Performance Enhancement of Mobile Ad Hoc Networks Using Nodal Cooperation

(Invited Paper)

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ABSTRACT

Mobility is known to drastically affect the performance of wireless ad hoc networks. Link breakages are one of the primary causes leading to the degradation of network performance. Recent research on cooperative communication in networks demonstrates that spatial diversity achieved through cooperation significantly improves the performance of wireless networks. In this paper, we investigate the impact of introducing cooperation to mitigate the adverse effects of mobility on network performance. Preliminary results show that introduction of a cooperative MAC sub-layer can improve network performance under nodal mobility.

Categories and Subject Descriptors

C.2.1 [**Computer Communication Networks**]: Network Architecture and Design–Wireless communication
; C.2.3 [**Network Operations**]: Performance Analysis
; C.2.5 [**Local and Wide Area Networks**]: Multi Access Schemes

General Terms

Cooperative Communications

Keywords

WLAN, Cooperation, Mobility

1. INTRODUCTION

Developments in wireless technologies in the past decade have revolutionized the way people use networks. Through wireless networks, users have experienced a new found freedom from the geographical constraints of wired networks. Wireless Internet access has spawned a wide variety of mobile hand held devices such as laptops, PDAs, etc at affordable costs. Mobile users are interested in exploiting the technology at their fingertips, as wireless networks bring closer the "anytime, anywhere" promise of mobile networking.

Since the advent of IEEE's 802.11 standard [1], Wireless Local Area Networks (WLAN) have gained widespread acceptance in providing broadband wireless access to portable devices. The performance of any WLAN is largely affected by node mobility as well as the wireless environment available to the participating nodes. This is because mobile nodes experience frequent link breakages while interference and fading effects negatively affect the overall throughput achieved. Spatial diversity is known to minimize the ill effects of channel fading and realizing it generally requires incorporation of newer technologies such as Multiple Input Multiple Output (MIMO) systems. None the less, it is impractical to equip every node in a WLAN with multiple antennae, primarily due to their size and energy constraints.

Recent research on cooperative communication [2] [3] [4] [5] [6] [7] demonstrates that spatial diversity can also be achieved by exploiting some unique features of the underlying wireless medium. The inherent broadcast nature of the wireless channel suggests that any signal transmitted on the medium can be overheard by all nodes within the receiving range. If such nodes were to retransmit the overheard signal towards the destination rather than discarding it completely, they would effectively provide the destination with extra observations of the source signal. These observations at the destination are all dispersed in space and are akin to observations resulting from MIMO systems. In short, one can think of a cooperative system as a virtual antenna array, where each antenna in the array corresponds to one of the assisting neighbors [7].

In addition to interference and fading effects, nodes in WLANs can also suffer from fairness problems resulting from multi-rate modulation scheme employed by IEEE's 802.11b standard. As shown in [8] if all the nodes have uniform traffic to/from the access point (AP), the lower data rate nodes will use much more channel time than the higher data rate nodes. This results in two negatives: not only do the lower data rate nodes get poor service they also reduce the bandwidth of the higher data rate nodes [9]. This in turn reduces the effective throughput of the entire network. In

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[10] it is shown that a multi-hop extension to IEEE's 802.11b infrastructure mode can increase the overall throughput of a WLAN while also providing a more uniform coverage within the service set.

The focus of this paper is on the performance analysis of a new IEEE 802.11b compatible MAC protocol that realizes the benefits of cooperation at the MAC sub layer while implementing the multi-hop extension proposed in [10]. With the studied protocol, low data rate nodes transmit their packet first to an intermediate node which in turn forwards the packet to the destination at rates higher than otherwise possible. Also, we demonstrate the resilience of this protocol to node mobility and validate the protocol's performance by means of extensive simulations. Results show that the new protocol can improve on standard 802.11b's throughput even in mobile environments.

2. SYSTEM OVERVIEW

IEEE 802.11b's physical (PHY) layer uses Direct Sequence Spread Spectrum (DSSS) which operates in the 2.4GHz industrial, scientific, medical (ISM) band and uses DBPSK, DQPSK and CCK modulation schemes to support transmission rates of 1Mbps, 2Mbps, 5.5Mbps and 11Mbps. The protocol provides access to the shared wireless medium primarily through a contention-based access mechanism, called the Distributed Coordination Function (DCF). The DCF mechanism is based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) under which a node with data to transmit, has to first sense the wireless medium to determine if it is free. It also employs virtual carrier sensing by using frames like Request to Send (RTS) and Clear to Send (CTS). These two control frames set the Network Allocation Vector (NAV) using which nodes in the network are able to avoid collisions resulting from hidden terminals. If the data packet following the control frames is received without any errors, the destination node sends an acknowledgement (ACK) packet back to the source.

