Expected Path Bandwidth-based Metric Routing Protocol in Wireless Mesh Networks

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***Abstract* — Wireless mesh networks (WMNs) are currently used to provide broadband access to the Internet anytime and anywhere. Many routing protocols have been proposed in the literature. The inter-flow and intra-flow interference in WMNs greatly affect the performance of the routing protocol. To solve this problem, Expected Path Bandwidth-based metric routing (EPBMR) protocol in Wireless Mesh Networks is proposed in this paper, which improves the performance of WMNs. EPBMR protocol uses a novel routing metric, which is a combination of intra-flow and inter-flow interferences, and bandwidth, to select best paths to transmit data. Simulation results show that the proposed EPBMR improves the network performance and outperforms existing routing schemes, which are based on Expected Transmission count (ETX), and Expected Transmission Time (ETT), more specifically, EPBMR yields 26% and 33% more throughput compared with ETX, ETT, respectively. Delay End-to-End of EPBMR is reduced by 25% and 35%, compared with ETX, ETT, respectively.**

Keywords - wireless mesh networks; routing protocol; collision domain; interference

I. INTRODUCTION

With the growing number of connected devices, Internet traffic is supposed to improve two to six times over the next three years. Therefore, in the next decade, it is estimated that even more Internet infrastructures will be used to support this in the Internet traffic[1-2]. So the cost of next-generation wireless networks is taken into consideration, which including the cost to cover large areas or crowed events. This makes a big challenges for wireless networks. The estimated cost is related to the cost of renting frequency bands and number of required base stations. Moreover, network reliability is another challenge, which is an important issue that is taken into consideration to guarantee systems can be to tolerate faults in case of disasters[3].

As internetworking of imparity wireless technologies representative, long-term evolution is one of promising technologies to develop next-generation wireless networks[4]. Based on 3G standard, long-term evolution can provide high transmission rate, e.g. on the downlink, its transmission rate range 100Mbps to 326.4Mbps. So,it is used to address high traffic demands since that it employ advanced technologies. However, it introduced additional cost since that it need to buy more frequency bands. Another promising wireless technology for next-generation of wireless networks is wireless mesh networks.

Wireless mesh networks(WMNs) have emerged as a promising technology for next-generation of wireless networks. The nodes of WMNs are divided into two types: mesh router(MRs) and gateways(GWs). The former construct the backbone network, and is responsible for relay traffic between clients and GWs. The latter provide Internet connection to the mesh network, typical architecture is shown as figure1. Generally, MRs only move a little, and it just like stationary routers. In Such network, it offers cost-effective ubiquitous wireless connection to the Internet in large areas.

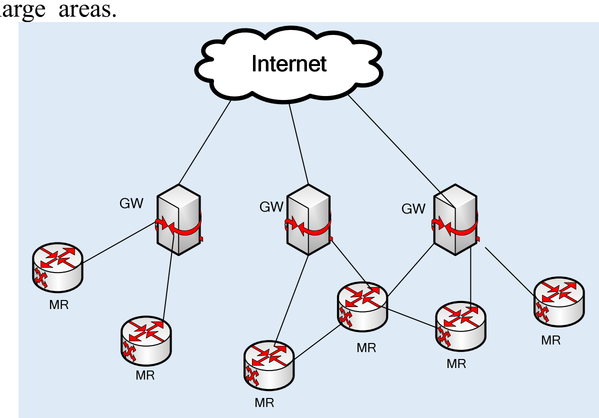

Figure.1 Typical architecture of WMNs

The performance of WMNs is deteriorated by Interference and data transmission congestion. To address the issue, Stine used directional antennas to ease interference [5]. Ja introduced the MIMO (Multiple-Input-Multiple-Output) to improve the performance of WMNs[6].Kyasanur suggest multi-channel/multi-radio solutions to reduce congestion[7].However, only single use of these technologies are not enough to improve network performance. The technologies should be combined with routing protocol to reduce inference and congestion, and meet applications requirements of WMNs.

Therefore, a novel routing metric WMNs routing is proposed in this paper. The proposed Expected Path Bandwidth-based metric routing (EPBMR) protocol has taken interference and bandwidth into consideration, which improve the routing performance and throughput of network.

