Performance Evaluation of Routing with Load-Balancing in Multi-Radio Wireless Mesh Networks

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Abstract

Wireless mesh networks (WMNs) face several challenges such as architectural design and network protocol design issues. The capacity of WMNs is very limited, such as the result in an available single-channel bandwidth system compared to a multi-channel system. Two problems affect the capacity of mesh networks; i.e. load balancing and interference. To support the mesh network infrastructure, it is necessary to balance the traffic load and reduce the interference. One important direction for improving the capacity of WMNs is to use multiple radio interfaces and multiple channels simultaneously. The proposed load balancing routing algorithm method provides the load balance for multi-radio mesh networks by using a good routing metric, which captures the differences in transmission rates, packet loss ratio, traffic load and intra/inter flow interferences. The simulation results of this study, which used the network simulation NS-2, showed the capacity improvement that helps distributing the traffic load for efficient resource utilization.

Keywords: Wireless Mesh Network, Routing Metric, Multi-radio, Multi-channel, Load Balancing

1. Introduction

Wireless mesh networks (WMNs) consist of mesh routers and mesh clients. Mesh routers form the backbone of WMNs, whereas mesh clients can be either stationary or mobile. They provide the network access for both mesh and conventional clients. Mesh routers, which provide connection to other networks such as the Internet, cellular networks, sensor networks, IEEE 802.11, etc., can be accomplished through the gateway and bridge functions in the mesh routers. The nodes of mesh routers are designed to provide the mesh clients with the access to the Internet, as shown in Figure 1. [1], [2],[3],[27],[30].

Conversely, capacity limitation is one of the most important issues in wireless mesh networks. The concept of capacity indicates the amount of data links or network paths that can deliver packets per unit of time. According to (Tehuang Liu et al. 2006), the capacity of a link is defined as the number of packets that can be transmitted over the link during a limited period of time. On the other hand, (Prasad et al. 2003) defined the capacity of a hop as the bit rate. In other words, the capacity of a path is defined as the capacity of an end-to-end path, which is the maximum packet rate that can be transferred from a source to its destination [15], [17],[18].

Enhancing the capacity in the wireless mesh networks can be alleviated by equipping the mesh routers with multiple radio interfaces tuned to non-overlapping channels. Each node uses one interface channel to communicate with other nodes and channel interface tray to choose one channel to control and the other for the radio data channel network. However, the channel assignment of the algorithm conception needs to support higher traffic load by choosing the links that are given higher capacity than other links among the number of nodes [7], [19], [20].
The mesh backbone network must be designed to support the high capacity and speed over all links of mesh networks in order to guarantee the minimal congestion in them. Following this, there are two main techniques that can be employed in order to improve the wireless capacity: (I) If the data rate of the wireless channel is increased, this technique can be improved by applying better modulations, multi-antenna techniques and better Medium Access Control (MAC) protocol. (II) The capacity of a WMN can be improved if non-overlapping wireless channels are used simultaneously.

A multi-radio mesh network requires a multi-channel assignment and a routing scheme. The multi-channel assignment scheme can choose the best channel with the lowest load among the non-overlapped channels to a specific radio interface at each node among the link paths. This helps to reduce the intra-flow and inter-flow interferences. Meanwhile, the routing scheme requires efficient, high-capacity routes to be computed between the source-destination pair of nodes [16], [21], [22],[23]. The goal of a channel assignment in a multi-channel WMN is to bind each network interface to a radio
channel. This is done by using a path that will help transport a common channel available bandwidth on each link to balance the load and to reduce the interference by minimizing the number of neighbors interfering the various multi-channel assignment methods that have already been proposed [9], [22], [23], [24], [25].

In a wireless mesh network (WMN), the capacity is reduced by the interference from the simultaneous wireless transmissions and the balancing load. Two types of interference affect the throughput of the multi-hop wireless networks: the intra-flow interference exists between the adjacent nodes on the same routing path, whereas the inter-flow interference is caused by the neighboring nodes on the other path [1], [28], [31]. To provide the backbone support, it is necessary to reduce the interference and the balancing load in the wireless mesh networks. Hence, (Anh-Ngoc LE et al.2009) designed and implemented the load-balancing routing (LBM) that can support the routing protocols in order to decrease the interference and balance the load in the wireless mesh networks (WMNs), which was derived from the Ad hoc On-demand Distance Vector AODV-MR protocol [16].

Furthermore, this work also focused on the performance capacity issues and the techniques that were used to solve the problems of capacity issues such as inter-flow/intra-flow interferences and balancing load in the wireless mesh networks. The simulation results showed how the load balancing metric LBM algorithm can affect the metric routing protocols in achieving a good balancing load capacity over all mesh networks.

2. RELATED WORK

Routing protocols are the most important key element in a wireless mesh network. This is because, a routing protocol needs to find the best path in the network, whereby it captures the critical design features such as the end-to-end delay, throughput, bandwidth, etc. Therefore, a good routing metric should find the paths with the component links that have low loss ratio and high data rate, and experience low levels of interference. In recent year, there are increasing amount of related research [8], [9], [12]. There are many routing metrics proposed for the multi-hop wireless mesh networks as in [10], they are: Hop Count [2], [5], [10]. Expected Transmission Count (ETX) [2]. Expected Transmission Time (ETT) [13]. Per-hop Round Trip Time (RTT)[29]. Weighted Cumulative Expected Transmission Time (WCETT) [10],[11]. Metric of Interference and Channel Switching (MIC) [10].

