Congestion Adaptive Routing in Wireless Mesh Networks

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Abstract **–The main reason for packet loss in Wireless Mesh Networks (WMNs) is due to congestion. Presently, routing in WMNs is not congestion-adaptive. Routing may let a congestion happen which is detected by congestion control. The way in which the congestion is handled results in longer delay and more packet loss and requires significant overhead if a new route is needed. Hence, we propose a congestion adaptive routing protocol (CARP) for WMNs with such properties. Our ns-2 simulation results confirm that CARP can successfully achieve a high packet delivery ratio with lower routing overhead and latency in WMNs.**

Keywords *- Wireless Mesh Networks, routing protocols, HWMP, congestion adaptivity.*

I. INTRODUCTION

A WMN is formed with the help of two distinct types of nodes i.e. Mesh Routers/Mesh Access Point (MAP) and Mesh Clients/Mesh Point (MP). The Mesh Routers, with multi-radio transceivers and access to external power sources, form the multi-hop wireless backhaul network. This network is used by the Mesh Clients to communicate among each other and also to gain access to an external network through a gateway. The Mesh Routers are generally static and act as general packet forwarders, while the Mesh Clients portray a disparate mobility pattern and only communicate through the Mesh Routers.

A Hybrid WMN is formed when, in addition to the Mesh Routers, the Mesh Clients also act as packet forwarders and assist in establishing the backhaul network [1] and [8]. Thus a Mesh Client in a Hybrid WMN episodically performs the role of a Mesh Router by executing a routing protocol. A Hybrid WMN is the most versatile form of autonomic network and depicts self-configuring, self-healing and self-optimizing characteristics. Owing to the peculiar characteristics of Hybrid WMNs, these networks are considered a promising technology for Public Safety and Disaster Recovery communications. A typical Hybrid WMN is shown in fig.1.

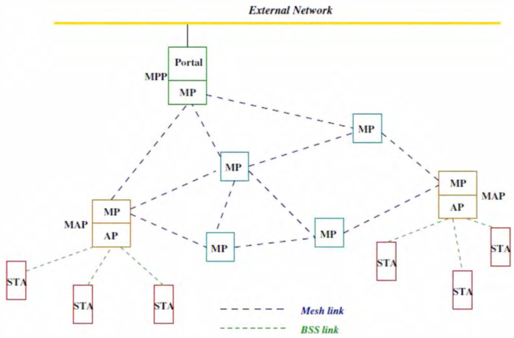

Fig.1. A typical Hybrid Wireless Mesh Network

Routing is an important problem in need of a solution that not only works well with a small network, but also sustains efficiency and scalability as the network gets expanded and the application data gets transmitted in larger volume. Though essential, routing in WMNs (e.g. [7], [9], and [15]) is a nontrivial matter. Routing protocols assure connectivity between the Client- Router and Router-Router pairs. A number of approaches have been proposed for providing communication support in WMNs. These approaches can be broadly categorised into three types i.e. Pro-active, Reactive and Hybrid.

In proactive protocols (e.g. [2]) routes between every two nodes are established in advance even though no transmission is in demand. This is realized by a node periodically updating its neighbors with the routing information it has known thus far, hoping that every node eventually has consistent and up-to-date global routing information for the entire network. This approach is not suitable for large networks because of the persistent overhead due to route management and the resulting limited scalability.

The reactive approach (e.g. [3]) is more efficient in that a route is discovered only when needed for a transmission and released when the transmission no longer takes place. The advantage of the reactive approach is the low routing overhead at the cost of increased route discovery latency.

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The hybrid (e.g. [4]) approach generally employs proactive routing in the static portion of the network and reactive routing in the mobile portion of the network. It is essential to clarify here that the proactive and reactive routing approaches are equally applicable to a hybrid WMN as is the hybrid routing approach.

There is another dimension for categorizing routing protocols: congestion-adaptive routing [5] versus congestion-unadaptive routing. The existing routing protocols belong to the second group. In this paper, we propose a new routing protocol for WMNs that belongs to the first group. We note that some of the existing protocols for WMNs are congestion-aware e.g. HWMP, but they are not congestion-adaptive. In congestion-aware routing techniques (e.g. [11], and [14]) congestion is taken into consideration only when establishing a new route which remains the same until mobility or failure results in disconnection. In congestion-adaptive routing, the route is adaptively changeable based on the congestion status of the network.

The congestion unawareness in routing in WMNs may lead to the following issues.

A. Maximum delay to find a new route:

Traditional routing protocol takes maximum time for congestion to be detected by the congestion control mechanism. In severe congestion situations, it may be better to use a new route. The problem with an on-demand routing protocol is the delay it takes to search for the new route.

