

A RSSI-Based Mesh Routing Protocol based IEEE 802.11p/WAVE for Smart Pole Networks

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Abstract— This paper proposes a RSSI-based routing protocol for smart pole mesh networks equipped with multiple IEEE 802.11p/WAVE radios. In the IEEE 802.11p based multi-radio multi-channel environments, the performance of traditional mesh routing protocols is severely degraded because of metric measurement overhead. The periodic probe messages for measuring the quality of each channel incurs a large overhead due to the channel switching delay. To solve such an overhead problem, we introduce a routing metric that estimates expected transmission time and proposes a light-weight channel allocation algorithm based on RSSI value only. We evaluate the performance of the proposed solution through simulation experiments with NS-3. Simulation results show that it can improve the network performance in terms of latency and throughput, compared to the legacy WCETT routing scheme.

Keywords— wireless mesh network, routing protocol, smart pole, RSSI, channel allocation, IEEE 802.11p, WAVE

I. INTRODUCTION

Intelligent Transportation System (ITS) helps us to make roads safe, capable of monitoring road conditions in real-time, and of preventing accidents. Vehicles and infrastructures are connected to share data and to collaborate with each other for improving road safety [1]. For example, a smart street pole equipped with not only light but various IoT sensors including a camera, and an artificial intelligence computing unit can predict accidents by collaborating with nearby vehicles and other smart poles [2]. To support a smart pole mesh system, a low latency wireless communication technology for Vehicle to Infrastructure (V2I) and Infrastructure to Infrastructure (I2I) is essential. IEEE 802.11p is the standard for a vehicular wireless network that provides medium access control (MAC) and physical layer (PHY) specifications to support Wireless Access in Vehicular Environments (WAVE) [3]. Wireless mesh network technology capable of operating in IEEE 802.11p/WAVE is required.

IEEE 802.11s is a standard for WLAN based wireless mesh networks [4]. The hybrid wireless mesh protocol (HWMP) is the default routing protocol for the IEEE 802.11s. To operate IEEE 802.11s-based HWMP protocol on the IEEE 802.11p/WAVE network, it is necessary to modify the

protocol by considering the IEEE 1609 operation such as multi-channel operation which is periodically alternating the control channel (CCH) and service channels (SCH). Also, the multi-radio operation should be considered for multi-hop communication in IEEE 802.11p/WAVE based mesh networks.

The Distance Vector (DV) and Air Link Metric (ALM) are used as some default metric values when the routing algorithm is selecting a multi-hop routing path in HWMP. These metrics have limitations in that the performance is rapidly decreased in a multi-radio multi-channel environment [5]. To overcome the limitation, Draves et.al proposed weighted cumulative expected transmission time (WCETT) to minimize the latency with interference-aware routing [6]. Liu et.al maximized the system throughput by distributing the traffic load [7]. These approaches have significantly improved system performance by maximizing the throughput while minimizing the end-to-end delay. However, when these metrics are applied over IEEE 802.11p/WAVE based smart pole mesh networks, there are some limitations. First, to calculate the metric, periodic probe messages should be exchanged for each channel, which incurs huge overhead due to the channel switching delay (e.g. 4ms in WAVE device). Second, it requires prior information that is difficult to know in the vehicular environment.

To overcome these limitations, we propose a RSSI-Based Mesh Routing Protocol (RBMRP) for multi-radio multi-channel IEEE 802.11p/WAVE based smart pole networks. In RBMRP, no probe messages are exchanged and only the received signal strength indication (RSSI) value is employed to maximize the throughput and minimize the end-to-end latency. Also, the RSSI-based multi-radio multi-channel management scheme allocates the channel in a disjoint manner.

The remainder paper is organized as follows. Section II describes the proposed routing protocol RBMRP more in detail. Section III presents our NS-3 based simulation environments and analysis of the performance results. We then conclude our work in Section IV.

II. PROPOSED SCHEME

In this section, we introduce the RSSI-Based mesh protocol(RBMRP) including a multi-radio multi-channel

management scheme and routing metric without exchanging probe messages. We first give an overview of the targeting mesh network environment and then describe the channel allocation algorithm and routing protocol details.

Before introducing the proposed scheme, we will describe our assumptions about the targeting environment. We use the 7 channels (i.e. one CCH and six SCHs) according to IEEE 1609.4 standard and two radio interfaces in our targeting environment. We manage the radio interface by setting one interface as the sending interface and another interface as the receiving interface to minimize channel switching overhead. While the assigned interface channel is being switched, the node cannot transmit or receive any data. The required time to change the channel for an interface is called the channel switching overhead. According to WAVE standard, the expected channel switching overhead is 4ms. If the channel is frequently switched during the SCH communication period, the network performance could be largely decreased. To minimize channel switching overhead, we set the channel of the receiving interface is fixed and the sending interface channel is switchable according to the receiving interface's channel before transmitting data. Based on the assumptions described above, we will describe the channel allocation algorithm and routing protocol in detail.