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The remainder of this paper is organized as follows. Related work is highlighted In Section п. In Section ш, the proposed WMNs routing is decribed. The simulation and performance of the proposed routing is analyzed in Section IV. Finally, concluding remarks is offer in Section V.

II. RELATED WORK

In WMN routing protocol, selecting shortest path to GW based hop count is usually considered to be a metric that discovery routing. The hop count is equal to number of nodes between source and destination. However, the metric easily result in congested path[8]. So that, some quality-aware metrics is suggested by researchers, which reflect link quality characteristics. ETX (Expected Transmission Count) is considered to be widely metric. Couto firstly employ ETX to discovery routing [9]. At first, link quality based on periodically exchanged probe packets is computed. Afterwards, it uses the reverse delivery ratio d_r and the forward delivery ratio d_f to estimate the ETX of link, which is as follows:

$$\mathrm{ETX} = \frac{1}{d_f \times d_r} \tag{1}$$

Note that equation (1), bandwidth, packet size and interference are not taken into consideration in ETX. When it is only metric that make decision to discover routing, the performance is not well, which result in high transmission rate and a large packet size. Indeed, when interferences increase, packet losses increase, and consequently, ETX increases. In addition, another imperfection is the assumption of ETX, which refer to symmetric links [10]. However, in most cases, the links in network are not symmetric.

Moreover, ETT (Expected Transmission Time)[11] is proposed to conquer the imperfection of ETX. ETT has taken into account the packet size and the link bandwidth in calculating the metric. Nevertheless, ETT does not capture the interference, and not solve the asymmetry link problem. To improve ETT, yang et.alhas considered interference and channel switch as an alternative metric to ETT[12], which is defined for a path p :

$$\mathrm{MIC}(p) = \frac{1}{N \times \min(\mathrm{ETT})} \sum_{link\ l \in p} IRU_l + \sum_{node\ i \in p} CSC_i \tag{2}$$

Where, N is the number of nodes in the network. CSC represent the cost of switch channel. IRU reflect user interference, and its definition is as follow:

$$\mathrm{IRU}_l = \mathrm{ETT}_l \times N_l \tag{3}$$

Where N_l represent the number of neighbors on link l. Despite the MIC consider Interflow and Intra-flow interference, but there are still lacks of the following:1) Assume that all link is within the scope of the interference with the degree of interference;2) CSC only consider the interference between the two consecutive nodes;3) To calculate the complexity of the MIC increase with the increase of the number of network interface.

Similar to the MIC, Literature [13] has used signal-to-noise interference SINR and the interference ratio signal-to-noise ratio SNR to estimate the interference ratio. For link l between node u and node υ, interference ratio of node u is defined as :

$$\mathrm{IR}_l(u) = \frac{SINR_l(u)}{SNR_l(u)} \tag{4}$$

Thus the interference ratio of link $l(u,\upsilon)$ is defined as:

$$\mathrm{IR}_l(u,\upsilon) = \min\left(\mathrm{IR}_l(u), \mathrm{IR}_l(\upsilon)\right) \tag{5}$$

GW plays an important role in the access to the Internet. Before access, each node needs a GW, and establishes a communication channel. At present, there are mainly three kinds of ways to choose the GW, proactive, reactive and hybrid, respectively.

Literature [14] strategy adopted proactive type. GWs periodically broadcast messages, including latest cost information of GWs. When receiving message, forwarding node update the table of GW, and forward. This strategy can maintain the freshness of information, but once the network node number increase, easy to cause more interference and packet loss. Literature [15] adopts a reactive strategy to choice GW. When nodes need to transmit data, it generate requirement message, and broadcasted or unicasted to available area. This strategy is able to reduce interference ratio.

Literature [16] has combined proactive and reactive policy features, which is a hybrid strategy. path choice is made by the GWs load, and it aims to balance the load between the GWs. However, Only based on the load path of GW is not the best choice, in fact, in most cases within the WMNs, a GW load is low, and the other a GW interference and packet loss is high.

III. NETWORK MODEL AND PROBLEM STATEMENT

A. Network Model

We consider a multi-hop network, including two kind nodes, respectively MRs, and GWs. The network topology is represented by Graph $G = (R, E)$, Which R is the set of MRs, and E is the set of links. For any Interface in R set, we assign a different channel. For many nodes in R set , GWs provide access service for them. At some time, GWs load is dependent on length of the average interface queue[17].

