Evaluating Effectiveness of DSDV Routing Protocol on IEEE 802.11n Wireless LANs

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Abstract— High-speed Wireless LANs based on 802.11 technologies are becoming increasingly ubiquitous. IEEE 802.11n is the last standard toward achieving higher speeds and aims to enhance 802.11 for higher throughput. Few works studied 802.11n medium access control (MAC) layer, but unfortunately, effects of higher physical rates is still unknown to the upper layers and especially routing layer of these networks. The main purpose of this paper is to assess efficiency of routing algorithms on IEEE 802.11n networks. We selected DSDV routing protocol, as one the popular algorithms, for this purpose. Based on various studies and simulations carried out, results indicate that increase in physical layer speed, does not necessarily lead to improving throughput and efficiency of the network layer. In addition, results indicate that 802.11n performs slightly better than 802.11 for large enough packet sizes; also we show the DSDV routing algorithm flaws when it work on 802.11n.

Index Terms— IEEE 802.11n, Routing Protocols, Routing Algorithms, High-Speed Wireless Networks.

I. INTRODUCTION

With increasing use of wireless networks, need to further improvement of these networks have been raised. Protocol IEEE 802.11n, a recently approved standard [1] and an amendment to IEEE 802.11 [3] for higher throughput, provides a desirable solution to high throughput and improving efficiency. Increasing physical rate and bandwidth in this protocol is less effective on improving efficiency of the routing layer although efficiency of the MAC layer increases to some extent. This means that if bandwidth increases an order of magnitude, the performance in the routing layer will not increase to this extent. The main issue in this article we investigate is the performance of routing algorithms on this network access mechanism.

An ad hoc network is a dynamically reconfigurable wireless network with no fixed wired infrastructure. Due to limited transmission range of wireless network nodes, multiple hops are usually required for a node to exchange information with other nodes of network. Therefore, routing protocols play an important role in ad hoc communications. These networks have quite a many constrains because of uncertainty of radio interface and its limitations, e.g., in available bandwidth. Also, some terminals have limitations concerning battery energy in use.

Due to a dynamic nature of ad hoc networks, traditional fixed network routing protocols are not viable. Based on that reason several proposals for routing protocols have been presented. All application areas have some features and requirements for protocols in common. The routing protocol overhead traffic is not allowed to drive the network to congestion. In addition, a local change in a link is not allowed to cause a massive control traffic storm throughout the network.

Destination Sequenced Distance Vector (DSDV) [20] is a table-driven routing protocol. Each node’s table contains all the network existing destinations, a next hop for every destination, and a metric that indicates the cost of the route. Also each destination has a sequence number, indicating how old a route is. When a route update with a higher sequence number is received, it replaces the old route. In case of different routes with the same sequence number, the route with the better metric is used. Updates have to be transmitted periodically or immediately when any significant topology change is detected.

Owing to significance of routing protocols in communications of an ad hoc network, in this paper, we investigate effectiveness of routing protocols on high-speed wireless ad hoc networks. We simulated various scenarios on IEEE 802.11n MAC which were executed on NS-2 [29].

Section 2 overview MAC operations of IEEE 802.11 and 802.11n. In Section 3, DSDV protocol is introduced. Section 4 reviews related works and in Section 5, we study performance of routing layer protocols using 802.11n MAC. Section 6 compares effects of the two MAC protocol IEEE 802.11 and IEEE 802.11n on routing layer and also, investigates efficiency of 802.11n in routing thoroughly. Simulation results are also shown in Section 6 and finally, Section 7 concludes the paper and states future works.

II. OVERVIEW OF IEEE 802.11

A. Legacy IEEE 802.11 MAC Operations

Distributed coordination function (DCF) is a distributed channel access mechanism based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). Optional Request To Send / Clear To Send (RTS/CTS) mechanism should be along with the CSMA/CA channel contention mechanism. The RTS/CTS operation is used to solve common wireless problems such as hidden node.