IEEE 802.11b modulates all control packets and the header part of the data packets using DBPSK at 1Mbps. The modulation scheme used for the payload part of the data frame is indicated in the PHY header of the transmitted frame.

Figure 1, obtained from [11] shows the Bit Error Rate (BER) vs. Signal to Noise Ratio (SNR) for different modulation schemes of 802.11b. While these curves can be derived theoretically, for the purpose of this paper and to achieve a solution closer to reality, we use the above empirical curves provided by Intersil for its HFA3861B chip. From the figure we can derive that given a BER one can find the most suitable modulation scheme based on the received SNR.

3. SYNERGY MAC PROTOCOL

The Medium Access Control (MAC) protocol described in this section is based on 802.11b's DCF mechanism. Synergy MAC can be described as a cooperative MAC protocol for infrastructure wireless LANs whose main aim is to combat channel fading by achieving spatial diversity through cooperation. The following are some of its assumptions:

1. Transmission power for all nodes in the network is fixed.

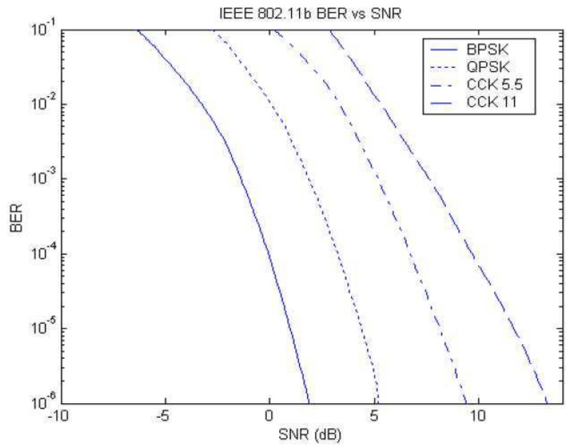

Figure 1: BER vs. SNR for different 802.11b PHY modes

2. Communication channel between any two nodes in the network is symmetric.
3. Threshold SNR for each modulation scheme is predefined and stored in a physical mode table on every node.
4. Transmitting nodes choose their data modulation scheme based on the received signal to noise ratio (SNR).
5. Control frames like RTS, CTS and ACK are overheard by other nodes besides the transmitter and the receiver. The following subsections present the underlying details of Synergy MAC protocol.

3.1 The Synergy Table

After associating itself with an access point (AP), a node starts listening for control and data frames sent out by other nodes on the shared channel. This is required by 802.11b, as all nodes in the network need to correctly update their NAV. In addition to this, Synergy MAC requires each node to maintain a Synergy Table as shown in Table 1 to help determine its ability to volunteer as relay during cooperation. Each row in this table has five fields and is similar to the one maintained by [9]. The first field of this table stores the ID (MAC address) of the source followed by the $Time$ that the last packet from that node was heard. The third field is used to record the data rate that can be used to send data packets from the source to the current node and is denoted by R_{sr}. The fourth field stores the ID (MAC address) of the destination followed by R_{sd} which represents the data rate used between the source and the destination.

Source ID	Time	Src-Rly Rate	Destination ID	Src-Dst Rate
N_s	$Time$	R_{sr}	N_d	R_{sd}

Table 1: Synergy Table

Synergy Table gets updated in the following manner:

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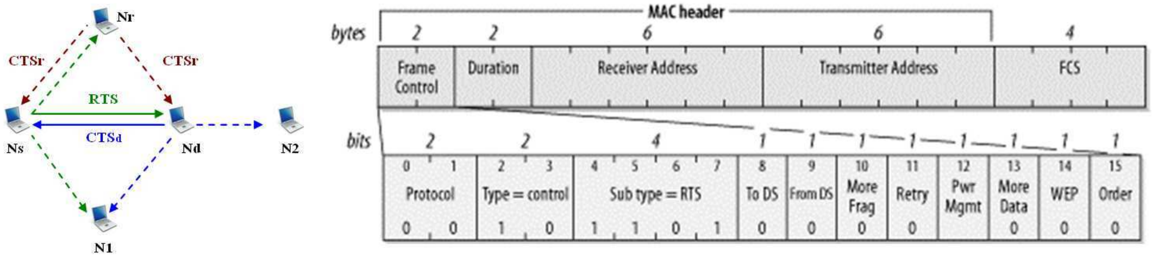

