An Overlay Algorithm to Improve the Support of Multi-Hopping in the IEEE 802.11 WLANs

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Abstract— **Previous studies have argued that the performance of the IEEE 802.11 protocol is poor when used as a platform to implement multi-hop ad hoc networks. In this paper, we analyze the negative behavior caused by having multiple overlapping IBSSs (Independent Basic Service Sets) operating at the same frequency channel in an 802.11 ad hoc network. We propose an overlay algorithm on top of 802.11 to help discipline the interaction of overlapping IBSSs. Our algorithm yields noticeable improvement in the aggregate normalized throughput value per IBSS as well as the stability of the system.**

Keywords-Ad hoc; WLANs; IEEE 802.11; MANETs

I. INTRODUCTION

Today we see a great expansion in the production of technology to support mobile computing. Not only are the computers themselves getting more and more capable, but also many new applications are being developed and wireless data communications products are becoming available that are much improved over those available in the past. Such rapid advancement in portable computing platforms and wireless communication technology has led to significant interest in the design and development of instantly deployable, wireless networks often referred to as "ad-hoc networks". Mobile ad hoc networks (MANETs) have no fixed routers; all nodes are capable of movement and can be connected dynamically in an arbitrary manner. They have several advantages such as:

- On demand setup: MANETs don't rely on wired base stations and therefore are capable of being deployed in places with no existing infrastructure.
- Fault tolerance: In a cellular system, a malfunction in the base station will impair all mobiles in its cell. In MANETs, a malfunction in one node can be easily overcome through network reconfiguration.
- Unconstrained connectivity: In a wired network the physical cabling is done a priori restricting the connection topology of nodes. This restriction is not present in the wireless domain, provided that two nodes are within hearing distance of each other; an instantaneous link between them is automatically formed.

However, the benefits of MANETs come with some new challenges. Lack of any centralized control and possible node mobility give rise to many issues at the network, medium access and physical layers, which have no counterparts in the wired networks like the Internet, or infrastructure-based wireless networks like cellular networks. In this paper, we focus on the medium access control (MAC) issues that affect ad hoc networks.

A number of standards and products that allow the development of small-scale ad hoc networks have already emerged. Wireless local area products (e.g. IEEE 802.11) are now widespread and provide in-building wireless access [1]. The IEEE 802.11 MAC protocol dominates today's WLAN market. It is already used in almost all of the test beds and simulations for wireless ad hoc network research.

The IEEE 802.11 platform, though being widely used as a platform to implement MANETs, was not designed to be used in multi-hop wireless links. It may work well in small enterprises or homes where a single hop network may exist but not in a large-scale network where multi-hopping is a necessity. Its behavior has been studied and it has been proven that it does not perform well in multi-hop networks [2][4][5][6][7].

In this paper, we are going to analyze the negative behavior caused by operating the 802.11 in a multi-hop environment. Then we are going to present an overlay algorithm that will discipline this behavior. This algorithm will essentially lay out the framework to implement a multi-hop ad hoc network on top of 802.11 that spans over the coverage area of multiple IBSSs. This paper is organized as follows; Section II analyzes the negative behavior encountered in a simple multi-hop network. In section III we propose an overlay algorithm that counteracts such behavior and finally section IV presents the simulation results.

II. DIFFICULTIES IN 802.11 MULTI-HOPPING

In the IEEE 802.11, an ad-hoc network is named an IBSS (independent basic service set). An IBSS enables two or more IEEE 802.11 stations to communicate directly without requiring the intervention of either a centralized access point or an infrastructure network. Hence, the IBSS can be considered as the support provided for mobile ad hoc networking by the

IEEE 802.11 standard protocol. However, the ad-hoc support provided in 802.11 only means operation without an access point in a single hop network composed of one IBSS. It is not intended to support the wireless mobile ad-hoc network, in which multi-hop connectivity is one of its most prominent features. It has been shown several times that the IEEE 802.11 MAC protocol has several problems when used in a multi-hop ad hoc network [2][3][4][5][6][7]. In this section, we are going to elaborate on the kind of problems that may arise through the following simple example.