When a station has a data frame which is called MAC service data unit (MSDU) to transmit, MAC headers are added to form MPDUs. The station waits a fixed time interval called DCF inter-frame space (DIFS) before transmission. After MAC finds the channel idle, it enters a backoff procedure with a backoff timer, which is determined...
randomly by the contention window (CW). If the channel is still idle during and after the backoff procedure, the station wins contention and can immediately access the channel.

Each station that successfully receives the MSDU should send an acknowledgment (ACK) frame back to the sending station. A short inter-frame space (SIFS) waiting time is used before replying the ACK message. The whole transmission procedure ends when the sender successfully receives the ACK frame.

By looking into the procedure of a packet transmission, we note that DCF is inefficient in channel utilization. During the transmission procedure, transmission time is divided into a DIFS, a Contention Window backoff time, the PPDU transmission time, a SIFS, and the ACK frame transmission time. The PPDU transmission time can be further divided into two parts: 802.11 header and data payload transmission time. Other than the payload transmission portion is the overhead. The overhead of the DCF mechanism results in the inefficiency of the channel utilization, and thus limits the data throughput.

**B. IEEE 802.11n**

To satisfy the need of the high-speed wireless network access today, the major target of IEEE 802.11n, which is next generation WLAN standard under development, is to provide high throughput mechanism based on state-of-art design while allowing the coexistence of legacy 802.11 devices. To meet the requirements of “high throughput”, two possible methods can be applied. One is increasing the data rate in the physical layer (PHY layer), and the other is increasing the efficiency in the medium access layer (MAC layer). Based on the foundation of 802.11a/b/g/e, numerous new features in PHY and MAC layers are introduced to enhance the throughput of IEEE 802.11 WLAN.

To achieve high throughput in 802.11 wireless networks, the most commonly used method is to increase the raw data rate in the PHY layer. Legacy 802.11 PHY layer uses single-input single-output (SISO) system in 20 MHz bandwidth channel with one antenna. IEEE 802.11n expands the channel bandwidth to 40MHz to increase the channel capacity, and operates in OFDM scheme with the multi-input multi-output [3] (MIMO) technique. With this enhancement in the PHY layer, the peak PHY rate can be boosted up to 600 Mbps.

Aggregation mechanism is the key feature to improve the 802.11 MAC transmission efficiency. In IEEE 802.11n MAC, the aggregation mechanism is designed as two-level aggregation scheme. Two types of aggregation frame are defined: aggregate MAC protocol service unit (A-MSDU) and aggregate MAC protocol data unit (A-MPDU). The aggregation mechanism can function with A-MPDU, A-MSDU, or using both of them to form two-level aggregation. A-MSDU is composed with multiple MSDUs and is created when MSDUs are received by the MAC layer.

The block ACK mechanism is further enhanced in 802.11n large frames in high bit-error-rate (BER) wireless environment have a higher error probability and may need more retransmission. The network performance might be degraded. To overcome this drawback in aggregation, the block ACK mechanism in 802.11n is modified to support multiple MPDUs in an A-MPDU. When an A-MPDU from one station is received and errors are found in some of the aggregated MPDUs, the receiving node sends a block ACK only acknowledging those correct MPDUs. The sender only needs to retransmit those non-acknowledged MPDUs.

Reverse direction mechanism is a novel breakthrough to enhance the efficiency of transmission opportunity (TXOP). TXOP was originally proposed by [2] and defines a period of time for a station accessing the channel to transmit multiple data frames. During a TXOP period, the station can transmit multiple data frames without entering backoff procedure, which reduces the overhead due to contention and backoff and thus enhances the efficiency of channel utilization. Reverse direction mechanism allows the holder of TXOP to allocate the unused TXOP time to its receivers to enhance the channel utilization and performance of reverse direction traffic flows.