Hop-count metric is the most commonly used in famous routing protocols such as: AODV [7], Dynamic Source Routing DSR [8], and Destination-Sequenced Distance-Vector Routing DSDV [14]. Address all links in the network with draw paths with minimum number of hops. Hop-count doesn’t consider to difference of transmission rate, packet loss ratio or interference. Therefore, hop-count results have low level of performance. The routing metric ETX which captures both the packet loss ratio, this metric is the summation of link in the length path. ETX does not consider for the data rate and which packets are transmitted or over which over each link. ETX does not capture the intra/ inter-flow. The routing metric ETT [16] improves ETX by capturing the data rate for each links. ETT is defined as the expected MAC layer for a successful transmission of a packet on a wireless link [1]. ETT impact the link capacity on the path to achieve better of performance. However, ETT does not fully capture the intra/ inter-flow interference in the network. ETX and ETT do not support multiple channels and they do not consider how link is busy.

Weighted Cumulative Expected Transmission Time (WCETT) [3] is proposed for multi-radio wireless mesh networks. WCETT enhances ETT by capturing the data rate that used in each link, the drawback limitation of the WCETT metric is that it does not capture inter-flow interference. However, final result of WCETT is in poor throughput because it finding routes in more congested areas. Metric of Interference and Channel Switching (MIC) [10] is designed as the routing metric for Load and Interference-Balanced Routing Algorithm (LIBRA) [13]. Routing metric MIC improves WCETT by scaling up the ETT , MIC captures inter-flow interference by the number of interfering neighbors, and the degree of interference caused by each node interfering is not the same. It depends on the signal strength of the interferer’s packet at the sender or the receiver [10]. The disadvantage of MIC metric is very complexity. For estimation of routing metric, it requires each the total number of nodes and the smallest value of ETT in wireless mesh networks [16]. Interference Aware routing metric (iAWARE)
This metric is proposed for multi-radio mesh networks. This metric captures loss ratio, differences in transmission rate such as inter and intra-flow interference that affects variation of link. The drawback of this metric is captures the interference from physical layer.

There are various load-balancing routing protocols that have been proposed, most of them only represent a single channel wireless network. Such as Dynamic Load-Aware Routing (DLAR) [13]. However, these metrics represent a single radio wireless network. Furthermore, many routing protocols have already been proposed for multi-radio mesh networks. R. Draves, J. Padhye and B. Zill, proposed Routing in Multi-Radio Link-Quality Source Routing (MR-LQSR) protocol to find the highest throughput paths based on WCETT routing protocol[10]. A. A. pirada, et al. They proposed a multi-radio extension to the Ad-hoc On-Demand Distance Vector Routing (AODV) protocol [4]. C. Perkins, et al. They proposed Ad-hoc On-Demand Distance Vector Routing (AODV-MR) [5]. However, all these protocols do not support load balancing, and packets can be routed through hot spots. Furthermore, a good routing metric needs to capture the load correctly to balance load in WMNs, also a good routing protocol needs to distribute traffic among mesh routers to avoid congested areas [1].

3. CHANNEL ASSIGNMENT PROBLEM

The capacity problem in the wireless mesh networks can be alleviated by equipping the mesh routers with multiple radios tuned to non-overlapping channels. However, channel assignment presents a challenge because the collocated wireless networks are likely to be tuned to the same channel. The resulting increase in the interference can adversely affect performance [19]. On the other hand, the multi-channel wireless mesh network (WMN) architecture equips each mesh node with multiple 802.11 interface cards. The objectives of this design issues are channel assignment and routing proposed [24], [30]. Moreover, the goal of channel assignment in a multi-channel WMN is to bind each network interface to a radio channel using the path to help transport the common channel available bandwidth on each link. This is to balance the load and to reduce the interference by minimizing the number of interfering neighbors [23]. Besides, the channel assignment algorithm protocol for multi-radio wireless mesh networks is used to address the interference problem and to propose the solution of intelligently assigned channels to radios in order to minimize the interference in the mesh network [25].

4. LOAD-BALANCING ROUTING PROTOCOL FOR MULTI-RADIO MESH NETWORKS (LBM)

The goal of the load balancing routing algorithm protocol is to enhance the route between all traffic and to avoid the bottleneck links over the mesh network. Having mentioned that, load balancing describes the ability of a router to transmit packets to a destination over more than one path. This means that the routers send the packet from the source to the destination over the first path, the second packet for the same destination over the second path, and so on. Furthermore, load balancing guarantees equal load across all links. However, there is potential that the packets may arrive out of order at the destination because differential delay may exist within the network [26]. Hence, load balancing determines the outgoing interface for each packet by looking up the route table and picking the least used interface. This ensures equal utilization of the links [5], [6].

