Performance Evaluation of Receiver Directed Transmission Protocol with a Single transceiver in MANETs

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Abstract—Utilising multiple channels can increase the wireless ad hoc network capacity. Receiver Directed Transmission protocol (RDT) is designed to provide multichannel access using a single radio interface. RDT introduces a clever approach to support channel assignment and negotiation without relying on a control channel or time synchronisation. Protocols based on the RDT scheme normally use an extra radio interface, dual home channel or time synchronisation to overcome the expected issues in RDT, such as, hidden terminal and deafness problems. This paper demonstrates that using RDT with a single channel and single home channel it is still possible to increase the network capacity. Additionally, the paper investigates the effect of node density, mobility and number of available channels on RDT performance. NS-2 simulator is used to evaluate the proposed scheme. Simulation results confirm that using multichannel RDT scheme can effectively increase the throughput, the packet delivery ratio and reduce the delay compared to single channel protocol.

Keywords- Receiver Direct Transmission, Multichannel wireless network, Single Transceiver, MAC protocol

I. INTRODUCTION

A Mobile Ad hoc Network (MANET) is a self-organising network with mobile nodes using multiple hops to communicate through radio links without relying on any fixed infrastructure. MANET suffers from limited resources in mobile nodes, such as power, processing capability and limited bandwidth, interference in wireless links which has a bad impact on network scalability. It is well known that the performance of MANET degrades significantly as the number of mobile hosts increases, due to higher degree of contentions and a greater number of collisions in the single shared channel. Utilising multiple frequency channels offers tremendous potential to improve the network capacity in MANET. Using multiple non-overlapping channels reduce the collision probability by splitting the shared medium to a group of independent shared mediums. This introduces the possibility of simultaneous transmission among adjacent nodes operating on to different channels. The IEEE 802.11 standard [1], provides multiple non-overlapping channels. For instance, IEEE 802.11b/a offer 3 and 12 non-overlapping channels respectively. IEEE 802.11 standard enable nodes to switch their channel from one channel to another with a negligible switching delay about (80 us)[2]. The paper consider studying a multichannel wireless ad hoc network equipped with a single half-duplex radio interface. In single half-duplex transceiver, nodes can listen to or transmit on only one channel at a time. Therefore, the Medium Access Control (MAC) protocol in a multichannel network needs to address two issues. The first issue is channel assignment, which coordinates which channel should be used by which hosts, and the second is the medium access, where the problem of contention and collision is resolved. Different approaches [3] have been studied and analysed for channel assignment in MANET. The paper [3] suggests that using the semi-dynamic channel assignment approach can utilise multiple channels and improve network capacity without requiring explicit channel negotiation. In a semi-dynamic channel assignment approach, a fixed channel assigned to either the sender or the receiver and the node can switch its interface to the selected channel to communicate with other nodes. A well-known scheme in this approach is the Receiver Directed Transmission (RDT) protocol [4] which is considered in this paper.

This paper aims to evaluate the performance of a multichannel RDT scheme with a single radio interface and without relying on a control channel or time synchronisation. Additionally, investigating the effect of node density, mobility and number of available channels on RDT performance. The performance is compared with the standard single channel IEEE MAC 802.11 protocol. The rest of the paper is organised as follows. In the next section, related protocols based on the RDT communication scheme are reviewed and analysed to provide a context for our work. Section III describes the process of Multichannel RDT protocol. Section IV outlines the simulation parameters and performance metrics and Section V presents the performance results. Finally, the conclusions and future work are presented in Section VI.

II. RELATED WORK

Designing channel assignment and negotiation mechanisms in a wireless multichannel network is vital to ensure that the transmitter and the receiver are using the same channel before communicating. Proposed protocols [5] [6], usually achieve this by either using a separate control radio/channel to perform channel negotiation, or require time synchronisation. However, RDT uses a clever approach to support channel assignment with no need for negotiation, control channel or
time synchronisation. In this section we review RDT protocol architecture and relevant protocols which use an RDT scheme as the main approach of communication. One of the earliest works to utilise multiple channels in a radio packet network was the Receiver Directed Transmission (RDT) protocol [4]. In RDT, every node is assumed to be equipped with a single half-duplex radio interface. In addition, every node is assigned or select a well-known quiescent channel for itself which always tune to when it is not transmitting. However, when the node has a packet to send to a node operating in a different channel, the transmitter will switch its interface to the destination quiescent channel, transmit the packet and then switches its interface back to its quiescent channel. The intermediate node will forward the packet until it reaches its destination. Shacham et al. [4], evaluated the proposed architecture theoretically using an analytical model only.