**III. OVERVIEW OF AD HOC ROUTING PROTOCOLS**

The Destination-sequenced Distance-Vector (DSDV) Routing Algorithm [20] is based on the idea of the classical Bellman-Ford Routing Algorithm with certain improvements.

Every mobile station maintains a routing table that lists all available destinations, the number of hops to reach the destination and the sequence number assigned by the destination node. The sequence number is used to distinguish stale routes from new ones and thus avoid the formation of loops.

The stations periodically transmit their routing tables to their immediate neighbors. A station also transmits its routing table if a significant change has occurred in its table from the last update sent. So, the update is both time-driven and event-driven.

The routing table updates can be sent in two ways: a “full dump” or an incremental update. A full dump sends the full routing table to the neighbors and could span many packets whereas an incremental update only those entries from the routing table that have a metric change since the last update and it must fit in a packet. If there is space in the incremental update packet then those entries may be included whose sequence number has changed. When the network is relatively stable, incremental updates are sent to avoid extra traffic and full dump are relatively infrequent. In a fast-changing network, incremental packets can grow big so full dumps will be more frequent.

Each route update packet, in addition to the routing table information, also contains a unique sequence number assigned by the transmitter. The route labeled with the highest (i.e. most recent) sequence number is used. If two routes have the same sequence number then the route with the best metric (i.e. shortest route) is used. Based on the past history, the stations estimate the settling time of routes. The stations delay the transmission of a routing update by settling time so as to eliminate those updates that would occur if a better route were found very soon.

On-demand routing is one of the most popular routing approaches in ad hoc networks. Instead of periodically exchanging routing messages in proactive routing protocols which brings in excessive routing overhead [21] [22], on-demand routing algorithms discover routes only when a node needs to send data packet to a destination and does not have any route to it. Most of the existing on-demand routing protocols (for example, Dynamic Source Routing (DSR) and Ad hoc On-demand Distance Vector (AODV) build and rely on single path for each data session. Therefore, route recovery process is required after each route failure, which causes to lose transmitted data packets in such protocols.

Multipath routing allows the establishment of multiple paths between a single source and single destination node. It
is typically proposed in order to increase the reliability of data transmission (i.e., fault tolerance) or to provide load balancing [23], [24], [25], and [26]. Recently, some adaptive ad hoc routing protocols have been reported. For example, Associatively Based Routing (ABR) [27] which according to this algorithm, each node periodically transmits beaconing tickets to identify itself, and a stable link exists if a large amount of the tickets are received and accumulated at the receiving node. This protocol selects a shortest route path through stable links.

Another protocol that uses stability is Signal Stability-based Adaptive routing (SSA) [28], chooses the route if the receiving signal strengths of radio links along this route are larger than a threshold value; otherwise, the shortest path routing algorithm applies to find another route. However, since the correlation time between two receiving signals or tickets is short for MANET, these two protocols find stable links and routes from deterministic parameters without considering the variation of signal strengths and network topologies of mobile ad hoc networks.

IV. RELATED WORKS

Burst acknowledgement, e.g., [6] [8] [9] [12] and [13], and block acknowledgement, e.g., [1], [1] approaches have been proposed in the literature to improve efficiency of high-speed wireless networks. Burst ACK performs the backoff process discussed above once for a series of data packets and ACK frames. Moreover, Block ACK improves further by using a single ACK frame for multiple data frames, thus reducing the number of ACKs and SIFS. Aggregation schemes try to amortize the PHY header overhead across multiple packets. This is achieved by transmitting multiple data packets in a single large frame in the physical layer.

In [5] the authors present a theoretical model to evaluate the saturation throughput for the burst transmission and acknowledgment (BTA) scheme under error channel conditions in the ad-hoc mode show some advantages of BTA over the legacy MAC.

The author in [11] proposes two enhancement mechanisms to reduce the overhead, concatenation (CM) and piggyback (PM). The idea of a CM is to concatenate multiple frames into a single transmission. The idea of the PM is that a receiver station is allowed to piggyback a data frame to the sender station once the receiver station has a frame to send to the sender.