B. Huge routing overhead:

In case a new route is needed, it takes processing and communication efforts to discover it. If multipath routing is used, though an alternate route is readily found, it takes efforts to maintain multiple paths.

C. Heavy packet loss:

Many packets may have already been lost by the time congestion is detected. A typical congestion control solution will try to reduce the traffic load, either by decreasing the sending rate at the sender or dropping packets at the intermediate nodes or doing both. The consequence is a high packet loss rate or a small throughput at the receiver.

The above problems become more visible in large-scale transmission of traffic intensive data such as multimedia data, where congestion is more probable and the negative impact of packet loss on the service quality is more of significance reactive and proactive approaches. The mechanism of reactive and proactive is combined.

In this paper we present a routing protocol Congestion Adaptive Routing Protocol (CARP) for WMNs that permits establishment of high performance routes and tries to prevent congestion from occurrence in the first place and be adaptive when congestion occur. The protocol is a derivative of the well known HWMP routing protocol and, hence, inherits its core self-configuring and self healing properties. The protocol is very scalable and supports high mobility. The simulation results indicate a significant improvement over the HWMP in terms of packet delivery ratio, routing overhead and latency.

In rest of the paper, we first present the protocol details of CARP in Section II. Simulation environment and results are discussed in Section III. In Section IV, we discuss works related to routing in WMNs, followed by conclusions in Section V.

II. CONGESTION ADAPTIVE ROUTING PROTOCOL

The Congestion Adaptive Routing Protocol (CARP) is a variant of the standard HWMP protocol for hybrid WMNs with a congestion adaptive mechanism. We inherited some properties from [5] and introduced its preliminary concepts in [12]. In this paper, we present a complete design with more insight and an in-depth evaluation of CARP for WMNs. In order to explain the working of CARP we first briefly explain the standard HWMP protocol in this section.

HWMP is a mesh routing protocol that combines the flexibility of on-demand routing with proactive topology tree extensions. The combination of reactive and proactive elements of HWMP enables optimal and efficient path selection in a wide variety of mesh networks (with or without infrastructure).

The on-demand mode is the default function mode, it is very similar to the one used in the wireless ad-hoc network (like wireless sensor network) ad-hoc on-demand distance vector (AODV) [3]. The second mode, proactive, is used when the wireless network has one or more portal node (MPP) configured. This node, called the root, sends announcement packets periodically in order to inform its neighbors about its a live status. This mode uses the same functions of the Distance Vector Tree Based (DVTB) protocol. The protocol specifies four kinds of packets: Root announcement (RANN), Root Request (RREQ), Root Replay (RREP), and Root Error (RERR). All the packets, except the RERR, carry three vitals information: *Destination sequence number* (DSN), *Time to live* (TTL), *Metric*. The two firsts information are used to avoid loops inside the WMNs. The Metric is used to find the best alternative path to the destination on the top of the one computed based on the number of hops (Hop Counter).

In both modes of the protocol, the packets RERR are used to indicate the unavailability of the path crossing an MP which loss the connection with its neighbors. The figure 2 shows all the functions mode of HWMP.

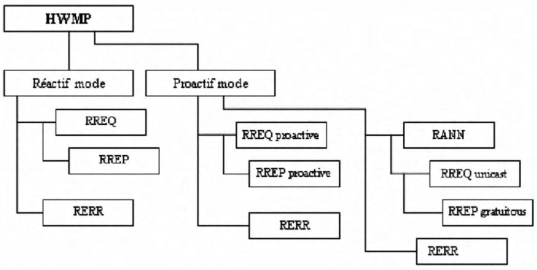

Fig. 2: Functions Mode of HWMP and Information Elements used.

In CARP, every node appearing on a route warns its previous node when prone to be congested. The previous node uses a "bypass" route for bypassing the potential congestion area to the first non-congested node on the primary route. Traffic is split over these two routes, primary and bypass, thus effectively lessening the chance of congestion occurrence. CARP is hybrid working like HWMP with congestion adaptive mechanism that is described below.

Step1. Every node or MP Check the occupancy of link layer buffer periodically. Let S, be the congestion status estimated.

Step2. Compute congestion status S in percentage

$$S=\frac{\text{Number of packet buffered in Buffer}}{\text{Buffer Size}}$$

Set the congestion status of node in three state
Green: when 0<= S <= 50,
Yellow: when 51<= S <= 75,
Red: when 76<= S<=100

Step3. Sender discovers the primary route to the receiver by a standard way [4] using RREQ and RREP as we discussed earlier. Each node has two routing tables one is PTABLE for primary route information and other one BTABLE for bypass route information.

Step4. Generating UDT (update) packet that contains the node's congestion status and a set of tuples [destination R, next green node G, distance to green node m], each for a destination appearing in the primary routing table, and will periodically broadcasts with TTL =1.

