Addressing the Effects of Missing Receiver Problem in Access Networks

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***Abstract*—The implementation of multi-channels at the MAC layer has created a new interference problem, the Missing Receiver Problem (MRP). The MRP is a multi-channel problem which relates to the use of multi-channels concurrently. As nodes communicate on different channels, they become unreachable and deaf. Bandwidth will be wasted when communication is initiated with deaf nodes. The paper evaluates the effects of MRP on network performance. The bandwidth of one control and two data channels is considered in relation to the size of control and data packets. Channel switching delay is also factored in the analysis. An analysis of channel bandwidth given the size of packets is presented. The proposed MRP solution is based on the cyclical scheduling algorithm, a proposed framework for solving multi-channel interference challenges. The framework is described at length and thereafter the analyses and the analytical results are discussed. The results show that the effects of the MRP can be reduced.**

Keywords-Channel Coordination; Channel Selection; Common Control Channel; Deafness; Missing Receiver Problem

I. INTRODUCTION

Wireless Mesh Networks (WMN) can be deployed effectively as a community wireless access network. However, the capacity of WMN falls short in meeting the requirements of time bounded data, largely due to interferences, such as the Hidden Terminals, the Exposed Terminals and the Terminal Deafness Problem. In general, the implementation of multi-channel systems has availed more capacity for wireless systems and improved their performance. Nevertheless, the above mentioned problems still require to be addressed for the increased network capacity to be realized.

WMN are widely touted as the possible future community access network offering high speed broadband connectivity offer last mile broadband wireless access. They overcome the shortcomings of ad hoc networks by overlaying or integrating mobile terminals with static nodes. The static nodes have high processing power, are more energy efficient and do act as a semblance of an infrastructure based network. However, more has to be done to position WMN as high speed last mile broadband wireless network solution.

One of the proposed directions of research aimed at increasing network capacity exploits the availability of the multi-channels at the physical layer prompting the need to redesign the Medium Access Control (MAC) protocols to handle multiple channels. In general, the results of the multi-channel schemes are encouraging [1] [2]. However, multi-channel interferences, such as the MRP still require attention.

This paper first presents in detail a proposed Cyclical Scheduling Algorithm (CSA), through which the multi-channel interferences such as the MRP can be addressed. The CSA is the multi-channel coordination, scheduling and channel selection scheme which transmit data in phases. The MAC schedules data transmissions in cycles. It then presents the assumptions underpinning the MRP solution. The MRP solution is premised on wasted bandwidth, given the ratio of control channel dwell on time to the data channel dwell on time, when an instance of the MRP is encountered.

The Missing Receiver Problem is caused by a would-be receiver, which is currently busy on a different channel either receiving or transmitting or just listening on it, while a sender is trying to send packets to it on a different channel. The sent packets fail to reach a receiver because the intended receiver would be tuned on a different channel. The MRP is caused by lack of synchronization between the sender and the receiver in multi-channel systems. The lack of synchronization of the sender and the receiver wastes bandwidth and network resources.

The need to reduce multi-channel interferences and for multi-channel approaches at the MAC layer is discussed in Section 2. Section 3 discusses related work. The proposed CSA model is presented in Section 4. The impact of the MRP on network performance and the analytical results are presented in Section 5. Section 6 and Section 7 summarize the future work and the proposed model, respectively.

II. MOTIVATION

Mesh networks combine the advantages of ad hoc networks and infrastructure based networks into one community based network. Different access networks can be deployed in a community forming an auto configuring, self healing and self organizing mesh network. The need and the requirements of quality of service and the time bounded data can be met by well designed multi-channel mesh networks.

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Multi-channel techniques are robust, flexible and do increase network capacity. However, the coordination, selection and scheduling of multi-channels needs to be explored further.

The increase in network capacity in multi-channel systems comes at the expense of channel switching delay. The net effect of trading off channel switching cost with network capacity may improve the overall network performance.

The multiple channels are available at the physical layer; unfortunately the MAC layer is not designed for multi-channel systems; while the network layer is optimized for multi-channels and is designed to address the shortcomings of the MAC layer. The reconfiguration of the MAC will therefore, result in the realization of more capacity and flexibility. The channel selection, coordination and the terminal deafness challenges may be solved at the MAC layer for improved network performance.

We propose a multi-channel cyclical scheduling algorithm and present it as a framework for solving multi-channel interference problems. The MRP solution which is based on the proposed multi-channel framework is then presented and evaluated analytically.