In the AFR scheme [4], multiple packets are aggregated into and transmitted in a single large frame. If errors occur during transmission, only the corrupted fragments of the frame are retransmitted. In this scheme, a new delimitation mechanism allows for higher throughput with less overhead compared to previous designs such as [11].

Since communications take a large amount of energy in these networks, efficient communication schemes are of significant importance to prolong the network life time. Hence, the notion of virtual backbone [14] whereby some of the network nodes are selected as communication points to access other nodes is exploited. A connected dominating set (CDS) can form an interesting virtual backbone. A CDS serves as a promising routing backbone.

Wu and Li proposed in [16] a distributed algorithm to construct CDS. Wu et al. in [18] also present an algorithm for power aware connected dominating set based on [17]. Acharya et al. in [19] present a power aware minimum CDS construction when introducing a concept of threshold energy level for dominating nodes based on [17]. Those algorithms have some energy demands, but do not consider the balance of energy consumption in the network. In [15], the authors propose a local reconstruction technique which is able to reconfigure the CDS locally in the presence of mobility and energy balancing without the need for reconstructing the whole CDS. The algorithm does not increase the approximation factor of the algorithm which has constructed the CDS.

As noted above, most of the works concentrate on improving IEEE 802.11 MAC inefficiency and performance of the routing layer has not been investigated in these networks works. Routing problem is more sensitive when the wireless network consists of mobile nodes. In this case, due to overheads of existing routing algorithms, network throughput is increased up to a limited amount. Therefore, achieving a high-speed network requires effective methods of routing.

V. EFFECTS OF IEEE 802.11N ON ROUTING LAYER

IEEE 802.11n protocol supports appropriate bandwidth and supplies suitable throughput for most of the applications in wireless communications. Unfortunately, because of its wireless infrastructure and resultant inherent problems, we cannot utilize the whole bandwidth efficiently in this protocol.

As stated above, preparing a reliable connection between source and destination in wireless network is difficult because of many problems such as bandwidth limitation, energy consumption, hidden terminal problem and etc; so for sending data we must have confident about the connections. There are many algorithms proposed for network routing and solving the above problems. Also, they use control packets to find stable routes.

During transmission of control packets, network bandwidth will be wasted and nodes cannot receive data packets. Moreover, higher priority of control packets may cause increasing delay in sending actual data packets; therefore, we lose bandwidth capacity.

Sending control packet is one of the principle steps in routing algorithms, so we cannot eliminate this part of algorithms. In addition, increasing bandwidth will not solve the problems and the performance will not be increased accordingly.

When the routing algorithm uses more control packets on 802.11n MAC due to node movements, route recovery or new path detection; the average efficiency of the 802.11n will be less than that of the IEEE 802.11. Results show that in 802.11n, the major part of the bandwidth will be lost.

In the next session, we show simulation results of DSDV routing protocol on MAC layers of 802.11 and 802.11n and discuss more regarding the characteristics of 802.11 which may affect routing protocols.

VI. SIMULATION RESULTS

After presenting a review on IEEE 802.11n, we show performance results of DSDV in IEEE 802.11n high-speed networks using NS-2 simulator. In the simulation, we modeled a network of 50 mobile hosts which are placed uniformly in a 1000*1000 m² area. Radio propagation range for each node is 225 meters. Each simulation scenario runs for 300 seconds of simulated time. Also we use other conventional parameters of NS-2 in our simulations. The IEEE 802.11n is used as the medium access control protocol and the routing protocol is DSDV. Result of each scenario is averaged over 10 different runs.
Improvement in the network utilization is computed by the following metrics which are used by [4]:

- **Throughput**: Throughput represents the maximum rate at which the MAC layer can forward packets from senders to receivers. Throughput is the rate achieved by the whole system rather than by a single station (STA). The value of this metric is equal to the total number of bits of data transmitted in the wireless channel over the transmission time.