Step5. When a node N receives a UDT packet from its next primary node Nnext regarding destination R, N will be aware of the congestion status of Nnext and learn that the next green node of N is G, which is m hops away on the primary route. This information is crucial in case a bypass is needed.

Step6. Node N will check the congestion status of Nnext, if it is yellow or red then N will start find out a bypass route toward node G -the next green node of N known from the UDT packet. For this purpose, we are using new CARP packets BREQ (bypass route request) and BREP (bypass route reply). N will broadcasts a BREQ packet destined for G. This path is the bypass route that N will use. Since the distance to G should be short, the BREQ is set with TTL = 2*m to limit broadcast traffic. (Here, m is the distance from N to G on the primary route).

Step7. When the next primary node of N first becomes red, incoming packets will follow primary link of N with a probability p lets say 0.5 and follow bypass link of N with an equal chance (1-p=0.5). Hence, this traffic splitting effectively reduces the congestion status at the next primary node.

Step8. To adapt with congestion due to network dynamics, the probability p is modified periodically based on the congestion status of the next primary node and the bypass route. The basic idea is that we should increase the amount of traffic on the primary link if the primary link leads to a less congested node and reduce otherwise.

The Fig. 3 shows all the functions mode of CARP.

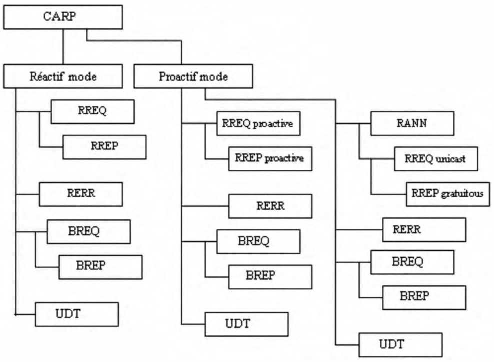

Fig. 3: Functions Mode of CARP and Information Elements used.

III. SIMULATION RESULTS AND ANALYSIS

We implemented CARP using the Network Simulator NS-2 version 2.33 [10]. We compared CARP's performance to that of HWMP, the most popular WMNs routing protocols. We present our observations in this section.

A. Simulation Environment

A WMN is established using 9 static Mesh Routers, which are distributed in a uniform 3x3 grid and each equipped with single 802.11b radios. The network further consists of 41 mobile Mesh Clients, each equipped with a single radio and placed randomly in the simulation area. Concurrent UDP flows are established between 20 randomly selected source and destination Mesh Client pairs. The performance metrics are obtained by averaging the results from over 10 simulation runs. The simulation parameters are listed in Table I.

TABLE I
TABLE 1: SIMULATION PARAMETERS

Examined Protocol	CARP and HWMP
Simulation time	900 seconds
Simulation area	1000 x 1000 m
Propagation Model	Two-ray Ground Reflection
Mobility model for Mesh Clients	Random waypoint
Speed of Mesh Clients	0, 10, 20,30, & 40 m/s
Transmission range	250 m
Traffic Type	CBR (UDP)
Packets size	512 Bytes
Max No. of Flows	20
Flow Rate	128 kbps

B. Performance Metrics

The simulations provide the following three performance metrics [6]:

Packet Delivery Ratio (PDR): Percentage of data packets received at the destinations out of the number of data packets generated by the CBR traffic sources.

End-to-End Delay: The accumulative delay in data packet delivery due to buffering of packets, new route discoveries, queuing delay, MAC-layer retransmission, and transmission and propagation delays.

Routing Packet Overhead: The ratio of control packets generated to successfully received data packets.

C. Results and Analysis

The simulation results under varying Mesh Client speeds are shown in Fig. 4, and results under varying number of connections in Fig.5. Nodes move continuously in this simulated network, where packets are lost or dropped not only because of congestion but also mobility.