III. RELATED WORK

Maheshwari et al. [1] reduces the effects of MRP by employing a receiver initiated solution. Unfortunately, it only alerts transmitters which are in their back off intervals. A new collision technique may be required to resolve contention of two or more invited transmitters which respond to the same invitation simultaneously. Furthermore, the user based quiescent channels may lead to network portioning.

Shi et al. [2] solve the multi-channel interference challenge through the synchronization of nodes on the control channel. However, synchronization is a challenge for mobile nodes.

Toham and Jan [3] employ a multi-interfaces approach and it solves MRP at high overhead cost of hello messages which degrade the network performance. It is also expensive in terms of hardware requirements. Mo et al. [4] proposed a similar multi-interfaces scheme. It also solves the deafness problem at high hardware cost.

Toham and Jan [3] argue that the use of a common control channel causes bottleneck. The implementation of a common control channel facilitates network connectivity and ensures that the network is not partitioned.

Seo and Ma [5] proposed a synchronous scheme using one transceiver. The system broadcast channel releases messages, and keeps both a neighbor status list and a channel status list. A significant percentage of bandwidth is lost in signaling and synchronization is a challenge. The proposed contention window may be too small in backlogged environments.

A CTS packet reserves a channel in [6] and fails to notify nodes in the neighborhood of the transmitter. However, the use of two transceivers minimizes the effects of missing receivers albeit at high cost of hardware.

Incidents of the missing receiver problem increase due to lack of coordination in multi-channel systems. The pair of nodes may be on two different channels or one node may switch to a different channel thereby becoming unreachable. When one node is busy on one channel while a number of nodes (at least one) are trying to communicate with it on different channels, an unreachable terminal is said to be deaf [7].

IV. THE SYSTEM MODEL

The proposed CSA framework has four distinct components. The framework has the following techniques: the channel switching penalty, the Request To Send (RTS) based data channel reservation and access scheme, the inter-cycle, and the phasing of data transmission in cycles. We describe each of these four aspects separately and then show how they are integrated. The framework employs one dedicated control channel and N number of data channels. We then show how the envisaged framework reduces the effects of MRP.

The channel switching technique associates all the switching costs with the data channels. It considers two channel switching penalties. When a transceiver switches to and from a given data channel from the control channel it incurs two channel switching delays. When the transceiver switches to the data channel, it incurs a switching delay of 224µs (the maximum cost specified by the IEEE 802.11 standard) and the same duration is also incurred when it switches back onto the control channel. The effective channel switching delay is therefore set to 448µs to capture its double effect on data channels. The value of the switching delay is added to the data packet transmission duration.

Ideally, this will keep a data channel busy for a longer duration. However, it improves the performance of the control channel and it increases its capacity to drive more data channels before it saturates. In general, this approach is capable of improving the overall system performance.

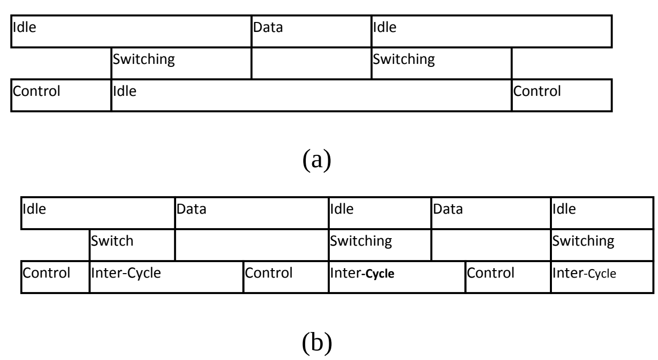

Figure 1. The channel switching penalty model.

In Fig. 1a, we model the conventional approach where the next transmitter waits for the channel switching process to be performed first before contending for the control channel. All the terminals should be on the control channel before the next transmission is initiated. This approach wastes the capacity of the control channel and increases its saturation rate. The capacity of the control channel may be increased to improve the performance of the network. As shown in Fig. 1b, the capacity of the control channel has been improved. The control channel can now drive more data channels. In the proposed scheme, the data channel is reserved when it is about to finish the current transmission. As the current communicating pair switch back onto the control channel, the next pair switch onto the data channel. The terminals will cross each other as they switch to opposite directions. This equips the control channel with more capacity to support more data channels, which, in essence, increases its scheduling capacity and reduces its idleness. It should also be noted that there is no need in this case for nodes to perform a channel switching prior to control channel contention.

The RTS-based data channel reservation and access scheme limit channel contention to the control channel. Two terminals intending to exchange data will contend for and reserve the control channel. Thereafter, there will not exchange packets to negotiate which data channel to reserve. The reservation of the data channels will be linked to the reservation of the control channel. This is possible in the CSA framework given the fact that data transmission is scheduled in phases. The control channel is reserved during timeslots in which a given data channel is known to be idle. The main goal of this scheme is to reduce the contention and channel reservation duration and to avail more bandwidth for network performance improvement.