B. Problem Statement

In WMNs, most flow traffic is to face to the Internet, and transmitted through the GWs. In this structure, MRs plays an intermediate node, and forward data to GWs. When there is a GW, routing is relatively simple. In the Case, each MR

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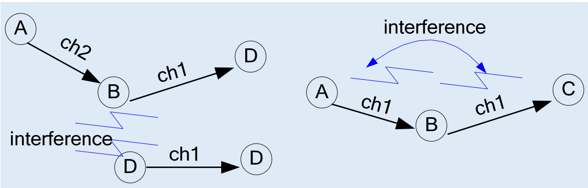
simply finds only the best path with connecting GW. However, GW is a bottleneck of the type network [18]. To solve the problem, it needs various GW. The network performance is improved by transferring data through multiple paths and different GWs. However, as the number of GWs increase, average network capacity may not be able to increase. In fact, network capacity is dependent on the network connection and the position of the GWs.

When there are multiple GWs, routing problem is not only searching for the best path, but also is the process of selecting the best GW. To select only GW or choose path only based routing metrics are not the optimal solution. Therefore, the following aspects are taken into consideration in designing the routing scheme: 1) how to define the metrics, and the path is chose by metrics;2) how to select the optimal GW.



(a) Interflow interference (b) Intra-flow interference

Figure.2 two typical interferences

The routing metrics should include the interference information. In WMNs, there are two type interferences: interflow interference and intra-flow interference, its definition is shown as figure2. Interflow interference happen when nodes that are in the interference range of each other simultaneously operate on the same channel. Intra-flow interferences occur when two or more successive links on the same path share the same channel. Figure.2 illustrates the two type interference. Figure.2(a) illustrates interflow interference and Figure.2(b) illustrates intra-flow interference. In Figure.2(a), node B and D use the same channels and transmit data toward C and E, respectively. In this case, node B and D causes interflow interference. In Figure.2(b), node A and B transmit data toward B and C, respectively. They are in the same path and use the same channel. In this case, this results in intra-flow interference.

IV. EXPECTED PATH BANDWIDTH-BASED ROUTING

A. Expected Path Bandwidth

In WMNs, the interflow interference and intra-flow interference, making discovering the maximum throughput is a challenging problem. As shown as Figure 3, Source S sent unidirectional toward destination node D from left to right. All links shares the same channel and compete channel access opportunities. In this case, it forms a collision domain. In the domain, only one link is sending data in anytime. Therefore, the throughput in collision domain is much less than bandwidth. According to reference [19], we have known:

$$BW_c = \left(\sum_{l \in c} \frac{1}{BW_l} \right)^{-1} \tag{6}$$

Where, l is a link in collision domain c. BW_l represents the bandwidth of link l.

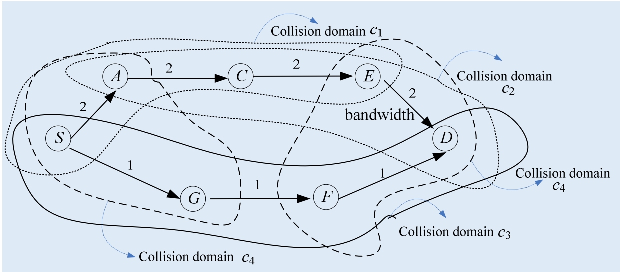


Figure.3 network example, collision domain $c_1 = (SA, AC, CE)$, $c_2 = (AC, CE, ED)$, $c_3 = (SG, GF, FD)$, $c_4 = (SA, SG)$,

For path P_i, its Expected path bandwidth (EPBW) is dependent on bottleneck of bandwidth in collision domain. On the other hand, expected path bandwidth of P_i is that the minimum value of BW_c, its definition is shown[20]:

$$EPBW(P_i) = \min_{c \in C_{P_i}} (BW_c) \tag{7}$$

Where, c_{P_i} is the set of collision domain for path P_i.

