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 IEEE 802.11 protocol is quite 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 operating at the same frequency channel in an 802.11 ad hoc network. Then 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 such value.**

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, fault tolerance and unconstrained connectivity.

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 dominates today’s WLAN market and this makes it a very good candidate to implement a multi hop mobile ad hoc network. 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 to implement MANETs, was not designed to be used in multihop 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 doesn’t perform well in multi hop networks [2][3][4][5][6].

In this paper we are going to analyze the negative behavior caused by having multiple overlapping IBSSs operating at the same frequency channel. 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.

The paper is organized as follows, Section I analyzes the negative behavior encountered in multiple overlapping IBSSs. In section III we propose an overlay algorithm that corrects such behavior. Section IV presents simulation results and finally section V concludes our work.

II. THE PROBLEM STATEMENT

It has been shown several times that IEEE 802.11 MAC protocol has several problems when used in a multi hop network [2][3][4][5][6]. Although it can support some kind of ad hoc network architecture, which only means a distributed network as opposed to a centralized one, it is not intended to support the wireless mobile ad hoc network, in which multihop connectivity is one of its most prominent features. In this section, we are going to elaborate on the kind of problems that may arise through the following simple example.

Assume a simple 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

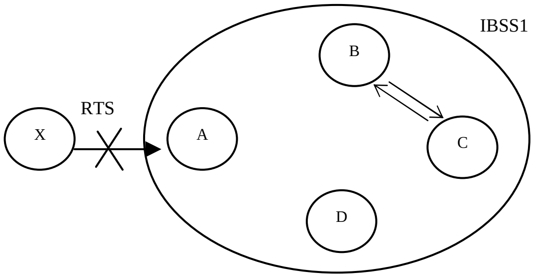

Fig. 1 Node X unable to sense IBSS1 medium

only. Suppose there is an ongoing communication between nodes B and C. Node X wants to communicate with node A. It senses the medium and can not detect the ongoing communication in IBSS1 so it sends an RTS message to node A. In this case we may have two scenarios. First, IBSS1 may be physically busy and therefore the RTS message will collide at node A. Second, IBSS1 is virtually busy but physically idle. In this case, node A will receive the RTS but will cease to respond with a CTS because IBSS1 is engaged with an ongoing transmission. 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 communicate with node A. It may retry over and over and each time increase its backoff time until it reaches a maximum value and the packet is dropped after a specified number of retries.

Consider a more advanced scenario as in Fig.2 in which we have two simple overlapping IBSSs, IBSS1 and IBSS2. 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 overlapping section. It can communicate with all nodes in both IBSSs. For the same reasons in the previous case, nodes X, Y and Z will have difficulty communicating with node A.

Moreover, when node X sends and RTS, all the other nodes in IBSS2 will cease to engage in communication for a period equal to the NAV value included in this RTS message. Despite the fact that node X has realized after a time out period that the 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".

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, node A has less chances to initiate any 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 wins will negatively affect the performance of the other IBSS. This behavior will be demonstrated through simulations in section ?

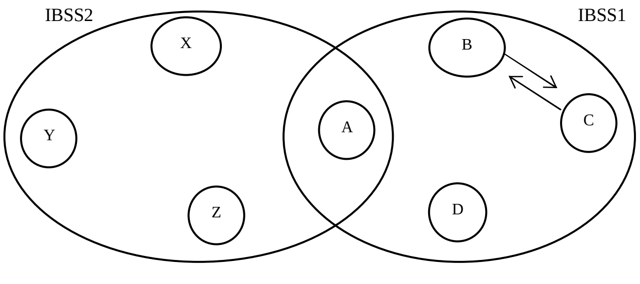

Fig. 2 Two overlapping IBSSs

This behavior is mainly responsible for the poor performance suffered when attempting to build a MANET on top of an 802.11 platform. Therefore, in the next section will propose a solution to correct this unwanted behavior.

III. PROPOSED ALGORITHM

Looking from a multi hop perspective, nodes that belong to the overlapping zones of different coexisting IBSSs are of particular importance. These nodes are responsible for relaying traffic between IBSSs. As illustrated in the previous section, these nodes have less priority in engaging in a communication whether to transmit or receive.

In this section we will present an over lay algorithm on top of 802.11 platform to regulate the interaction among overlapping IBSSs. In this algorithm we will choose to give more priority to nodes in overlapping zones. We will call those nodes Virtual Access Points (VAPs) as they perform a similar distribution role like the access points in the IEEE 802.11 infrastructure mode.