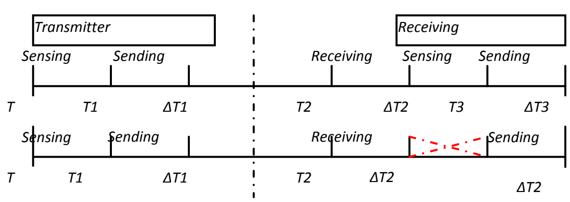

Figure 2. The RTS based channel reservation scheme.

In Fig. 2, the transmitter has to first identify idle data channels between time T and T1 and then sends the list to the receiver including its preferred data channel at T1. The receiver will also upon receiving the RTS packet at time T2, check whether the sender's preferred data channel is also free at its end. It may check other data channels in the list if the preferred data channel is not available. Thereafter, it will send either the confirming or the rejecting CTS back to the transmitter [2]. These processes are shown in the top block.

The bottom block shows the proposed approach where a sender does not have to first check whether the preferred data channel is indeed idle. The sender only includes one data channel in its RTS packet which is known to be idle and the receiver would be expected to accept it. The receiver will agree with the sender on the preferred data channel without having to first sense the medium. The sender chooses a preferred data channel without sensing the medium using virtual carrier sensing and network support scheme. The nodes are, therefore, able to determine when channels would be idle without relying on both the physical and the virtual carrier sensing mechanisms.

The implementation of the RTS-based data channel reservation assumes that the data channels would be available when the sender reserves the control channel. The receiver will therefore be expected to agree with the sender on the preferred data channel.

The inter-cycle scheme marks the beginning and the end of a given cycle. It defines the shortest duration a data channel will be busy before it is available for the next data transmission in the next cycle. It is the hold off duration which forces all terminals intending to use a given data channel to hold off their next transmissions long enough to allow data packets to be delivered successfully. In essence the inter-cycle is the time when the last control packet was received in the previous cycle to the time the next control packet is sent in the next cycle.

The inter-cycle duration is not fixed it varies with the number of data channels implemented. It is inversely related to the number of data channels. It has the longest duration when there are only two data channels and its length decreases as more data channels are added.

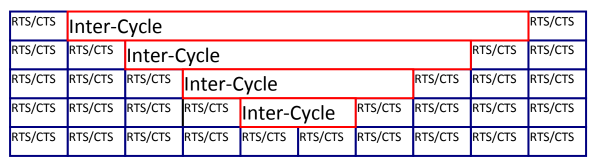

Figure 3. The Inter-Cycle Scheme.

Fig. 3 shows the behavior of the inter-cycle duration as the number of data channels is increased. The inter-cycle duration decreases with the number of data channels. As it shrinks, the control channel becomes busier and its capacity improves. The control channel can schedule and drive more data channels.

The top row depicts a situation where there are two data channels. The control channel will lie idle after performing the first handshake of the two data channels until the current data transmissions are about to complete. Then the next handshake will be performed in the next cycle. The duration of the inter-cycle will reduce in the next row when two more data channels are added. This behavior will be exhibited by the inter-cycle for every additional data channels to been added. For the purposes of the analytical work, we assume that all the channels are orthogonal to each other.

Lastly, we describe briefly the cyclical nature of the algorithm. This attribute of the algorithm is related to the inter-cycle technique. All the available data channels will be accessed in phases through the control channel. When the last data channel in the current cycle finishes its transmission, the first channel, will be reserved for the first transmission in the next cycle. This attribute of the CSA is detailed in [8] [9] with accompanying diagrams.

The following pseudo-code gives an overall picture of the entire algorithm with its four components. The pseudo code gives the bird's view of the CSA. It explains the CSA

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in a very concise manner. The pseudo code also shows how the components of CSA are integrated to each other.

PSEUDO-CODE 1. CHANNEL SELECTION AND SCHEDULING

For (j && i = 0; j && i <= n-1; j++ &&i++)

1. *Begin channel access for terminal X+j*
2. *defer for the inter-cycle duration for next cycle NC+i*
3. *Contend for the control channel access C0*
4. *RTS and CTS agree to reserve Data Channel DC, i+1*
5. *Sender and receiver both Switch to DC, i+1*
6. *Transmit on DC for DATA + 2 * switching delay(sw_p)*
7. *Switch back to C0*
8. *repeat 2 to 7 until DC, is equal i + n - 1*
9. *Reset counters and Begin next cycle, NC + i*

We now discuss how the framework reduces the effects of the MRP. We assume that there are three channels, one control and two data channels. In each cycle, two data flows are scheduled. Given this assumption, we consider the number of terminals which are likely to be deaf and how terminals can be quickly synchronized to reduce the MRP.