Figure 2: (a) (b)
Control Frame Exchange in Synergy MAC **IEEE 802.11b RTS Frame Header**

When any transmission between other nodes is overheard by a node (N_r), it will check if the transmitting node (N_s) is already in the table. If not, a new row is added for the sender and is identified by the senders *ID*. Then N_r computes the relative channel condition between the sender of that packet and itself by measuring the received power level (in dB). Path loss can be calculated by subtracting the transmission power (in dB), which is fixed for all nodes and the received power. By checking its physical mode table, N_r can find the data rate between N_s and itself and use this value to update the rate R_{sr} for N_s. If any data packet between source N_s and destination N_d is overheard by N_r, it will be able to detect the transmission rate used, by looking into the PHY header of the data frame, which is always transmitted at the base rate of 1Mbps. This value along with the destination's *ID* is used to update the R_{sd} field for N_s. The time field is updated every time a packet from N_s is overheard by N_r.

3.2 The RTS frame

When a source node N_s wants to send L octets of data to destination N_d, it consults its Synergy Table and calculates the time needed to transmit all the octets using direct transmission. Following this, node N_s begins to sense the shared channel for any wireless activity. If the channel is found to be idle for distributed inter-frame space (DIFS) time and N_s has completed the required backoff procedure, an RTS frame is sent to the destination N_d, reserving the channel for the time needed for direct transmission. If the channel was sensed busy, node N_s waits until the channel is idle plus a DIFS interval and then sends its RTS frame to destination N_d. Figure 2a shows the exchange of control frames in Synergy MAC protocol.

Figure 2b shows the IEEE 802.11b RTS control frame format. According to [12], the *More Fragments* bit field in 802.11b frame header is set to 0 on all frames other than those data or management frames that have another fragment of their current MAC Service Data Unit (MSDU) or MAC Management Protocol Data Unit (MMPDU) to follow. This means that control frames in 802.11b never get fragmented and consequently always have their *More Fragments* bit set to 0. It is therefore feasible for Synergy MAC to use this bit to distinguish its control frames from those of standard 802.11b's. Apart from setting its *More Fragments* bit to 1, Synergy MAC requires no other change to the legacy RTS frame format. An alternative strategy for Synergy MAC would have been to use a different protocol version in the *Protocol* field of the RTS control frame header, but doing so would have rendered it incompatible with existing versions of 802.11b implementations.

3.3 Relay Identification

When an intermediate node N_r, overhears an RTS transmission between source N_s and destination N_d, it estimates the length of the subsequent data frame based on the transmission duration obtained from the *Duration* field of the overheard frame and the rate of data transmission R_{sd}, between nodes N_s and N_d obtained from its Synergy Table. Next, N_r computes the time required to transmit the same data frame over two hops with itself acting as the relay. If the data frame is L octets long, the transmission time via N_r ignoring overhead and the contention time is $8L/R_{sr} + 8L/R_{rd}$ where, R_{sr} is the rate of data transmission between N_s and N_r and R_{rd} is the rate of data transmission between N_r and N_d. N_r obtains both R_{sr} and R_{rd} from its Synergy Table. Such two hop transmission via N_r is efficient only if $8L/R_{sr} + 8L/R_{rd} < 8L/R_{sd}$. If this is indeed the case, node N_r will indicate its availability for cooperation by transmitting a self addressed CTS frame with *Duration* set to $8L/R_{sr} + 8L/R_{rd}$ after short inter-frame space (SIFS) time. Like with the overheard RTS, node N_r sets the *More Fragments* bit to 1 in its CTS-to-self frame header. To resolve potential collisions between many candidate relay nodes, the CTS-to-self frame from all eligible intermediate nodes are governed by a contention window. The contention window size used by candidate relays for transmitting their self addressed CTS frame is small when compared to that used by source nodes for transmitting their data frames. Moreover, candidate relays shall always choose their random slot time within [1, CW_r] for transmitting their self addressed CTS frames. The candidate that picks the lowest slot in the window wins while the remaining candidate relays update their NAV based on the *Duration* contained in the winning CTS frame. In an infrastructure basic service set (BSS), the value of CW_r can be announced by the AP in its beacon while in an IBSS, the nodes choose $CW_r = CW_{min}$.