5. PERFORMANCE EVALUATION

In this part, we considered the mesh networks, where each node was equipped with only one radio interface and all the radio interfaces were configured to the same channel. Meanwhile, in the second part of the evaluation, we considered the mesh networks, where each node had multiple radio interfaces that were configured to different channels. Since channel switching might reduce intra-flow interference, the ability to capture intra-flow interference affected the performance capacity of the routing metrics. The metrics that were compared in this part included WCETT, MIC and LARM.
The topologies of simulations were randomly generated. In the simulation of this study, all flows were destined to the Internet gateways and the sources of the flows were randomly located in the mesh network. All flows were CBR flows with 512 bytes of packets. The evaluation of all protocols was based on the performance of the system after the routing tables were stabilized. The transmission range was 250 m, and every node had two radios and each radio could be configured to one of the three channels. The study established using 1000 m × 1000 m wireless mesh networks, with 100 nodes generated randomly.

NS-2 simulation tool was used and three simulation scenarios were considered to evaluate the performance for WCETT, MIC and LARM metric protocols [32], [33]. The common parameters for all the simulations are listed in Table 1.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic type</td>
<td>CBR (UDP)</td>
</tr>
<tr>
<td>Packet size</td>
<td>512 bytes</td>
</tr>
<tr>
<td>Packet rate</td>
<td>4,8,12,16,20 packets/second</td>
</tr>
<tr>
<td>Buffer size</td>
<td>50 Packets</td>
</tr>
<tr>
<td>Number of node</td>
<td>100</td>
</tr>
<tr>
<td>Number of channels</td>
<td>1,2,3,4,5</td>
</tr>
<tr>
<td>Simulation range</td>
<td>250m</td>
</tr>
<tr>
<td>Simulation area</td>
<td>1000m×1000m</td>
</tr>
<tr>
<td>Simulation time</td>
<td>300s</td>
</tr>
</tbody>
</table>

6. SIMULATION RESULTS

The simulation experiments revealed various results of the different metric protocols (i.e WCETT, LARM and MIC). Every router was equipped with different radio channels and the packet rate was set up to four packets per second. The simulation was run with various numbers of radio channels on each router, and the packet rate was varied from 4 to 20 packets per second with the traffic load of 50 constant bit rate (CBR) with traffic User Datagram Protocol (UDP) flows. The simulation showed how the number of channels affected the capacity performance by increasing the number of channels.

![Figure 2. The number of radio interfaces](image)

As shown in Figure 2, the performance capacity load and reliability of the routing metrics were rapidly increasing with the number of radio channels on the mesh router.
When one channel radio interface was used on the mesh routers, it was revealed that the simulation results reflected the amount of one channel of data and showed how the LARM metric protocol style presented the packet delivery, as compared with WCETT and MIC in terms of percentage. In addition, when the mesh routers were equipped with multi-radio channels, the channel selection helped to balance the traffic if there were no non-overlapping channels.

![Figure 3. Simulation results with three-radio mesh router of varying traffic loads](image)

In this simulation, the varying packet rate as a metric was used. The packets ranged from 4 to 20 packets per second where the number of flows stated 50 and the simulation ran with multiple radio channels.

On the other hand, as shown in Figure 3, LARM metric protocol reduced the interference in the wireless mesh network as compared with MIC and WCETT. When the simulation was run with 20 packet/second, it revealed that the LARM metric protocol still gave the best rate compared with MIC and WCETT.

![Figure 4. Simulation results with varying numbers of flows](image)

Figure 4. Shows the percentage of packet delivery of the wireless mesh network. The results showed that the LARM metric protocol gave the best result compared to the WCETT and MIC metrics. For a single radio, LARM presented the highest percentage of packet delivery among all the mentioned networks, i.e. about 57% at 50 flows, compared with WCETT, i.e. about 45% at 50 flows and MIC, i.e. about 50% at 50 flows.
However, when the mesh routers were equipped with multiple radio interfaces, the traffic load was increased while the packet loss ratio was decreased. For the three-radio case, at 50 flows, LARM displayed the best result among all the selected routing metrics.

7. CONCLUSIONS

In this paper we presented the major problems in multi-radio infrastructure mesh networks and we presented the major solutions for solving the balance loading and inter-flow interference and intra-flow interference problems. Also, we described the requirements that routing metrics need to ensure the capacity of mesh networks. In addition, this study investigated the possible choices of routing protocols for mesh networks which capture the difference in transmission rates, packet loss ratio, intra-flow/inter-flow interferences and traffic load in multi-radio WMNs. These metrics were incorporated into a load-balancing routing protocol, which was used in this study to find the paths that are better in terms of balancing the load and reducing the inter-flow and intra-flow interferences in the multi-radio networks. Finally, the performance of these routing metrics was compared. It appeared that LARM displayed the best performance among all the selected mesh networks, i.e. WCETT and MIC routing metrics.

For future research, the development of new load balancing metric protocol is needed in order to enhance more router protocols in handling the problems of interference. Further investigation is also needed to identify the performance of all existing metrics in the real mesh networks based on actual hardware measurements. Finally, a study on how $\alpha$ affects the delay and throughput of flows overall load on the multi-radio mesh networks.

8. References