In any given cycle there are two possible nodes which may be deaf. If other terminals try to send packets to them, bandwidth will be wasted. Furthermore, returning nodes will not have a complete picture of the network upon their return to the control channel. The status of some nodes is likely to change during their absence. Technically, two nodes may be unknown to any returning node when two data channels are implemented. This is possible because data channels are reserved whilst some nodes are still busy transmitting on data channels. As terminals in the current cycle are switching back to the control channel, the next set of terminals for the next cycle will be switching onto the data channels.

To reduce the effects of terminal deafness, returning terminals may be starved of their next transmission until they have knowledge of the network.

Deaf terminals are within the transmitter's communication range but are not able to overhear or receive packets from a transmitter because they are busy receiving or transmitting on a different channel. We therefore do not consider transmission ranges of terminals. We assume that all terminals are within the communication range of each other and can decode all received or overheard packets. The impact of MRP is modeled and analytically explored in the following section.

V. ANALYTICAL RESULTS

This section analyzes the effects of the missing receivers on network performance and analytical results are presented.

Throughput y, which is available to each node in the network, is given by dividing the capacity of the network by the number of nodes in the network [10]. Given this formula, the allotment of throughput to the nodes can be ascertained and predicted. The equation is given below: c is the capacity, while N the number of nodes.

$$y = {}^{c}/_{N} \qquad (1)$$

In the multi-channel environment, the capacity of the network increases with the number of channels implemented. It increases approximately at N times the channel capacity. Nc is therefore the total capacity of all the channels.

So and Vaidya [11] argues that a dedicated control channel in a three channel system constitutes a third of the total capacity. Generalizing the capacity of the control channel Cc, with M, the number of channels, the following formula is obtained:

$$C_c = \frac{N_c}{M} \quad , \qquad (2)$$

The instance of the MRP is equivalent to the control channel overhead as it wastes the same amount of bandwidth. Factoring the effects of the MRP in the allotment of bandwidth in (3) is obtained.

The network throughput in the presence of MRP, denoted by *YMRP* is expressed as follows:

$$Y_{MRP} = \frac{N_c\,(1-\frac{n}{M})}{N} \qquad (3)$$

Network capacity is denoted by Nc, the instance of the MRP by n and N denotes the number of nodes.

Given (3), the effects of the MRP can be modeled. If there are three channels, then one encounter of the missing receiver will result in one third degradation of the network throughput.

Two encounters of deafness in the proposed CSA will result in two-thirds throughput degradation. Fig. 4 depicts network throughput degradation under these assumptions, when the capacity is set to 12 Mbs and M to 3. *YMRP* denotes throughput in the presence of MRP.

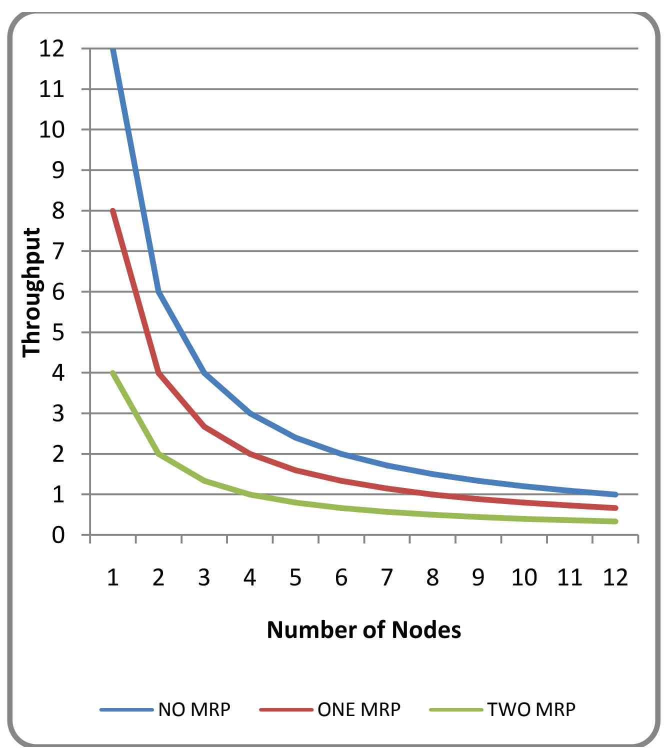

Figure 4. Effects of MRP on throughput

When the transmission durations of the control and the data channels are considered, it becomes apparent that the effects of MRP would be less severe. The transmission ratio of the control channel to the data channel is approximately *11 to 1* in terms of transmission durations taking into consideration the channel switching delay. The results of an *11 to 1* ratio are expected to differ significantly from the results in Fig. 4 which are based on a *2 to 1* ratio. The instance of a MRP will therefore cause a twelfth of network degradation.