Assume a simple network topology as in Fig.1 in which we have an IBSS called IBSS1 that contains nodes A, B, C and D. Node X lies within the communication range with node A only. Suppose there is an ongoing communication in IBSS1 between nodes B and C. Node X wants to initiate a communication with node A. It senses its medium and can not detect the ongoing communication in IBSS1 so it sends an RTS message to node A to request communication. In this case, we may have two scenarios. The first scenario is that IBSS1 is physically busy and therefore the RTS message will collide at node A. The second scenario is that IBSS1 is virtually busy but physically idle. In this case, node A will receive the RTS but will cease to respond with a CTS. After a time out period, node X will detect the failure of its attempt and will backoff and retry again and the whole scenario may repeat. The point to notice here is that, since node X can not sense IBSS1 medium, it will have difficulty to pick the right time to request communication with node A. It may retry several times and each time increase its backoff time until it reaches a maximum value and the packet is dropped after a specified number of retries [1].

Consider a more advanced scenario as in Fig. 2 in which we have two simple overlapping IBSSs, IBSS1 and IBSS2 operating on the same frequency channel. IBSS1 contains nodes B, C and D and IBSS2 contains nodes X, Y and Z. Node A belongs to both IBSSs as it is located in the overlap zone. It can communicate with all nodes in both IBSSs. For the same reasons outlined in the previous case, nodes X, Y and Z will have difficulty communicating with node A.

Moreover, when node X sends an RTS, all the other nodes in IBSS2 will cease to engage in communication for a period equal to the NAV (Network Allocation Vector [1]) value included in this RTS message. Despite the fact that node X has realized after a time out period that its communication attempt has failed, the rest of the nodes will not realize that until the NAV period is over. This is known as "False Blocking" [8].

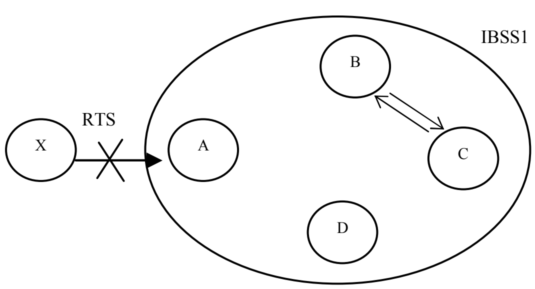

Figure 1. Node X unable to sense IBSS1 medium

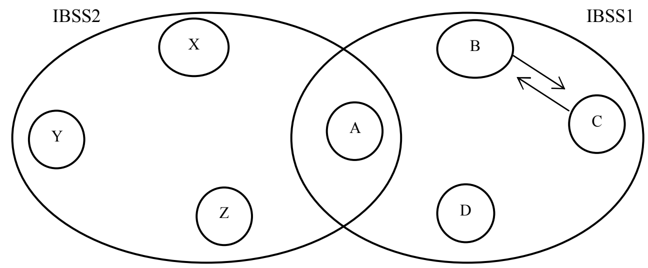

Figure 2. Two overlapping IBSSs

In another scenario, suppose node A wants to start communication with one of the nodes in IBSS2. Node A is exposed to the ongoing communication in IBSS1. Node A will have to verify that both media are idle before it starts any transmission. Knowing that the rest of the nodes will only have to verify that one medium is idle to be able to start any communication, node A has fewer chances to initiate a communication.

Collectively, the above reasons will result in a situation such that when an IBSS grabs the medium, it will cause the performance of the other IBSS to degrade significantly. This is due to false blocking and the inability of nodes hidden in this IBSS to sense that the other medium is busy. As a consequence, serious instability may occur in the system in which the aggregate saturation throughput per IBSS can not be sustained. Both IBSSs will start competing for the medium and whoever grabs the medium will negatively affect the performance of the other IBSS. This unstable behavior will be demonstrated through simulations in section IV.