Though the candidate nodes could have used any new frame format to announce their availability, using a self addressed CTS frame to accomplish this task has its benefits. Not only is the CTS-to-self frame compatible with 802.11b standard as mentioned in [12], it also serves the purpose of reserving the medium for the duration of cooperation. In addition to this, a CTS-to-self frame lets the source and the

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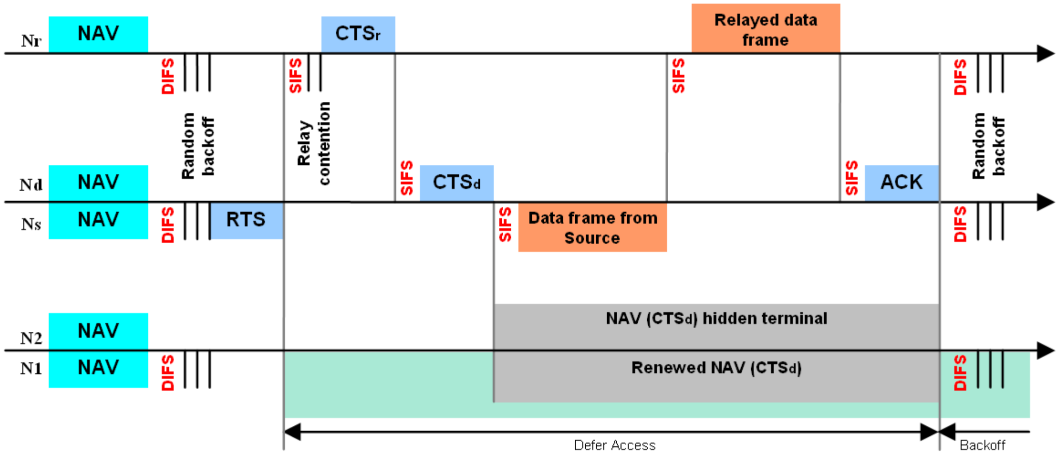

Figure 3: NAV update mechanism in Synergy MAC

destination nodes know the identity of the assisting relay N_r.

3.4 The CTS Frame

After receiving the initial RTS frame from source, the destination waits to overhear the CTS-to-self frame (CTS_r) transmitted by the winning relay. If the CTS_r from the relay N_r is overheard by the destination N_d, it sends out a CTS frame (CTS_d) to source N_s after SIFS time, reserving the channel for the time needed to complete a two hop transmission via N_r. If a CTS_r is not overheard within a period of $CTS_{RelayTimeout}$, N_d still sends out a CTS_d frame to source, but this time reserving the channel for the time needed to complete a direct transmission. In case of the former, Synergy MAC sets the *More Fragments* bit in the CTS_d frame header to 1, requesting the source to use relay assisted transmission for its subsequent data frame. As the latter case is similar to that of legacy 802.11b, the *More Fragments* bit in the response header remains set to 0.

In situations where the destination is a legacy 802.11 device, a CTS response to a Synergy MAC RTS, is sent immediately after SIFS time. Contending relays would overhear this response and update their NAV, behaving as if the destination had picked the lowest slot in the relay contention window. This results in 802.11b mode of operation using Synergy MAC.

3.5 Cooperative Communication

Once node N_s receives a CTS_d frame from destination N_d, it starts transmitting its data frame after SIFS time with the *Duration* field set to CTS_d's estimate duration. If CTS_d's *More Fragments* bit was set to 1, N_s sends the data frame to N_r using rate R_{sr}. Node N_r then checks the CRC field of the received data frame and if correct, forwards the frame to N_d, using rate R_{rd} after SIFS time. If CTS_d's *More Fragments* bit was set to 0, N_s sends the data frame directly to N_d using rate R_{sd} It is also possible that node N_s does not overhear a CTS_r from the winning relay before receiving a CTS_d from N_d with its *More Fragments* bit set to 1. This might occur due to drastic change in channel condition between N_s and N_r during frame exchange. But because N_d had overheard a CTS_r from relay, its *Duration* estimate in CTS_d would be far less than the *Duration* contained in the initial RTS frame. If this is the case, source N_s resorts to fragmenting its data frame, based on CTS_d's *Duration* and its data transmission rate R_{sd} in order to maintain consistency of the NAV.

