisions reduce. Thus, the modified Z-MAC's behavior approaches that of schedule-based scheme. Finally, in the same figure, it can be seen that for BAZ-MAC, the channel utilization remains more or less stable at 0.72. This is so because in this case, only the transmitting nodes are allocated transmission slots, thus, as it is the owner node that is transmitting, average back off duration is very less and there is no collision. The scheme behaves as schedule-based scheme.

In case of multiple-hop scenario, we again see (Figure 6) that the performance of BAZ-MAC is much better than that of Z-MAC. It can be seen in the figure that channel utilization of Z-MAC falls down with increase in the number of transmitting nodes till number of transmitting node is ten. From the multiple-hop topology (Figure 3), it can be seen that the first ten transmitting nodes are located in cluster-1 (lab1). As the slot have been allocated equally, without considering bandwidth requirement of the nodes, the nodes node-21 and node-22 form bottle neck. Increase in the number of transmitting nodes cause congestion, and hence the fall in channel utilization. When the number of transmitting nodes increase from ten, the nodes at one-hop distance from the sink have started transmitting. Thus, the channel utilization now starts to improve as data from these nodes do not have to go through any bottle neck. From this observation, we can infer that non bandwidth aware slot allocation causes even more performance deterioration in case of multi-hop case than one-hop case.

2) Transmission Delay : In this sub-section, average access time for Z-MAC and BAZ-MAC have been compared. Three dimensional graphs have been employed to capture the effect of variation in the number of transmitting nodes and data rate (given as packets per second), on the average access time values in one-hop and multi-hop scenarios. Figures 7, 8, 9 and 10 give average access times for Z-MAC in one-hop, BAZ-