If we look at this problem from a multi-hop perspective, we will notice that the negative behavior explained above has its direct effect on multi-hop traffic that spans across IBSSs. The traffic that is directed to the overlap zone may have difficulty to engage in a successful communication. Also, the traffic that originates from the overlap zone has fewer chances to engage in a successful communication. As a consequence, a multi-hop ad hoc network built on top of 802.11 will suffer from poor performance.

III. PROPOSED ALGORITHM

In this section we will present an overlay algorithm deployed over the 802.11 platform. In this algorithm, nodes in overlap zones will have a critical role since they will be responsible for regulating the exchange of traffic among overlapping IBSSs operating on the same frequency channel. We call those nodes 'virtual access points' (VAPs) as they perform a similar distribution role as the access points in the IEEE 802.11 infrastructure mode.

Consider again the network topology in Fig. 2 where two IBSSs overlap each other. Node A would be the VAP of the two IBSSs. From the perspective of higher layer protocols, this VAP provides the means for communications between different IBSSs in a multi-hop scenario. However, in the current 802.11 protocol, communication with these nodes is not regulated and therefore it causes problems to higher layer protocols. In our algorithm we regulate the communication with VAPs. VAPs are only allowed to send or receive packets during specified periods. Normal nodes are only allowed to send packets to VAPs during specified periods and otherwise should only send packets not directed to VAPs. This imposed regulation will eliminate false blocking problems described in the previous section. Moreover, nodes who want to communicate with VAPs will now know when it is allowed to do so. This will protect those nodes from the repeated failed attempts demonstrated as well in the previous section.

The algorithm is designed to allow the VAP to seize the medium every IIT (IBSS intercommunication time) which is an opportunity for inter-IBSS communication. The steps of the algorithm consist of:

- During IIT period, communication between any station and the VAP is disallowed until the VAP procedure is ON.
- The VAP contends for the medium with a high priority every IIT until it captures the medium.
- Once the VAP captures the medium, i.e., the VAP procedure is ON, it will send all the packets it has accumulated during the preceding IIT time.
- The VAP picks IBSSi (i = 1,2) to poll its stations for the traffic destined to VAP. Assume it picks IBSS1.
- The VAP broadcasts an RRV "Ready to ReceiVe" message to indicate that it has seized the medium for IBSS1 (VAP alternates among IBSSs to ensure fairness). Nodes in IBSS2 should cease to transmit until the procedure is OFF (see Fig. 3).
- Upon receipt of RRV, nodes in IBSS1 that have packets for the VAP will contend for the medium and whoever wins the contention will respond with an RTS towards the VAP. VAP will respond with a CTS and normal RTS/CTS handshake will continue (see Fig. 3).
- The VAP will repeat sending the RRV message until stations in IBSS1 have no more VAP packets.

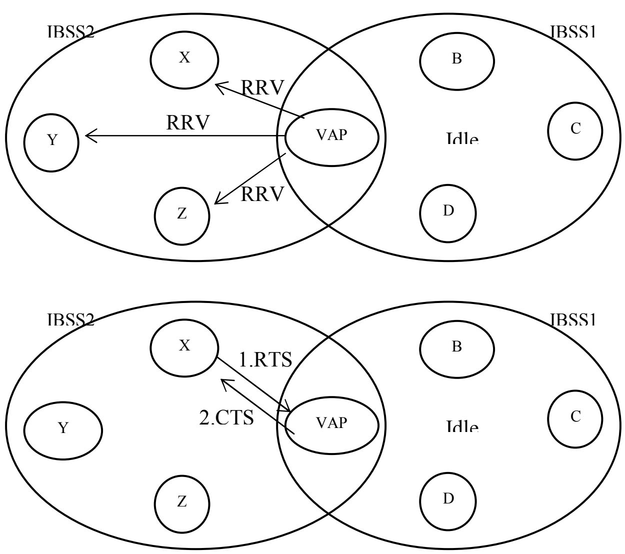

Figure 3. Virtual Access Points seize the medium on a regular basis

- The VAP sends a clear message for all stations in both IBSSs to indicate that the VAP procedure is OFF and stations can resume normal communication.
- After another IIT elapses VAP should repeat the same procedure with IBSS2.