After receiving the data frame, destination N_d responds back to N_s with an ACK frame indicating a successful reception. Otherwise N_d stays idle in which case N_s notices the failure of transmission after a timeout period and starts backing off exponentially, which is the same as in the standard IEEE 802.11b MAC.

3.6 NAV Mechanism

According to [12], all nodes receiving a valid frame except the one whose MAC address is equal to the RA (Receiver Address) mentioned in the frame header, are required to update their NAV with the information received in the frame's *Duration* field. When compared to [12], Synergy MAC differs slightly in the way its NAV is calculated. The *Duration* carried in a Synergy MAC RTS header is the time in microseconds required to transmit the pending data frame using direct transmission from source N_s to destination N_d, plus one CTS frame, one ACK frame, a relay timeout and three SIFS intervals as shown below.

$$Duration_{RTS} = 3T_{SIFS} + CTS_{RelayTimeout} + T_{CTS} + 8L/R_{sd} + T_{ACK}$$

This ensures that even if there is no intermediate node to volunteer, the data frame can be sent to the destination by direct transmission using rate R_{sd}. The *Duration* field in subsequent CTS_r will be set as follows,

$$Duration_{CTS_r} = 4T_{SIFS} + T_{CTS} + 8L/R_{sr} + 8L/R_{rd} + T_{ACK}$$

The *Duration* in the CTS_d frame header is calculated based on whether or not the destination overheard a CTS_r from the winning relay. If the destination overheard a CTS_r, the value of the *Duration* via N_r is set as,

$$Duration_{CTS_d} = 3T_{SIFS} + 8L/R_{sr} + 8L/R_{rd} + T_{ACK}$$

In cases where the destination does not overhear a CTS_r, the *Duration* in the CTS_d frame header is set as,

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$Duration_{CTS_d} = 2T_{SIFS} + 8L/R_{sd} + T_{ACK}$

Figure 3 illustrates the NAV update mechanism in Synergy MAC. Nodes that can overhear both RTS and CTS_d frames (e.g. N_1) need to set their NAV duration according to the RTS frame first. Once the CTS_r or CTS_d frame is overheard, they need to reset the NAV according to the duration contained in the new frame. Hidden terminals that can only overhear N_d's transmissions (e.g. N_2) need to update their NAV on overhearing a CTS_d. Terminals that can only overhear N_s's transmissions set their NAV according to the initial RTS frame and update it when the subsequent Data frame is overheard.

4. MOBILITY MODELS

Network simulations can simulate mobility in two ways; either using network traces or using mathematical mobility models. To analyze the performance of the protocol on *mobile* ad hoc networks, we use mobility models in simulation. Random Mobility Models [13] are widely used to model such mobile networks in which some of the parameters responsible for mobility are indeterministic. Some of these parameters may be node attributes such as speed, direction, etc [14]. In this paper, we use two random mobility models namely the Random Waypoint Model (RWP) and the Random Walk model (Brownian motion) in our simulations. These are the most commonly used mobility models in simulations.

Random Waypoint mobility model [14] is the most frequently used mobility model in MANET simulations. According to this model, nodes move independently to a randomly chosen destination with a randomly selected velocity. The destination, speed and direction are all chosen randomly and independently of other nodes. The simplicity of Random Waypoint model is the main reason for its widespread use in simulation [15].

However, RWP has some inherent deficiencies such as speed decay and non-stationarity as has been recently shown [16] . Stationarity means that statistical properties remain constant at all times during simulation. The most important among them is that the average speed of the nodes is consistently decreasing. In fact, over a large interval of time, speed decay will cause node velocity to become zero. With increasing simulation time, the speed of the nodes will have an exponential distribution [17] [18]. Hence what started off as a uniform distribution is changing with time and hence does not satisfy the condition of stationarity. Also, it suffers from border effect which means that nodes pass through the center of the simulation area with a greater probability than any other area. However, it is widely used since the decaying effects are only observed during long simulations.

The Random Walk model [19] has similarities with the Random Waypoint model because the node movement has strong randomness in both models. However, in the Random Walk model, the nodes change their speed and direction at each time interval [26]. For every new simulation interval, t, each node randomly and uniformly chooses its new direction θ. Similarly, the new speed follows a uniform distribution or a Gaussian distribution. If the node moves according to the above rules and reaches the boundary of the simulation area, the exiting node is bounced back to the simulation field with the angle of $\pi - \theta$ respectively. This effect is called border effect [15]. We have used a Random Walk model with *wrap around* effect.