A. Channel Allocation

In wireless mesh networks (WMNs), an efficient channel allocation algorithm is essential to send multi-media data to multi-hop distanced destinations. If neighbor nodes transmit data using the same channel, the communication performance is rapidly decreased because packet retransmissions are often occurred due to transmission collision. In a multi-hop environment, if channels are not allocated efficiently, the communication capacity decreases by less than half as the hops in the path increase [8]. In a multi-radio system, a node can transmit and receive data at the same time by exploiting multiple radio interfaces. If the channel is allocated disjointly, the transmission collision problem would be minimized. So efficient channel allocation algorithm is highly desirable.

RBMRP utilizes RSSI information for channel allocation. When there is no packet destined for a node, the RSSI for each channel measured by the node is treated as noise. To minimize transmission collision, we use the RSSI to disjointly allocate the channel. For efficient channel allocation, a node proceeds channel scanning by collecting C-RSS (Cumulative Received Signal Strength) for each SCH channel (i.e. 1~6) to select the optimal receiving channel. C-RSS is calculated by cumulating the RSSI value that is measured periodically. Through the C-RSS value, a node can determine the degree of noise for each channel. When the channel scanning starts, the Receiving node switches the channel from SCH 1 to SCH 6, measuring the C-RSS for each channel. When the measurement is completed for all channels, the channel with the lowest C-RSS is allocated to the receiving channel. Channel allocation of other nodes is handled in the same way. However, if two adjacent nodes allocate a channel at the same time, both nodes will assign the same channel. To avoid this situation, the adjacent nodes should not allocate a channel at the same time,

and the node to which the channel is assigned generates noise to update the C-RSS value of the neighbor nodes until all neighbor nodes allocate the channel. Through this method, neighbor WAVE devices can allocate their channel efficiently and disjointly. Figure 1 describes the detailed algorithm of the channel allocation scheme.

Algorithm 1 Channel Allocation Algorithm

Require: Number of node N;
 rssMin : rss minimum Value;
 rssMinCH(n): rss minimum Channel of node n;
 rssV : RSS Value;
 rssVA : array of rssV;
 T : RSS Measure Time;
 SCH[ch] = { SCH1, SCH2, SCH3, SCH4, SCH5, SCH6 };

Ensure: Select a channel with a minimum Received Signal Strength as the receive channel