Consider a more advanced scenario where we have more than two overlapping IBSSs and multiple VAPs, as shown in Fig. 4. VAP1 and VAP2 belong to both IBSS1 and IBSS2, while VAP3 belongs to all three IBSSs. The same approach can be applied in a more general way as follows:

- VAP1 and VAP2 belong to IBSS1 and IBSS2 while VAP3 belongs to all three IBSSs.
- If we follow the same logic as in the simpler case discussed above, when the Procedure is OFF, VAP1,2,3 can neither send nor receive data. The expiry of the IIT timer will trigger the contention among the VAPs to acquire the medium.
- Let us assume for illustration purposes that VAP1 was able to acquire the medium. The VAP procedure is turned ON.
- In this case, VAP1 will send all the packets it has accumulated over the preceding IIT period. Then, it will choose one IBSS to poll.

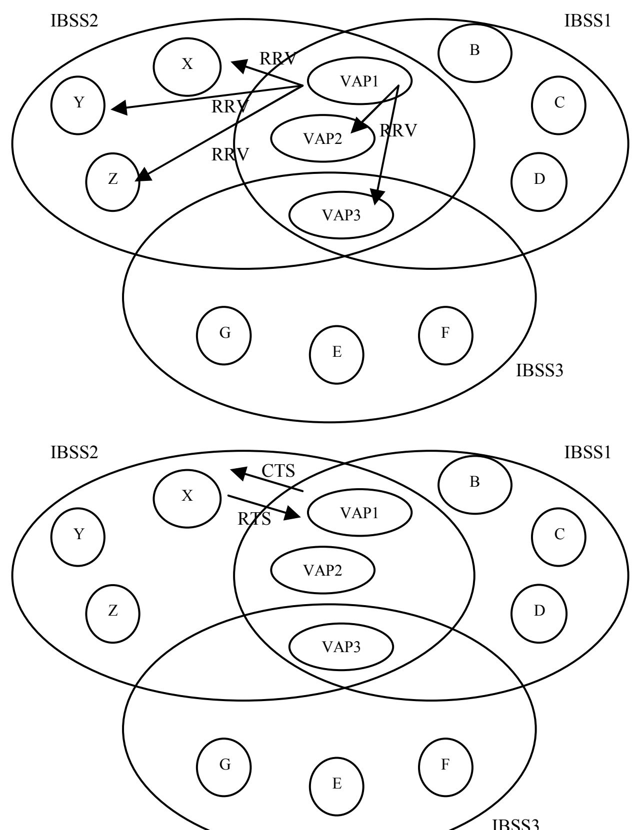

Figure 4. Three Coexisting Overlapping IBSSs

- Assume it picks IBSS1 to poll its stations (Note, that VAP will alternate among IBSSs to ensure fairness), it will broadcast an RRV message in IBSS1.
- Nodes in IBSS1 (including VAP2, 3) which have accumulated packets destined to VAP1 during the preceding IIT period, will contend to acquire the medium and the normal RTS/CTS handshake will continue.
- VAP1 will repeat sending the RRV message until stations in IBSS1 have no more VAP packets. Then, it sends a clear message to indicate that the VAP procedure is OFF and stations can resume normal communication.
- After another IIT elapses, the VAPs will contend and the procedure will repeat.