5. RELATED WORK

Cooperation in wireless networks is a relatively new area of research and towards improving the performance of networks. To the best of our knowledge, there has not been any extensive studies on how Cooperative MAC protocols behave in mobile environments. However, we are aware of other 802.11b based cooperative MAC protocols that have been proposed earlier. This section contrasts Synergy MAC against such protocols. In UTD MAC [20], the data frame transmitted by source is simultaneously made available at both the relay and the destination. It is only when the destination fails in its reception attempt that the relay intervenes to re-send the data frame after RIFS duration. Because the Duration in RTS and CTS remains unaltered, the protocol can lead to inconsistency in NAV propagation resulting in collisions. For example, nodes that can only overhear source node's transmissions would have a NAV value which does not account for the subsequent transmission by the relay. Though Coop MAC I [9] employs similar techniques as Synergy MAC, it requires considerable changes in the frame formats of 802.11 rendering it incompatible with legacy implementations. For example, Coop MAC I requires addition of at least three new fields to the legacy 802.11b RTS frame header. The protocol also requires the relay node to transmit a new frame called 'HTS' to indicate its willingness to assist the source node during cooperation. Coop MAC II [9] on the other hand does not require any such changes to the 802.11b frame formats but because it employs only a 2-way handshake, it can lead to collisions at the relay node. Also both Coop MAC I and II identify their relay nodes beforehand at source and are vulnerable to change in its availability caused due to node mobility. The complete list of differences between these cooperative MAC schemes is given in Table 2.

6. SIMULATION RESULTS

In this section, we present the simulation results obtained with Synergy MAC implemented in ns-2 simulator. Nodes in the network always choose their modulation scheme based on the received SNR such that BER $\geq 10^{-5}$. From Figure 1, this translates to data rates of 11Mbps if the node's distance from AP $<$ 48m, 5.5Mbps if the distance from AP $\geq$ 48m but $<$ 67m, 2Mbps if the distance from AP $\geq$ 67m but $<$ 74m and 1Mbps if the distance from AP $\geq$ 74m but $<$ 100m. Nodes located farther than 100m from the AP are considered to be out of communication range. Figure 4 shows the saturated throughput achieved for all possible source-relay-destination data rates in a simple 3 node wireless network. From the figure, it is clear that Synergy MAC outperforms 802.11b for stationary nodes.

The first experimental scenario consists of a single access point (AP) servicing variable number of end nodes in an infrastructure BSS. The AP is located right at the center of a rectangular area of dimensions 250m X 250m. All client nodes are mobile and are randomly uniformly distributed in this area. Nodes in the network move according to Random Waypoint or Random Walk mobility models in the grid.

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Characteristic	Coop MAC I	Coop MAC II	UTD MAC	Synergy MAC
IEEE 802.11b based	✓	✓	✓	✓
Backward compatible with legacy 802.11	X	✓	✓	✓
Employs three-way handshake	✓	X	X	✓
Relay node identified on the fly	X	X	X	✓
Avoids collisions during cooperation	✓	X	X	✓
Handles multi-rate fairness	✓	✓	X	✓