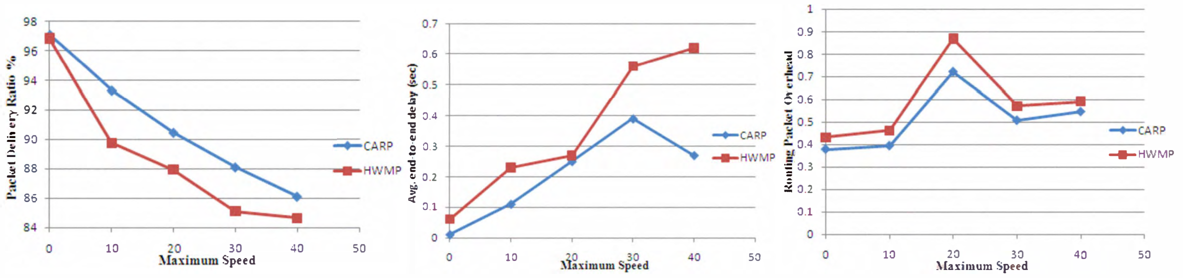

Fig 4. Simulation results under vaying maximum Speed

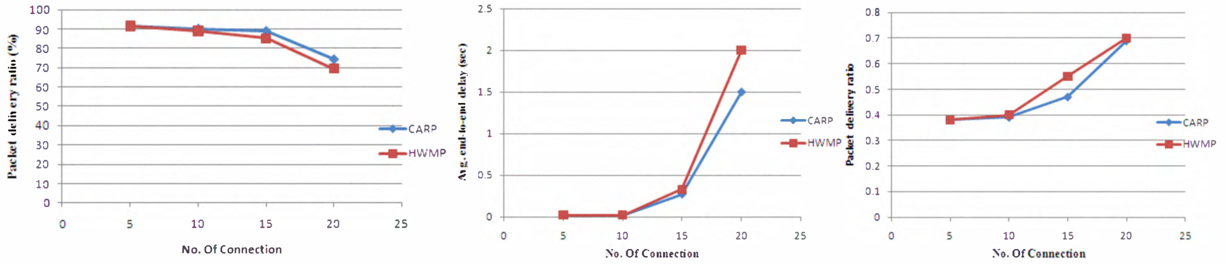

Fig 5. Simulation results under varying number of connection

Fig.4 PDR vs. Maximum Speed shows the lower packet losses incurred by CARP enable it to achieve a significantly higher PDR. The PDR of CARP drops from 97% to almost 86% when the maximum Mesh Client speed increases from 0 to 40 m/s. The PDR of HWMP drops from 96% to 84% for a similar increase in Mesh Client speeds.

In Fig.5 PDR vs. number of connection, we took varying number of flows in constant maximum Mesh Client speeds for showing effect of congestion. In heavy load, network suffered from congestion. In HWMP nodes are not aware of congestion status of their next nodes on primary path and keep on sending data packet via next node this increases packet drop. But CARP dealing with congestion using bypass mechanism as we discussed earlier. Hence, owing to its effective congestion adaptive routing, CARP always maintains higher PDR than HWMP PDR with increasing Mesh Client speeds.

In Fig.4 average End-to-End vs. Maximum Speed, CARP was better than HWMP when nodes were moving at a high rate (30 or 40 m/sec). For instance, when the Mesh Client speed was 30, the average delay of CARP was only 0.39 second around 70% of 0.57 second average delay of HWMP. The large delay is primarily due to congestion in the network.Fig.5 average End-to-End vs. number of connection shows CARP is better than HWMP when number of active flows is more.

In comparing their routing overheads, CARP was clearly better as shown in Fig.4. and Fig.5 CARP was more lightweight than HWMP in all scenarios. The reason is as follows: Upon link breakage, while HWMP tried to establish a new route to the destination by broadcasting a route request, CARP tried to make use of an available bypass. Therefore, route requests were sent less often in CARP, and resolving congestion by predicting its occurrence and adaptively distributing it over the primary and bypass paths was the reason why the routing overhead of CARP is less than HWMP.

IV. RELATED WORK

A number of routing protocols (e.g. [4], [13], [14] and [15]) have been developed for WMNs in recent years. All protocols use different routing metrics or modified routing mechanism for establishes optimal routes. Some people therefore proposed a modified version of AODV or HWMP which favors nodes with short queuing delays in adding into the route to the destination. While this modification may improve the route quality, the issues of long delay and high overhead when a new route needs to be discovered remain unsolved. Furthermore, these protocols are not congestion adaptive. They offer no remedy when an existing route becomes heavily congested.

V. CONCLUSIONS

A common problem observed in WMNs is the performance degradation over multiple wireless hops due to congestion. We have proposed CARP; a congestion-adaptive routing protocol for WMNs. CARP enjoys fewer packet losses than routing protocols that are not adaptive to congestion like HWMP. This is because CARP tries to prevent congestion from occurring in the first place, rather than dealing with it reactively. A key in CARP design is the bypass concept. If a node is aware of a potential congestion ahead, it finds a bypass that will be used in case the congestion actually occurs or is about to. Part of the incoming traffic will be sent on the bypass, making the traffic coming to the potentially congested node less. The congestion may be avoided as a result. Because a bypass is removed when the congestion is totally resolved, CARP does not incur heavy overhead due to maintaining bypass paths. Indeed, since CARP makes the network less congested, the queuing delay is less. Our ns-2-based simulation results indicate that the routing protocol CARP is able to achieve a significantly high packet delivery rate with low routing packet overhead and latency over HWMP in WMNs.

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