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1: for n = 1 ; n < N ; n ++ do
2:   rssMin = ∞;
3:   for ( ch = 0 ; ch < 6 ; ch ++ ) do
4:     Channel Start (SCH[ch]);
5:     rssV = 0;
6:     Receive a RSS in rssV during T;
7:     rssVA [ ch ] = rssV ;
8:     Channel Stop (SCH[ch]);
9:     if ch == 5 then
10:      for ( i = 0 ; i < 6 ; i ++ ) do
11:        if rssVA[i] < rssMin then
12:          rssMin = min ( rssVA[i] , rssMin );
13:          rssMinCH = i ;
14:        end if
15:      end for
16:      Channel Start rssMinCH(n)
17:      Generate Channel Noise
18:    end if
19:  end for
20:  if n == N then
21:    All stop making channel noise
22:  end if
23: end for
24: return;
```

Figure 1. The process of channel allocation algorithm of RBMRP

B. Routing Protocol

RBMRP is based on a hybrid wireless mesh protocol (HWMP) that is a default protocol of IEEE 802.11s standard [5]. RBMRP is designed by modifying the HWMP to suit for multi-channel and multi-radio environments. Thus, HWMP's control messages are employed to our protocol by modifying Hello, PREQ, and PREP messages. The Hello message is delivered to the sending interface during the CCH period, but it contains the receiving channel information. When a node transmits data to another node, it transmits the data after switching the channel of the sending interface to the channel

of the destination node's receiving interface that could be known through the Hello message. And a PREQ message is broadcasted including two metrics for uplink routing and downlink routing in a CCH interval.

RBMRP only uses RSSI value to calculate the routing metric. If a channel is indicating a high RSSI value, the channel is being used by other nodes for data communication. Each node can measure the RSSI of the channel without extra cost. Only the RSSI of the receiving channel is used in routing. This is because the sending channel is often switched to the receiving channel of the next destination node, but the receiving channel is fixed after channel allocation. Routing is divided into uplink routing and downlink routing. In uplink routing, the receiving channel RSSIs of all nodes except the source node is used for routing. In downlink routing, the receiving channel RSSIs of all nodes except the gateway is used for routing. At the destination of the route, the RSSI of each route is compared and the route with the lowest RSSI is selected.

In detail, each node scans SCH 1 through SCH 6 and allocates the channel with the lowest RSSI value as the receiving channel. To avoid overlapping of channels with nearby nodes, the node generates a noise through the selected receiving channel until channel allocation of other nodes is completed. The RSSI of the receiving channel is periodically updated. After that, control messages of RBMRP are transmitted in the CCH period. The information of the node including receiving channel information is delivered by a Hello message. And the route discovery to the gateway starts with PREQ due to RANN. When the PREQ is transmitted, each node adds RSSI of the receiving channel for downlink routing and uplink routing. The node received PREQ selects the downlink route to the best path with the least RSSI. When the gateway receives PREQ message, it compares the uplink metrics and transmits the PREP to the best path with the least RSSI. Like downlink routing, the node received PREP add the uplink route to the gateway. And through the Hello message, the RSSI of the neighbor node and the routing metric to the gateway is updated. If the updated routing metric exceeds the threshold, the node sends PERR and re-discover the route to the gateway. Figure 2 describes the flow chart of RBMRP.

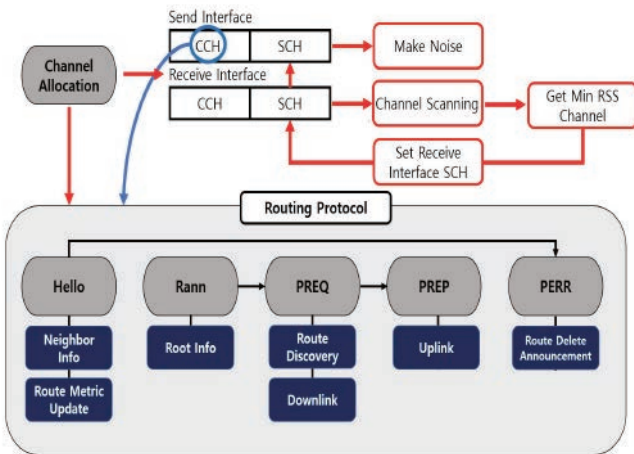


Figure 2. Flow chart of the RBMRP

III. PERFORMANCE EVALUATION

In this section, we carry out the simulation evaluation of our proposed scheme. We will explain the simulation environment and discuss the detailed simulation results. To evaluate the performance of RBMRP, we compare the performance of RBMRP and WCETT using the NS-3 simulator [9].

A. Simulation Setup

The detailed simulation setup is shown in Table 1. The simulation is conducted on a wireless mesh network environment consisting of 1 Gateway and 15 smart pole nodes in crossroads as depicted in Figure 3. Each node has 2 radio interfaces and 7 channels (1 CCH and 6 SCHs). Channel bandwidth is set to 10 MHz based on the WAVE default bandwidth. The data transmission rate is 27Mbps that is the maximum speed of WAVE. We set the transmission power to 25dBm and then the one-hop communication distance is about 50m. Smart pole mesh nodes are set to change in between CCH and SCH every 50ms according to the multi-channel operation of IEEE 1609.4. During the SCH interval, channels are allocated by the proposed channel allocation algorithm (i.e. RBMRP). Simulation time performed is 60 seconds.