Maheshwari et al. [7] proposed xRDT protocol to address potential issues in RDT, namely, the multichannel hidden terminal and deafness problems. In xRDT protocol every node is equipped with two radio interfaces, one for data packets, while the other works as a busy tone to notify the potential transmitting nodes about the current state of the channel. Using the busy tone notifier interface was intended to address multichannel hidden terminal problem. Moreover, the receiver nodes in xRDT broadcast a DTC message (Data Transmission Complete) in order to wake up all backed off potential transmitting nodes, which aims to eliminate the deafness problem. However, xRDT protocol requires an extra radio interface to transmit and receive the busy tone, which is complex to engineer, with a high cost. Based on a single transceiver, Wang et al. [8], proposed D-RDT protocol to address the multichannel hidden terminal problem and the missing receiver problem existing in RDT. D-RDT adopts dual default channel switching mechanism. Each node keeps detecting in its default control channel. The transmitter node will switch its interface to the default control channel of the receiver and exchange control packets (RTS/CTS). Upon a successful exchange, the transmitter and the receiver will switch their interfaces to the default data channel of the receiver node and start transmitting data packets. Following a successful communication, both nodes will switch back to their default control channel and broadcast a DTC packet to notify the backed off potential transmitting nodes. The main idea of D-RDT protocol is to avoid collision between the control and data packet.

Whang et al. [9], proposed Receiver-centric MAC (ReMAC) protocol to utilise multiple channels by reducing unnecessary channel switching. The ReMAC protocol consists of a channel selection phase on the control channel and a data transmission phase on a data channel. In ReMAC, if the sender and receiver are on the control channel, then they will negotiate which channel to use to transmit data. On the other hand, if the receiver is not on the control channel, then the sender will perform receiver-centric channel switching, with the support of neighbours listening to the control channel. ReMAC enables the sender node to gather the channel information of its intended receiver asynchronously and with the aid of its neighbour, without requiring explicit channel negotiation. ReMAC used a dedicated control channel, hence, some of the available channels will not be used to exchange data packets. We demonstrate via extensive simulations that, using the RDT communication scheme can implement the multichannel network without requiring extra hardware or time synchronisation. Moreover, it can improve the network performance compared with a single channel protocol, with a lower cost of hardware and less complex engineering.

III. MULTICHANNEL RDT PROTOCOL

The Receiver Directed Transmission protocol (RDT) facilitates channel assignment and negotiation without using a control channel or time synchronisation. In RDT, each node is assigned a home channel to which the node is listening when not transmitting by using the following equation:

\[ H_{Ch} = N_{Id} \mod T_{Ch} \]

where \( H_{Ch} \) is node’s home channel, \( N_{Id} \) is node IP address and \( T_{Ch} \) is the total number of available channels in the network. Therefore, nodes will be clustered based on their home channels. The home channel for any node in the network can be calculated using the above equation (1). When node \( S \) has data to send to node \( D \), node \( S \) will calculate the destination’s home channel by equation (1) and tune to that channel for this transmission only. From neighbours in the destination home channel, the packet will be routed until it reaches its destination. Since the multichannel wireless network is aimed mainly at a highly dense network, it is more likely that every node will find at least one neighbour operating in every channel. The details of RDT protocol process are as follow:

**RDT-AODV:** A slight modification has been made to the AODV routing protocol [10] to support the multichannel RDT communication scheme (RDT-AODV) in order to find a route in the destination home channel: namely, a new field has been added to the control packets in AODV to help the MAC protocol to determine which channel to contend in. In RDT-AODV, the sender (node \( S \)) will calculate the destination home channel (node \( D \)) by equation (1) and broadcast the Route Request (RREQ) in this channel, as shown in Fig. 1. Then, the sender will back to its own home channel. The standard route discovery procedures in AODV will be carried out/retry in the destination node’s home channel until the RREQ reaches the destination node or an intermediate node with a fresh route to the destination.

The Route Reply (RREP) will then be generated from node \( D \) in the next hop node’s home channel (node \( A \)), as shown in Fig. 2. The packet will be sent in the next hop node’s home channel until it reaches node \( M \). This node will switch its channel to the next hop node’s home channel (node \( S \)) and transmit the packet. Upon receiving the RREP at node \( S \), the route will be set up and the source node will start generating data packets following the same mechanism. In RDT-AODV, only two channel switches, at the most, might occur during the route discovery process.

**RDT-MAC:** Modifications have been made to the standard IEEE MAC 802.11 DCF protocol (S-MAC) in NS-2 [11] to support the multichannel RDT mechanisms (RDT-MAC) and enable nodes to carry out the carrier sensing mechanisms in the destination node’s home channel. Apart from that, RDT-MAC deploys similar contention mechanisms to those in S-MAC, such as (RTS/CTS). Fig. 3 shows the processing flow of RDT-MAC protocol to access the medium and send data.
In RDT-MAC, every node listens to its home channel when idle. A transmitter, \( S \), switches its channel to receiver \( D \)'s home channel. Then it senses this channel. If the channel is found to be busy, the node will then use the contention mechanism similar to that of S-MAC, which is not described here, for brevity. When the channel sensed is idle, for the appropriate contention resolution, \( S \) and \( D \) will exchange RTS/CTS/DATA/ACK in \( D \)'s home channel. Absence of CTS/ACK signals to the transmitter that retransmission is necessary. The retransmission is tried after a backoff procedure, which is again similar to that in S-MAC. After a successful transmission, node \( S \) will switch back to its home channel, setting the contention window to the minimum value and selecting a random backoff. The same procedure will carried out for the next transmission.