- **Average delay**: This metric represents the average delay a packet experiences until it is successfully received.

- **Efficiency**: The value of this metric is equal to achieved throughput of a scenario over its channel physical rate. In other words, this value shows how much data is transmitted over the network. Consequently, transmitting more control packets, especially those of routing protocols, results in less efficiency.

- **Fairness**: To measure fairness for all the STAs, we use the Jain’s fairness index I. In particular, given n STAs in the system, Jain’s fairness index I is defined as:

\[
I = \frac{\left(\sum_{i=1}^{n} S_i\right)^2}{n \sum_{i=1}^{n} S_i^2}
\]  

(1)

Where \(n\) stands for the number of STAs and \(S_i\) stands for the throughput of STA \(i\). When every STA achieves exactly the same throughput, \(I\) equals to 1. If only one STA happens to dominate the channel entirely, \(I\) approaches \(1/n\).

A. **Comparing DSDV on 802.11 and 802.11n**

In this subsection, we compare performance results of two MAC protocols: 802.11 and 802.11n. As we know many network devices designed base on 802.11 protocols so we set the physical rates that both of 802.11 and 802.11n devices can support it. Since maximum physical rate of 802.11 is 54Mbps, in order to compare these two protocols, we set the maximum rate to 54Mbps in the following simulation scenarios.

In the following scenarios, size of data payload is 256 bytes and there are 20 nodes as receiver and 2 nodes as sender. In Figures 1, 2, 3, and 4, comparison results between 802.11 and 802.11n protocols are shown. In these scenarios, physical rate is variable; data packet size is 1024 bytes and packets aggregation size is 2KB for 802.11n. Traffic flows are CBR which generate UDP packets at constant rate.

Throughput and efficiency of these protocols are shown in Figures 1 and 2. These two figures indicate that with the above settings, there is no important difference between these two protocols. As physical rate increases, throughput is also increased. This result is obvious since the number of bytes transferred in the channel is more per unit of time.
As shown in Figures 1 and 2, throughput and efficiency of 802.11n, in comparison with those of 802.11, reach 16% increase and 7% decrease, respectively.

Figure 3 shows average delay experienced by packets. In the simulated condition, 802.11n causes more delay on transmitting packets. This figure implies that due to faster transmission speed, average delay is decreased while physical rate increases.

In Figure 4, fairness indices of network are drawn for two protocols. This figure indicates that 802.11 is fairer in accessing wireless channel. The results show near to 10% decrease in fairness.

Scenario of Figures 5 to 8 is similar to that of Figures 1 to 4, except that in these figures packet size is variable and physical rate is fixed to 54Mbps. The other simulation parameters are remained unchanged. Packet size is the length of UDP data chunks generated by CBR traffic generator. Different applications may have various packet sizes. As an instance, HDTV is one the requirements of high-speed wireless LAN protocols such as IEEE 802.11n [1]. It has a constant packet size of 1500 bytes, a sending rate of 19.2-24Mbps, and a 200ms peak delay requirement.

As Figure 5 indicates, increasing packet size improves throughput of 802.11. This is resulted from this condition that data length (MSDU) of and MPDU increases and therefore, protocol overhead is reduced. Increasing the size is more beneficial to especially 802.11. Protocol 802.11 uses an MPDU for each packet, thus, smaller data packets leads to smaller MPDUs and also, PPDU which causes less efficiency. Since 802.11n takes advantage of packet aggregation, each PPDU may contain several data packets concatenated together. As a result, throughput and also efficiency are improved using this protocol especially when packet size is small. For sizes greater than 1024B, there is no considerable difference between the two protocols although 802.11n operates slightly better.