We set the data traffic to 5Mbps of high-quality video data. 5Mbps data traffic is generated by sending 1300Bytes packets at every millisecond. Data traffic is transmitted only during the SCH interval, which is the latter 50ms of 100ms. However, since the application does not consider the channel state, the data packet is generated in both the CCH interval and SCH interval. So that the packets which are generated in the CCH interval are stored in the queue until the SCH interval. As the simulation starts, node 12 in Figure 3 transmits data traffic to the gateway node, and after 20 seconds node 10 transmits data traffic to the gateway. Node 10 stops transmitting data traffic at 50 seconds.

In the scenario, we consider WAVE nodes as smart poles and a root node as Gateway pole, which means a mesh node has streaming data needed to be processed, so it transmits the data to the GW in the uplink path.

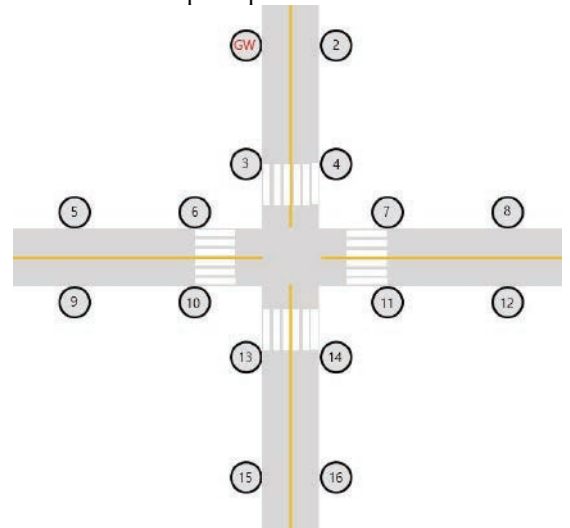


Figure 3. Simulation topology

Table 1. Ns-3 Simulation parameters setting

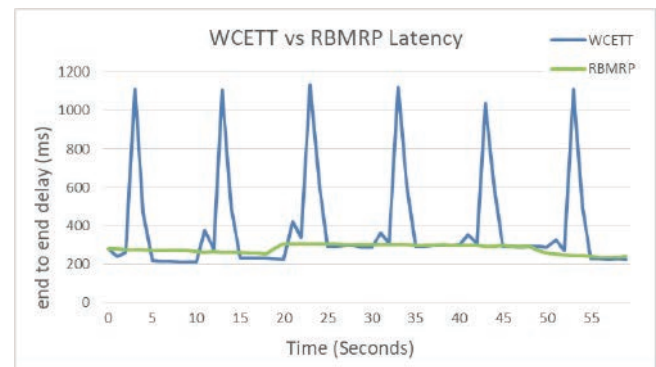
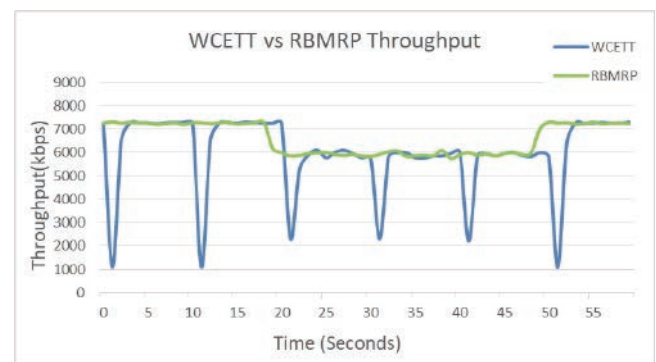
Parameter	Value
Numbers of nodes	Node 16, as seen in Fig 3
Numbers of radio interface and channel	2-interface, 7-channel (1 CCH, 6 SCH)
Channel bandwidth	10MHz
Transmission rate	27Mbps
Transmission power	25dBm
Communication range	50m
Multi-channel operation standard	IEEE1609.4
CCH to SCH interval ratio	50ms each
MAC/PHY standard	IEEE 802.11p
Propagation delay model	Constant speed propagation delay model
Propagation loss model	Log distance propagation loss model
Data Traffic	5Mbps High-quality video data.
Simulation time	60s

B. Simulation Results

Figure 4 shows the simulation result for measuring the latency (i.e. end-to-end delay) of the scenario by comparing WCETT and RBMRP. The transmission request occurs every 1ms. However, the data generated during the CCH period will be transmitted in bulk during the next SCH period because the traffic is transmitted in only the SCH period. Therefore, consider the increased latency in the graph. WCETT periodically measures all link quality to the path and updates routing metrics of the path to detect and respond to changes in the network. The way to measure the quality of a link is to exchange the probe message. However, in the multi-radio multi-channel environment, the node should transmit the probe message to existing all channels to measure the quality of all links. Then, when the probe message is transmitted by channel, channel switching overhead occurs. In our environment, 6 channel switching occurs at the time of one probe message exchange. For this reason, the latency of WCETT fluctuates periodically. By contrast, RBMRP also detects and responds to changes in the network by simply measuring RSSI. Measuring RSSI does not incur any extra cost. Therefore, RBMRP is superior to WCETT in terms of low latency.

Figure 5 shows the simulation result for measuring throughput by comparing WCETT and RBMRP. This result indicates that the throughput of RBMRP is higher than WCETT because the throughput of WCETT is rapidly decreased when the probe message is exchanged. In RBMRP, no traffic is transmitted while the probe message is being exchanged. WCETT is famous for its efficient path with low latency and high throughput. Then, RBMRP, which does not require a probe message, also shows better performance in the throughput part.

In terms of latency, however, it shows that RBMRP is more efficient than WCETT, which periodically generates probe messages. That means, RBMRP does not require an extra cost for metric measurements, but it can discover a path that has similar performance to WCETT with an overhead for metric measurements.

**Figure 4.** End-to-End Delay**Figure 5.** Throughput

IV. CONCLUSIONS AND FUTURE WORK

In this paper, we proposed RBMRP that uses RSSI that can be easily measured for channel management and routing metric. Simulation results show that the RBMRP improves the network performance without dissipating probe messages for channel management and path management in comparison with the legacy WCETT routing scheme.

For future works, we plan to propose the multipath version of RBMRP and to implement smart SDN using Deep Reinforcement Learning.

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