Table 2: Comparison of Different Cooperative MAC Protocols

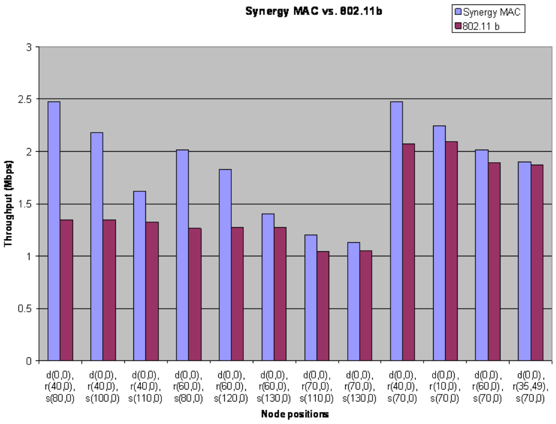

Figure 4: Synergy MAC Vs 802.11

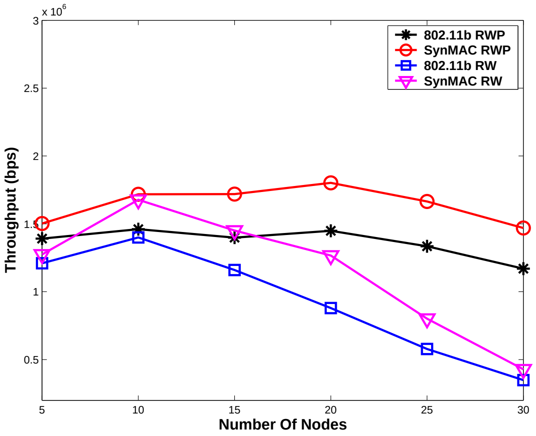

Figure 5: Throughput vs Number of Nodes

Random Walk mobility model was simulated using [21]. All nodes travel at speeds of 5 meters/second with a pause time of 1 second. At each node, data packets of length 1000 octets arrive at a rate of 500 packets per second to keep the network heavily loaded. The experiment sets the minimum contention window size (CW_{min}) to 31 slots and uses a maximum of 6 back off stages during retransmission. Nodes select their data rates based on the received SNR as described above.

Figure 5 shows the the saturated throughput achieved by both 802.11b and Synergy MAC protocols for different mobility models. Data points in the graph represents the average throughput derived from 20 simulation runs for varying number of nodes in the network. From the graph it is clear that the aggregate throughput achieved by both protocols is much less than maximum achievable throughput of 11Mbps. This is because not nodes are located within 48m of the AP to be able to use transmission rates of 11Mbps. Collisions and protocol overheads further reduce the achievable throughput. When compared to 802.11b however, Synergy MAC is able to achieve much higher throughput. This is because Synergy MAC allows nodes with low data rates to the AP utilize intermediate nodes as relays to achieve higher transmission rates. In doing so, the protocol also minimizes the effects of fading through spatial diversity.

Figure 5 also reveals that the throughput for 802.11b decreases with increase in the number of nodes on the network. This is mainly due to excessive collisions occurring on the shared channel. In case of Synergy MAC however, with

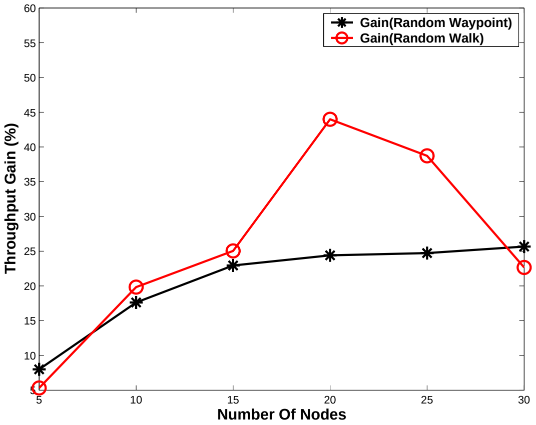

Figure 6: Throughput Gain vs Number of Nodes

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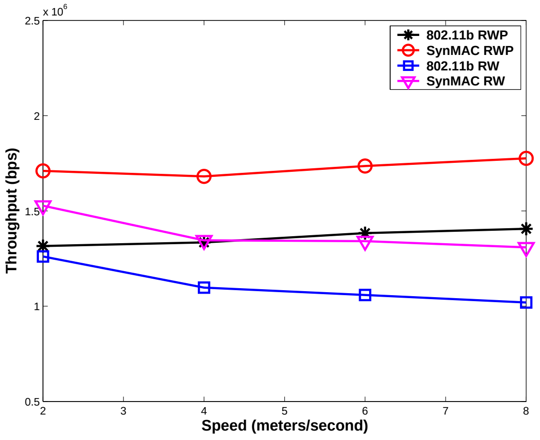