As shown as Figure 3, EPBW of path P_1 is the minimum of two collision domains:

$$EPBW(P_1) = \min(BW_{c_3}) = \left(\left(\frac{1}{1} + \frac{1}{1} + \frac{1}{1} \right)^{-1} \right) = \frac{1}{3} \tag{8}$$

For path P_2, its EPBW is that the minimum value of BW_{c_1} and BW_{c_2}, as shown as equation (9):

$$\begin{aligned} EPBW(P_2) &= \min(BW_{c_1}, BW_{c_2}) \\ &= \left(\left(\frac{1}{2} + \frac{1}{2} + \frac{1}{2} \right)^{-1}, \left(\frac{1}{2} + \frac{1}{2} + \frac{1}{2} \right)^{-1} \right) = \frac{2}{3} \end{aligned} \tag{9}$$

According to EPBW metric, performance of path P_2 outperform path P_1 .Finally, we define the EPBW of path between source S and destination D, it equate the maximum of bandwidth of all paths, as shown as equation (10):

$$EPBW(S, D) = \min_{P_i} = (EPBW_{P_i}) \tag{10}$$

Where, P_i is the effective path between two nodes.

B. Route Discovery

The proposed BBBB protocol discover route on demand in order to reduce the routing overheads. When Source S wants to send data toward destination D, it triggers the route discovery process. Source S broadcast routing request packet RREQ. Receiving the RREQ, neighbor nodes compute SNR of links, and calculate the EPBW of path. They continue to forward broadcast RREQ, until RREQ reach the destination node.

Each RREQ packet includes unique sequence number ID, EPBW between source node and current node, and path vector. Path vector include the address of node, the probability of free link P_{idle} , and neighbor list. Node computes and compares the EPBW of the packet when received the same ID of RREQ packet. Node discards the RREQ packet if the EPBW of packet is less than recorded EPBW. Otherwise, it updates the recorded information according to the information of last RREQ, and broadcast the RREQ packet. This procedure is repeated until RREQ packet reach destination node or is discarded. Once received RREQ packet, destination node compares EBPW with the same ID of RREQ packets, and selects the path with maximum EPBW. In waiting *T*, destination node has received many RREQ packets, and compared their EPBW, and then searched the bigger EPBW's RREQ packets. At last, the RREQ packet with largest EPBW construct the routing reply packet (RREP), which include the path vector and EPBW. Then destination node reply RREP packet toward source node along reverse path.

C. Route Maintenance

In route discovery process, node constructs the effective routing, and transmits data. Nevertheless, the throughput of current path may be fall, even disabled due to dynamic network character. At the same time, there has existed better path in network. Therefore, the path in network should update.

Detecting that the throughput of path is fall, destination node transmits TREQ (Triggering Request) message. Once receiving TREQ message, source node trigger new route discovery, and send UREQ (Update Routing Request) packet. The data is transmitted by the new routing if the larger EPBW path is searched.

D. Route Repair

There are two reasons resulting in route break: 1) backward routing information from destination node to source node is discarded; 2) the link is break in transmitting process.

When RREQ packet has reached destination node, destination node transmit RREP packet toward source, which include the path vector and EPBW information. In general, the link in WMNs is not symmetry. The throughput of reverse path from destination node to source node is not same with path from source node to destination node. But the reverse path is able to transmit data.

In transmitting data process, the failure node sends RRER (Routing Error) packet toward source node when the path has break. Once received RRER, source node rediscover router and search new path.

V. SIMULATION AND NUMBER ANALIYSIS

In order to better analyze the performance of BBBB protocol, NS-2 simulator is used. The simulation parameters are shown as Table 1. Each simulation is independently replicated 100 times, and average value of simulation data is consider to be final simulate data.

Table 1 Simulation Parameters

Parameters	Values
Simulation Time	100 s
Network Area	1000×1000
MAC layer	802.11b
Data rate	11Mbps
Frequency	9.14e+8
Traffic Type	CBR
Packet Size	1000 bytes

In addition, routing protocol based different metrics is selected and compared with the proposed BBBB protocol. Specifically, metric ETX and ETT are considered. The performance is evaluated in terms of the following: 1) throughput; 2) average end-to-end delay; 3) average packet loss ratio.