Figures 7 and 8 show average delay and fairness of these protocols for various packet sizes. As indicated by Figure 7, Protocol 802.11n imposes more average delay on packets which is due to more frame sizes resulted from aggregation. In this situation, 802.11 treat better than 802.11n in term of delay.

Not only does 802.11 have lower delay than that of 802.11n, but it also provides more fairness for nodes. Since nodes may aggregate different size of data packets, the resultant frames are not necessarily of the same length. This may lead to unfairness of the protocol, as shown by the figure.
Results indicate that by increasing physical rate, wireless network throughput will not increase proportionally and thus a major part of the network bandwidth will be lost. Lack of efficiency, especially in high speeds, is resulted. As stated before, this problem occurs because of sending control packets in the network which dominate duration of transmitting data packets.

B. Evaluating DSDV in high physical rates

So far, in order to compare 802.11 and 802.11n in term of routing efficiency, we used physical rates up to 54Mbps. In this subsection, we only evaluate performance of routing algorithm DSDV on 802.11n for speeds upper than 54Mbps. The aforementioned metrics are also utilized to investigate the protocol.

Simulation scenario used in this part is the same as that of the previous part. The major difference is that physical rate and aggregation size are increased up to 648Mbps and 64KB, respectively.

Figure 9 shows achieved throughput for various aggregation sizes. As indicated by this figure, increasing aggregation size improves throughput especially for higher physical rates. As noted before, if physical rate increases, control packets dominate data packets and leads to lower throughput and losing efficiency. A compensation method is to aggregate more data and generate a larger frame. The figure implies that for higher physical rates, more packets should be aggregated to reach higher throughput values.

Efficiency of the protocol for various aggregation sizes is shown in Figure 10, the implication being that 802.11n performs less efficiently in higher speeds. Because of the protocol overhead, this result happens. Although increasing aggregation size assists in improving efficiency, a major reconsideration in the protocol is, however, required to achieve more efficiency in higher speeds. The current value is near to 40% for 648Mbps and this value will definitely degrade more as the number of nodes increases.

Fairness of the simulated scenario is shown in table 1. Fairness and delay are shown in table 1 that runs with different aggregation size. By increasing the bandwidth delay will be decrease and fairness will be increase.

<table>
<thead>
<tr>
<th>physical Rate (Mb/s)</th>
<th>Fairness (%)</th>
<th>Delay (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>54</td>
<td>80.85</td>
<td>0.7779</td>
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<tr>
<td>108</td>
<td>82.53</td>
<td>0.6363</td>
</tr>
<tr>
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<td>83.52</td>
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</table>

VIII. CONCLUSION

With increasing use of high-speed wireless networks, needs to further improvement of these networks have been raised. Although protocol 802.11n is suitable for broadband wireless applications, but due to the intrinsic overhead of the protocol, we cannot utilize bandwidth effectively in data transfer. This protocol is also backward compatible with it pervious protocol, IEEE 802.11, because of the extensive use of Wi-Fi tools all over the world.

Owing to importance of routing algorithms in ad hoc wireless communications, in this paper, we investigated performance of routing algorithms and in particular, DSDV, on IEEE 802.11n MAC. Results show that performance of 802.11n differed slightly from that of its predecessor, 802.11, for the same physical data rates although choosing appropriate packet size plays a significant role in the resultant performance.

Moreover, we performed specific simulations on higher physical data rates on 802.11n MAC. Results indicate that larger aggregation sizes should be chosen in order to improve throughput although efficiency degrades with increasing physical rate. Another consequence is that in general, using higher physical rates lead to lower average delay although delay variations is not small.

IEEE 802.11n not only causes variation in average delay, but it also has fairness lower than 0.9 in average, and also, fairness values vary which makes using QoS routing applications difficult.

ACKNOWLEDGMENTS

Our thanks to C. Wang and H. Wei, the authors of [10], for permitting us to use their NS-2 simulation source codes of IEEE 802.11n and also their help which allowed us to extend it for our purpose.
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