Figure 7: Throughput vs Node Speed

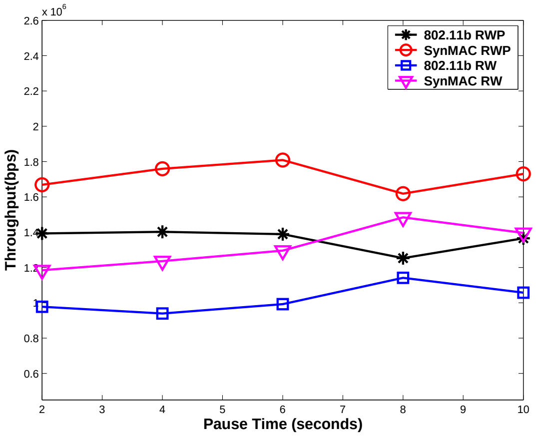

Figure 9: Throughput vs Pause Time

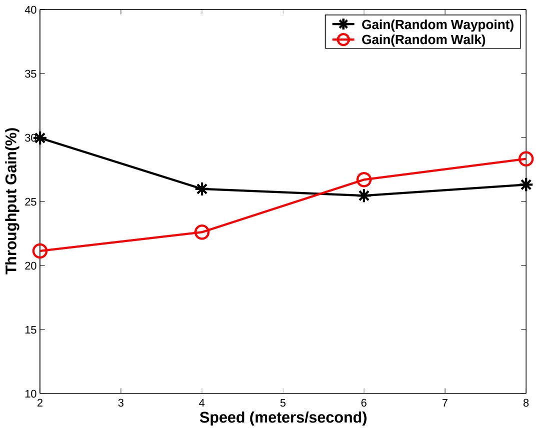

Figure 8: Throughput Gain vs Node Speed

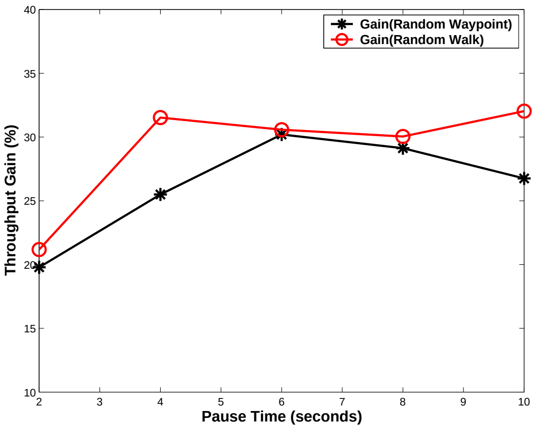

Figure 10: Throughput Gain vs Pause Time

more nodes in the network, there is a higher possibility for a node with low data rate to find an intermediate relay. This increased availability of relays not only offsets the degradation in performance caused by packet collisions but also leads to an increase in the overall throughput achieved by Synergy MAC. The relative gain in the throughput of Synergy MAC expressed as percentage versus number of nodes in the network is shown in Figure 6. From Figures 5 and 6, we see that Synergy MAC achieves better performance than 802.11b irrespective of the mobility model used.

The next experimental scenario tests the performance of Synergy MAC protocol when nodes travel at different speeds. The simulation setup is similar to the one described in the previous experiment with the exception that the number of mobile nodes within the network is fixed at 20. Also, the nodes pause for 5 seconds between successive movements.

Figure 7 shows the the saturated throughput achieved by both 802.11b and Synergy MAC protocols for this experimental scenario. Similar to the previous experiment, the data points in the graph represents the average throughput derived from 20 simulation runs for varying number of nodes in the network. From the graph we see that throughput achieved by both 802.11b and Synergy MAC almost remain constant at all speeds. From this we can infer that Synergy MAC is able to identify relay nodes even at higher node speeds. The relative gain of Synergy MAC's throughput when compared to 802.11b is in excess of 20% as shown in Figure 8.

The last experimental scenario tests the performance of Synergy MAC protocol when a fixed number of nodes traveling at constant speed pause for a variable interval between successive movements. The experimental setup consists of 20 nodes traveling at 5 meters per second.

Figure 9 shows the the saturated throughput for both 802.11b and Synergy MAC protocols. As before, results are averaged from 20 simulation runs. From the graph we see that throughput achieved by Synergy MAC almost remains constant for all pause intervals. However we see a small improvement in the performance of 802.11b indicating that the legacy protocol performs better when nodes are station-

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ary for longer periods. From Figure 10 we observe gains of almost 35% for larger pause intervals indicating that these values approach the performance of stationary nodes.

From all the experimental results, it is clear that Synergy MAC offers vastly improved performance gains when compared to IEEE 802.11b for different mobile scenarios.

7. CONCLUSIONS

In this paper, we analyzed the performance of Synergy MAC, a cooperative MAC protocol for WLAN based on 802.11b's DCF mechanism, for various mobility patterns. Synergy MAC protocol uses cooperation between wireless nodes to realize spatial diversity in order to combat the ill effects of signal fading. The protocol also addresses the multi-rate fairness issue in 802.11b by allowing nodes with low data rates to utilize an intermediate relay and transmit data at rates higher than otherwise possible. Simulation results show that Synergy MAC protocol outperforms standard 802.11b despite using the same PHY under various mobile scenarios. Synergy MAC is completely compatible with 802.11b and can be easily extended to suit other versions of the 802.11 standard.

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