Assume the same network topology as in Fig. 2 where two IBSSs, IBSS1 and IBSS2, overlap each other. As shown in Fig. 3, node A is the VAP of the two IBSSs. To upper layers this VAP provides the intercommunication means between different IBSSs in the multi hop scenario. However, in the current 802.11 protocol, communication

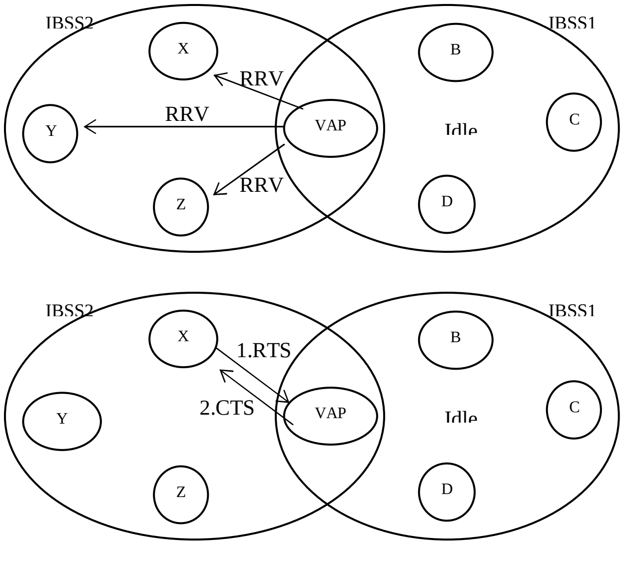

Fig. 3 Virtual Access Points seize the medium on a regular basis

with these nodes is not regulated and therefore it causes problems to upper layers. 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 the VAP 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 instead of the repeated failed attempts demonstrated in the previous section.

The algorithm will go as follows: The VAP should have the ability to seize the medium every IIT "IBSS Intercommunication Time" to give a chance for intercommunciation between IBSSs.

1) During IIT period, communication between any station and the VAP is disallowed until the VAP procedure is ON.
2) VAP contends for the medium every IIT period until it captures it.
3) Once the VAP captures the medium, i.e., the VAP procedure is ON, it will send all the packets it has accumulated during the IIT period.
4) VAP picks IBSSi (i = 1,2) to poll its stations for its traffic. Assume it picks IBSS1.
5) 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 over.
6) Upon receipt of RRV, nodes in IBSS1 that have packets for the VAP will contend for the medium and whoever wins will respond with an RTS towards the VAP. VAP will respond with a CTS and normal handshake will continue.
7) VAP will repeat sending the RRV message until stations in IBSS1 have no more VAP packets.
8) 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.
9) After another IIT elapses VAP should repeat the same procedure with IBSS2

Consider a more complicated scenario where we have more than two overlapping IBSSs and more than one VAP as in Fig. 4. In this case the same approach is 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 IBSSs 1, 2, and 3 are operational, VAP1,2,3 can neither send nor receive data. Each one of them has its IIT timer, whose expiry will trigger the contention for the medium. This contention may involve multiple VAPs.

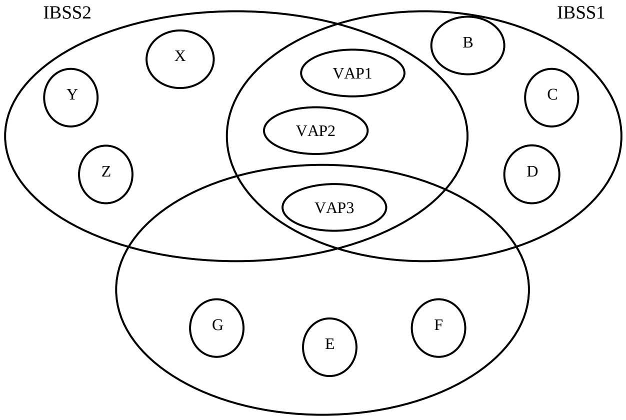

Fig. 4 Three Coexisting Overlapping IBSSs

- Let us assume for illustration purposes that VAP1 acquires the medium, then as before, it will send its RRV message for IBSS1. This message will disable all nodes not belonging to IBSS1 from transmission for a period "t".
- Nodes in IBSS1 (including VAP2, 3) will try to access the medium to send their RTS (if needed).
- Once this process ends all nodes come back to their normal states except if the next node that acquired the medium is another VAP, then the other nodes will have to wait for this node to finish its cycle as well.