(1) average end-to-end delay

The variation in average end-to-end delay with the change in data rate is shown in Figure 4. From the plot, we know that as data rate increases, there is a general increasing trend of average end-to-end delay. In addition, the delay of routing protocol based EPBW metric is least. When data rate is 1500kb/s, the delay of routing protocol based EPBW metric is reduced by 52% and 46%, respectively, compared with ETX and ETT. When data rate is 3000kb/s, the delay of routing protocol based EPBW metric is reduced by 25% and 14%, respectively, compared with ETX and ETT. The reason is that routing protocol based EPBW can select the optimal path to transmit data packet, which greatly decrease the delay.

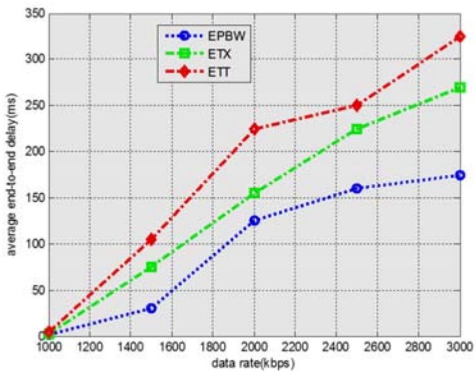


Figure.4 average end-to end delay versus data rate

(2) throughput

The variation in throughput with the change in data rate is shown in Figure 5. As known from Figure 5, the throughput of routing protocol based EPBW metric is highest. For example, when data rate is 3000kb/s, the throughput of routing protocol based EPBW metric is increased by 26% and 33%, respectively, compared with ETX and ETT . The reason is that: ETX and ETT have taken not interference into account, and they trend to select the intra-flow interference path. By contrast, EPBW metric can deal with the interference.

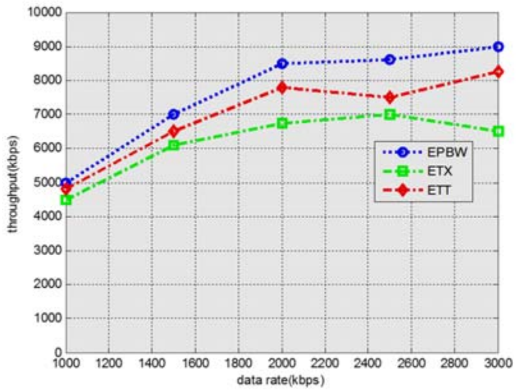


Figure.5 throughput versus data rate

(3) average packet loss ratio

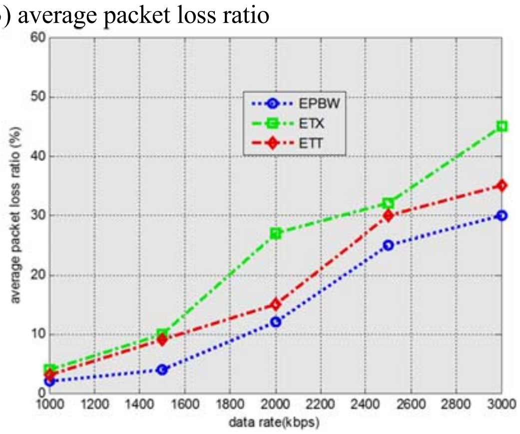


Figure.6 average packet loss ratio versus data rate

The variation in average packet loss ratio with the change in data rate is shown in Figure 6. As known from Figure 6, the average packet loss ratio of routing protocol based EPBW metric is lowest. Specifically, when data rate is 2500kb/s, the average packet loss ratio of routing protocol based EPBW metric is reduced by 25% and 35%, respectively, compared with ETX and ETT. In addition, from the figure, we see that as the data rate increases, the packet loss ratio increase. The reason is that the interference probability is improved by increasing data rate. It has result in losing lots of data packets.

VI. CONCLUSION

For the problem of routing in wireless mesh networks, we firstly has analyzed the shortcomings of existing routing, and we has proposed the Expected Path Bandwidth-based metric routing ((EPBMR)) protocol. Compared with traditional routing protocols, the proposed EPBMR protocol has taken intra-flow interference and inter-flow interference, bandwidth into account. The EPBMR metric maximize the network throughput. Finally, we implement the metric and protocol in NS-2. Simulation results show that the proposed routing protocol can adapt to the dynamics of the networks, and its throughput is improved, delay end-to-end is reduced.

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