Control channel overhead is represented by (1), when M is 12.

To calculate the network throughput after factoring the effects of the node deafness problem, equation (3) is employed. When an RTS is sent to a deaf node, a complete RTS/CTS handshake is recorded as a complete transmission amounting to a control channel overhead.

The amount of bandwidth utilized is therefore equal to the control channel overhead. The assumption that an instance of a MRP amounts to the control overhead is valid as the control channel would be unavailable for the entire duration of the RTS/CTS handshake.

The overhead caused by the instance of the MRP now translates to, $\frac{n}{12}$. Taking this fraction and factoring it into (3), we get the following equation.

$$Y_{MRP} = \frac{N_c\,(1-\frac{n}{M})}{N} \quad (4)$$

Given equation (4) and that N_c is 12 Mbs and M is 12; the results in Fig. 5 are obtained.

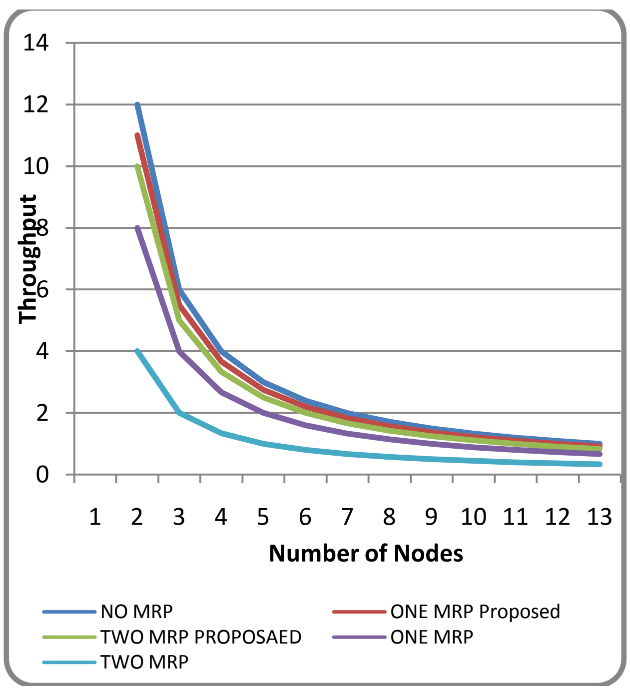

Figure 5. Effects of MRP on throughput in our proposed solution

Fig. 5 shows that the proposed approach is likely to perform better in the face of Missing Receivers and its performance would improve as more instances of MRP are encountered. For example, in Fig. 5 where two instances of node deafness are encountered, the proposed approach performed better that when only one instance was encountered. However, in any given cycle, at most two terminals may be deaf and unreachable, according to the CSA assumptions for a network with three channels.

The solution to MRP will improve the network throughput and reduce significantly the control channel overhead cost. Fig. 5 shows that the instances of missing receivers do increase the overhead of the control channel. It can also be seen in the same figure that the effects of node deafness in the proposed architecture will be less severe as compared to Fig. 4.

VI. CONCLUSION

Given the proposed underlying protocol the CSA, the MRP will be limited to the returning terminals. The returning nodes should be forced to delay their next transmissions until they have adequate information about the status of the network. This will reduce the effects of MRP. The waiting delay may be reconsidered where network support is implemented.

When the instance of the MRP is considered to be equal to the overhead of the control channel, and taking into consideration the actual packet lengths of both data and control packets, the effects of MRP will be reduced further. The phasing of data transmission enables terminals to have the correct information about the channels and to know when to contend for data channels when they become free.

The CSA also facilitates the implementation of the RTS-based data channel reservation and access scheme. Contention will be limited to control channel and there will be no need for the signaling packets to be employed in reserving and in agreeing on data channels to be used. The reservation of the data channels will be scheduled through the control channel when a given data channel is idle and available for the next data transmission.

The implementation of the CSA will make use of the virtual carrier sensing technique for data channel reservation. The physical carrier sensing, and the virtual carrier sensing, will be employed only for the control channel reservation.

The control channel facilitates network connectivity. Furthermore, there can be at most four channels available when non overlapping channels are considered [12]. We are experimenting on how network improves, assuming that all the channels are available and are orthogonal. Future work will look at how many possible channels can be utilized if the additional data channels do improve the performance of the network.

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