From this brief explanation, it is shown that no special handling for the multi-VAP scenario is needed.

IV. SIMULATION

We have developed a java-based simulator to simulate the basic features of the current IEEE 802.11 protocol as well as our overlaid algorithm. We have performed three experiments in which we observe the aggregate throughput within each IBSS 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 (figure 5). In the second experiment we had two overlapping IBSSs (figure 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 (figure 7). The IIT period was set to a value of 50*NAV.

From figure 6 we can see that the first experiment achieves a saturation throughput of 70% at a traffic rate of 0.7 Mbps. The second experiment shows that IBSS1 and IBSS2 saturate at a value of ~ 45% at 0.5 Mbps.

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

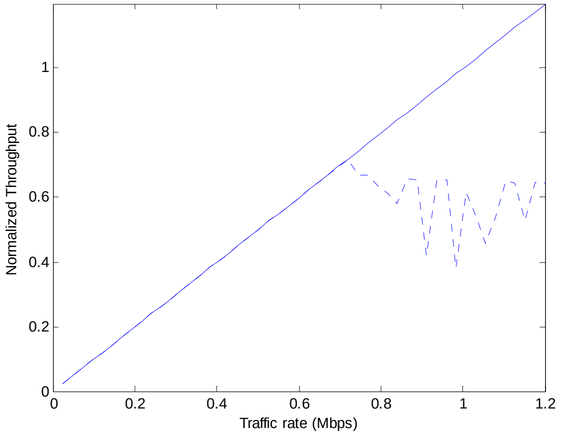

Fig. 5 Single IBSS Throughput

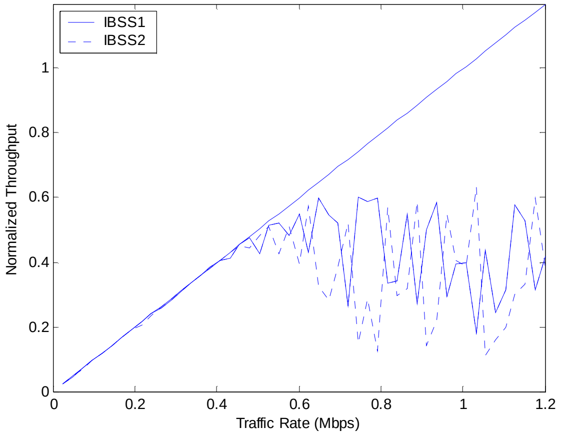

Fig. 6 Overlapping IBSS Throughput

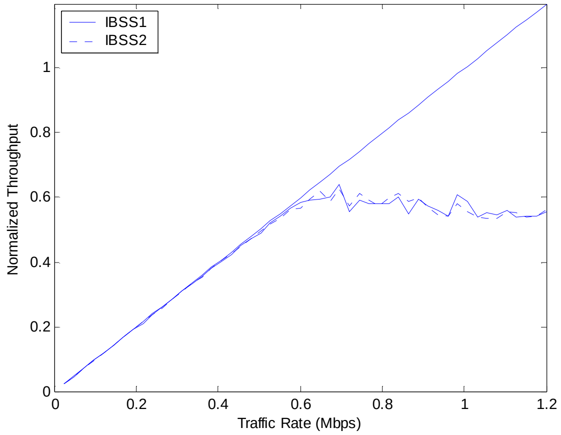

Fig.7 VAP procedure IBSS Throughput

Also, it shows the instability resulting at higher traffic rates. So the system may operate at the maximum throughput value but any little shift of the traffic rate may result in a huge drop of the IBSS throughput. There is no clear value of the traffic rate that the system can operate at to achieve maximum throughput. The third experiment shows the effect of our proposed algorithm where we can see that IBSS1 and IBSS2 saturate at a value of ~60 % at a traffic rate of 0.6 Mbps. Moreover the system can operate safely on this maximum saturation throughput value with out experiencing the unstable behavior encountered in experiment 2.

V. CONCLUSION

The current IEEE 802.11 standard does not handle the problems arising in the case where multiple IBSSs overlap each other. Our analysis shows the instability resulting from such scenario. If a multi hop ad hoc network is to be built on top of 802.11 platform, these issues will need to be handled to yield an acceptable performance. We have proposed an overlay algorithm that abides to 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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