![Fig. 1: Route Discovery process in RDT-AODV.](image1)

![Fig. 2: Working flow of RDT-MAC protocol.](image2)

### IV. Simulation parameters and performance metrics

We evaluated RDT-MAC and compared it with the S-MAC protocol, using the NS-2.35 simulator. In order to evaluate the performance of RDT-MAC under different conditions and environment, the simulation was performed for two scenarios, (static and dynamic networks). Table I, shows the simulation parameters which used for both protocols that compared. We followed the default common parameters in NS-2 for radio power and threshold levels. Source-destination pairs were selected randomly. Each data point in the figures is an average of 25 runs, with a randomly generated topology. Additionally, RDT-MAC simulated with different numbers of channels (3 and 6) to investigate the effect of the number of channels on RDT-MAC performance. In dynamic network scenarios, random way-point model were used, with a maximum speed of 10m/s and the pause time was 10s. In all cases, the 95% confidence interval was small compared with the values being reported.

<table>
<thead>
<tr>
<th>Number of nodes</th>
<th>75, 100, 150, 200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation area</td>
<td>500 m x 500 m</td>
</tr>
<tr>
<td>1000 m x 1000 m</td>
<td></td>
</tr>
<tr>
<td>Propagation model</td>
<td>Two-ray ground</td>
</tr>
<tr>
<td>Traffic type</td>
<td>CBR</td>
</tr>
<tr>
<td>Packet size</td>
<td>1000 bytes</td>
</tr>
<tr>
<td>Number of connections</td>
<td>Half number of nodes</td>
</tr>
<tr>
<td>generation rate</td>
<td>2 Packet/s</td>
</tr>
<tr>
<td>Simulation time</td>
<td>180 (sec)</td>
</tr>
</tbody>
</table>

![Fig. 3: Throughput in 500 * 500m area.](image3)

The following metrics were used to evaluate the network performance.

**Throughput**: is the number of data bits successfully delivered to the destination node (measured in Kbps).

**Packet delivery ratio (PDR)**: the ratio of data packets successfully received by the destination nodes to the number of data packets generated by the source nodes.

**End-to-End Delay (EED)**: is the average time between transmitting a data packet at the source node and its successful reception at the receiver node (measured in seconds).

### V. Performance Results

In RDT-MAC, each node listens to its home channel while in idle mode. This means the number of nodes listening to the same home channel would be the total number of nodes in the network divided by the number of available channels. In another words, if there are 50 nodes in the network and there are 3 available channels, then there would be about 16 nodes listening to the same home channel, which may affect the connectivity and network performance.

Figures 3 (a,b) depict the throughput in static and dynamic networks for S-MAC and RDT-MAC protocols with different node densities. RDT-MAC has better throughput than S-MAC protocol in static and dynamic networks, as the number of nodes increases. However, in the low node density in the dynamic network, S-MAC protocol performs better than RDT-MAC. This may due to the low connectivity in RDT-MAC, as fewer nodes are available in each channel. RDT-MAC protocol has better throughput at higher density at about 172% for 6 channels and at about 165% for 3 channels, compared with S-MAC. Regarding the impact of the number of available channels in RDT-MAC protocol, the throughput of RDT-MAC with 6 channels is superior to RDT-MAC with 3 channels as the number of nodes increases. This is due to the lower contention and fewer collisions in the medium with 6 channels than in the 3 channels network. Therefore, utilising RDT-MAC can significantly increase the network throughput, by increasing the possibility of concurrent transmission among adjacent nodes.
in RDT-MAC with 3 channels occurs, because more nodes will contend for the same medium and a higher degree of contentions and a greater number of collisions may occur. Generally, using multichannel RDT-MAC protocol will provide more than one medium for contention, which will reduce collisions and time to access the medium. Thus, end to end delay will be reduced.

VI. CONCLUSIONS AND FUTURE WORK

This paper has provided a performance evaluation of the multichannel RDT-MAC protocol in comparison with a single channel S-MAC protocol. RDT uses a clever approach to support channel assignment which does not require channel negotiation. We have demonstrated via an extensive simulation that using multichannel RDT-MAC protocol with a single radio and single home channel and without relying on a control channel or time synchronisation, it can still be possible to improve the network performance compared with the use of a single channel in a wireless network. We observed that RDT-MAC performed better in all aspects than the S-MAC protocol at medium and high node density. The results suggest node mobility has little effect on protocol performance. However, RDT-MAC performance is affected by the number of available channels and node density.

In our future work, a further enhancement to RDT-MAC protocol will be planned. For instance, in a sparse network, the problem of the absence of neighbour nodes listening to destination home channel requires further study.

REFERENCES