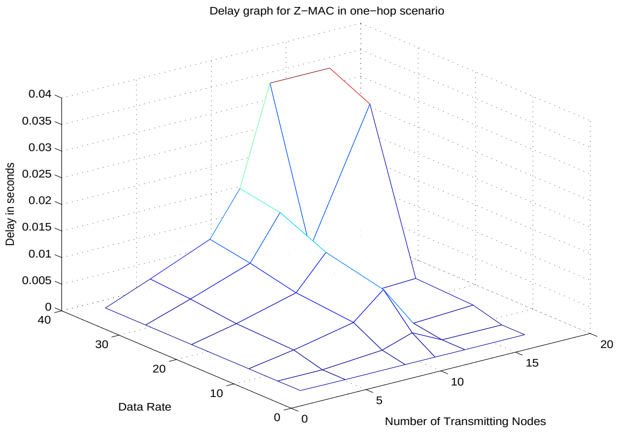

Fig. 7. Average Access time for Z-MAC in one-hop scenario

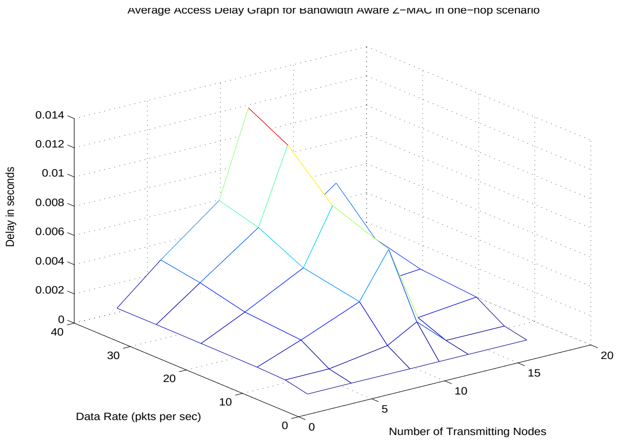

Fig. 8. Average Access time for BAZ-MAC in one-hop scenario

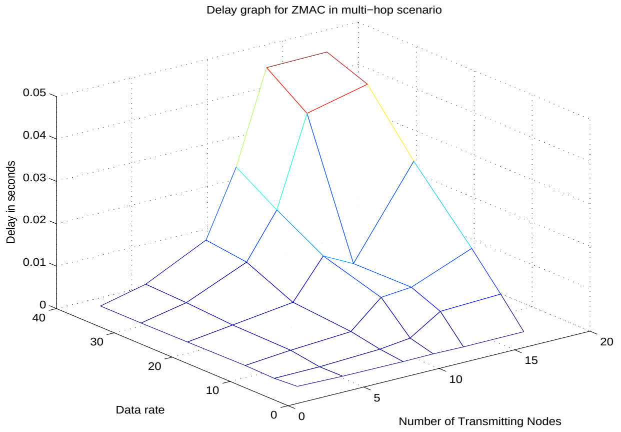

Fig. 9. Average Access time for Z-MAC in multi-hop scenario

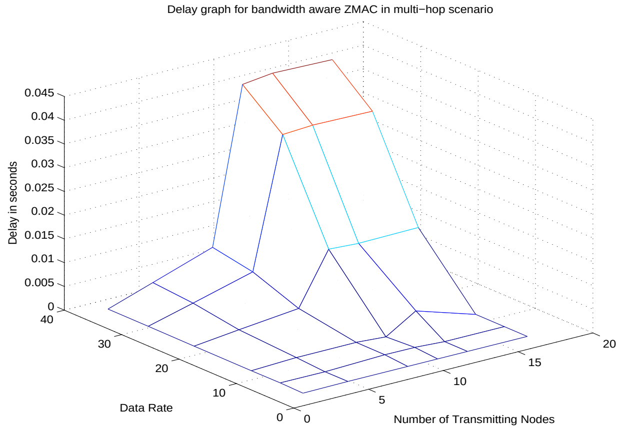

Fig. 10. Average Access time for BAZ-MAC in multi-hop scenario

MAC in one-hop, Z-MAC in multiple-hop and BAZ-MAC in multiple-hop environment respectively. It can be seen in the figures that BAZ-MAC has lower average access delays than Z-MAC. This is attributed to the fact that in BAZ-MAC, most of the transmissions take place in the slot owned by the node itself and thus lower occurrences of collisions and lower back off delays. The general trend, as can be seen in the figures, is that average access times increase with increase in the number of transmitting nodes and/or increase in the data rate. In the case of Z-MAC (for all data rates) and BAZ-MAC (for lower data rates), the increase in average access times is because increase in the number of transmitting nodes increases chances of collision. In the case of BAZ-MAC (high data rates), the increase in average access times is because increase in the number of transmitting nodes imply that the transmission schedule size increases and hence each transmitting node has to wait for longer duration for the transmission slot assigned to it. The average access times increase with increase in the data rate for the same reason as above. In figure 8 we see that there is exception to the above rule. With increase in the number of transmitting nodes after ten transmitting nodes, the average access value decreases. This can be attributed to the fact that apart from increased collision, increase in the number of transmitting nodes also results in more data being transmitted in ownership slots. The lower back off wait period for such data, off sets the increase in collision to give lower average access time values.

V. FUTURE RESEARCH

We plan to design and implement a dynamic hybrid scheme based on the same approach as ADAPT and Z-MAC. In addition we will add bandwidth aware slot allocation capability to our scheme. The new scheme being dynamic should be able to efficiently allocate and de-allocate slots to nodes based on traffic and topology changes in run-time. The feasibility of the scheme depends, fore most, on efficient run-time slot allocation/de-allocation algorithm whose message complexity and time complexity scale well with network density and size, and topology changes. Calculating optimal bandwidth to be reserved given the traffic and/or network dynamism is also very important. This is to ensure that nodes do not reserve more slots than they need, and also that they get the number of slots that they need. Finally, it is important to determine some policy to trigger re-scheduling to cope with changing bandwidth requirement (and/or changes in network topology). Care should be taken to ensure that the rescheduling overheads do not offset the gain from bandwidth aware slot allocation.

VI. CONCLUSION

Future applications intended for the next generation wireless ad hoc networks demand that the network be able to cater to high bandwidth demands and support QoS guarantees while maintaining their ad-hoc characteristics. The onus of meeting with these requirements fall, to a great extend, on the underlying MAC layer as they control medium access for data transmission. A number of solutions exist as a result of previous research efforts and more are being developed. Hybrid schemes such as ADAPT and Z-MAC, have been previously shown to give a better over all performance than most of the other existing solutions. They share a common approach that enables them to optimize their behavior by adapting to the contention level in the network. In this paper, we have proposed and shown that by employing bandwidth requirement aware slot allocation algorithm, performance of Z-MAC can be further enhanced. In our future work, we plan to develop and evaluate such a dynamic hybrid scheme based on the above approach.

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