An important aspect of this algorithm is the shared frequency among different IBSSs existing in the system. Some research efforts have attempted to extend the IEEE 802.11 protocol to a multi-hop network through the use of multiple frequency channels [9]. However, this solution is an expensive one on the terminal side. The terminal will have to work with dual transceivers to tune to different frequency channels simultaneously. In contrast, in our proposed algorithm, a single frequency channel is reused among all existing IBSSs while enhancing the multi-hop feature.

IV. SIMULATION RESULTS

We have developed a Java-based simulator to simulate the basic features of the current IEEE 802.11 protocol as well as our overlay algorithm. We have performed three experiments to observe the aggregate IBSS throughput normalized with respect to the channel capacity versus the traffic rate. Traffic sources were CBR (constant bit rate) and destinations were chosen based on a uniform distribution. Table I summarizes the system parameters used in our simulations.

The behavior of the current 802.11 protocol is demonstrated in the first two experiments. In the first experiment we had one IBSS consisting of 10 stations (Fig. 5). In the second experiment we had two overlapping IBSSs (Fig. 6). Each IBSS had 10 stations. Only one node belonged to the overlap region. The behavior of the proposed overlay algorithm is demonstrated in the third experiment with the same topology as the second experiment (Fig. 7). The IIT period was set to a value of 50*NAV.

TABLE I. ANALYTICAL AND SIMULATION PARAMETERS

Packet payload	2400 bits
ACK	112 bits
RTS	160 bits
CTS	112 bits
Channel bit rate	1 Mbps
SIFS	28 micro seconds
DIFS	128 micro seconds
ACK-Timeout	300 micro seconds
CTS-Timeout	300 micro seconds

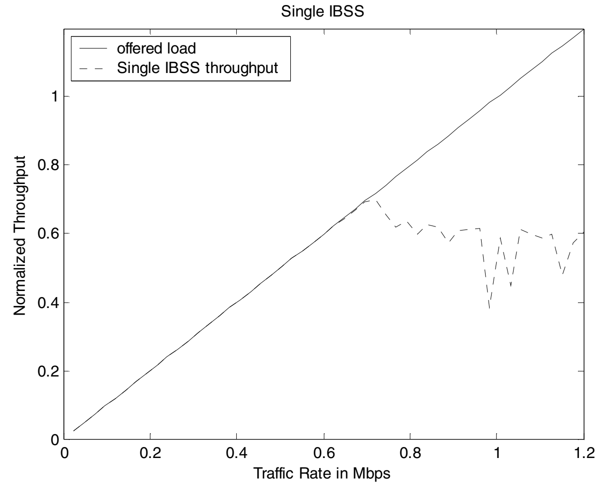

Figure 5. Single IBSS throughput

Figure 6 shows that the first experiment achieves a saturation throughput of approximately 65% at a traffic rate of 0.75 Mbps. The second experiment shows that IBSS1 and IBSS2 do not maintain a stable saturation throughput value. The maximum throughput achieved is approximately 60%. However, this value is highly, unstable and throughput degrades to a value that reaches approximately 10%. The average throughput is approximately 40%. So, the system may operate at the maximum throughput value but any little shift of the traffic rate may result in a major drop in the IBSS throughput.

The third experiment shows the effect of our proposed algorithm where we can see that IBSS1 and IBSS2 saturate at a value of approximately 60 % at a traffic rate of 0.6 Mbps (Fig. 7). Moreover the system can operate safely on this throughput value without experiencing the unstable behavior encountered in experiment 2.

Figure 8 shows the effect of varying the IIT algorithm parameter on the average normalized throughput per station. As the value of IIT increases, the VAP normalized station throughput decreases. This is because the VAP captures the medium less frequently. On the other hand, as IIT increases the throughput of each of the other non VAP stations increases until it saturates as shown in figure. Since the VAP interrupts the medium less frequently, other stations are allowed to exchange more packets. Although, these stations may have VAP packets queued to be sent during the VAP procedure, they have a chance to send other non VAP packets with a high throughput. Therefore, the high station throughput acheived here is mostly due to packets not destined to VAP. The optimum value of IIT to operate at would be the value that enables each and every station to have a fair share of the medium i.e. the point of intersection of both curves. With the parameters used in this specific experiment, the optimum value to operate at would be approximately 25 ms.

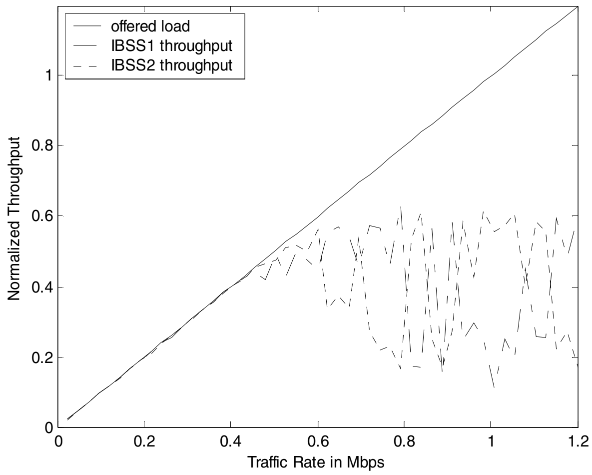

Figure 6. Overlapping IBSSs throughput

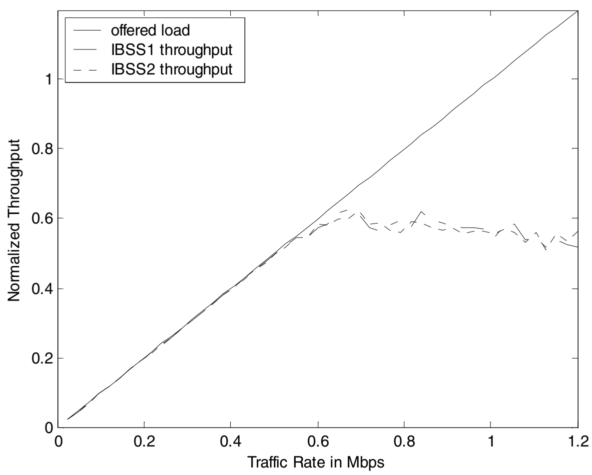

Figure 7. Algorithm throughput

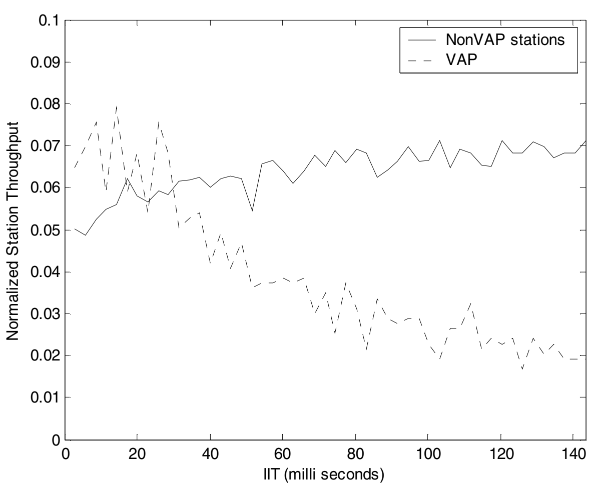

Figure 8. Optimum IIT value

V. CONCLUSIONS

The current IEEE 802.11 standard does not handle the problems arising in the case where multiple IBSSs overlap each other or in other words does not handle the multi-hop scenario. Our analysis shows the instability resulting from such scenario. If a multi-hop ad hoc network is to be built on top of the 802.11 platform, these issues will need to be handled to yield an acceptable performance. We have proposed an overlay algorithm that abides with all basic features of the IEEE 802.11 standard. This algorithm regulates the behavior of overlapping IBSSs operating at the same frequency channel. Simulation results have validated our algorithm and proved the improvement on the aggregate system throughput and stability.

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