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Regional condition-aware hybrid routing protocol for hybrid wireless mesh network

Yuan Chai, Xiao-Jun Zeng*

School of Computer Science, University of Manchester, Manchester, United Kingdom, M13 9PL

Abstract

A proper routing protocol can improve the performance of whole network dramatically. Due to the character of hybrid wireless mesh network, hybrid routing protocol combining both proactive and reactive routing protocols suits hybrid wireless mesh network well. However, existing research of hybrid routing protocol is quite few, and mesh routers may be used unreasonably during the process of mesh clients accessing mesh routers. Besides, the condition of whole path and regional condition of mesh nodes is neglected. This paper proposes a regional condition-aware hybrid routing protocol (RCA-HRP). In RCA-HRP, regional conditions of mesh routers and mesh clients are considered respectively. Furthermore, the state of whole proactive path is taken into account to make the access process more effective, and gateway- and client-oriented traffic is taken into consideration comprehensively. The simulation results by ns-3 show the strengths of RCA-HRP in terms of average throughput, latency, and packet loss rate.

Keywords: Hybrid wireless mesh network, Hybrid routing protocol, Gateway-oriented traffic, Client-oriented traffic

*Corresponding author

E-mail address: yuan.chai-2@postgrad.manchester.ac.uk (Y. Chai), x.zeng@manchester.ac.uk (X. Zeng).

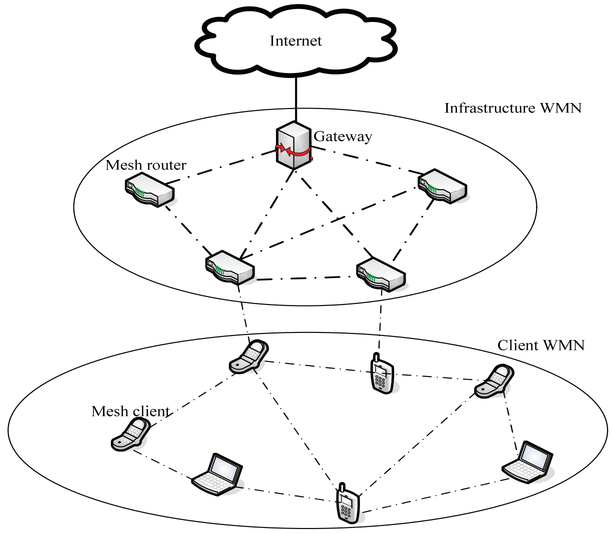


Figure 1: Network architecture of hybrid WMN

1. Introduction

As homogeneous wireless networks have poor performance and scalability, the research of heterogeneous networks has attracted the attention of researchers during the recent years [1]. Some researches have studied the related wireless issues [2] [3]. Hybrid wireless mesh network (WMN) is a kind of heterogeneous network, and it is flexible and extensible. Hybrid WMN is composed of two kinds of nodes, which are mesh routers and mesh clients [4]. Mesh routers are usually static with multiple radio interfaces. Infrastructure WMN is composed of mesh routers. Mesh clients are mobile and always only have one radio interface, constituting client WMN. Different from mesh routers, mesh clients have limited energy. Then, infrastructure WMN and client WMN form hybrid WMN. As mesh routers have multiple radio interfaces, the technology of Multi-Radio Multi-Channel (MRMC) can be used in hybrid WMN to extend network capacity [5]. The network architecture of hybrid WMN is shown in Figure 1.

There are two types of traffic in hybrid WMN. One is gateway-oriented traffic, and the other is client-oriented traffic. The gateway-oriented traffic means that the data flow is connected to the Internet. For instance, if a mesh client wants to send data to the Internet, it can access a mesh router first, and then connect the Internet through the gateway in infrastructure WMN. The data flow in client-oriented traffic is towards mesh client. The data packets can be conveyed to the destination mesh client by multiple hops.

Routing protocol provides an approach to find the route between source and destination. A proper routing protocol can improve the performance of whole network dramatically. In general, routing protocols can be categorized into three types: proactive routing protocol, reactive routing protocol and hybrid routing protocol [6]. In the proactive routing protocol, routes can be established before data packets are sent [7]. Some control packets are always used in the whole network to find and maintain routing, which may cause high cost in a mobile network. Thus, proactive routing protocol can work well in a static network. Reactive routing protocol only builds routes when data packets are conveyed in the network, which fits well for mobile network [8]. Hybrid routing protocol combines the features of both proactive and reactive routing protocols [9]. As there are both static and mobile nodes in hybrid WMN, hybrid routing protocol is ideal for hybrid WMN. However, existing hybrid routing protocols designed for hybrid WMN are quite few, and all of them neglect the condition of whole proactive path during the access process. Besides, for a mesh router or a mesh client, only its own condition is considered, and the situation of its neighbors is overlooked. To overcome these weaknesses, regional condition-aware hybrid routing protocol (RCA-HRP) is proposed in this paper. The main contributions are:

- Considering regional condition of mesh nodes, and setting weight values for mesh nodes by using the situation of neighbors. The weight values of mesh routers and mesh clients are set in different ways based on their different roles and features. For mesh routers, the load of themselves, the load and speed of neighboring mesh clients are considered. For mesh clients, the load of themselves and the number of neighboring mesh routers are taken into account. Further, not only considering the condition of a node itself, RCA-HRP also considers the situation of neighboring nodes. The obtained regional condition is then utilized and employed in the process of route discovery. As a consequence, the overall performance of a region and whole network can be improved.

- Taking both gateway- and client-oriented traffic into consideration, and processing them respectively. For the gateway-oriented traffic, during the process of mesh clients accessing mesh routers, the condition of the whole proactive path is considered, which is different from the existing hybrid routing protocols. The proactive path with a better condition will be used to convey packets. Only the access mesh router in this proactive path can send route reply (RREP) message. In client-oriented traffic, in addition to load and speed, the limited energy of mesh clients is also taken into account. The mesh nodes with a better regional condition will be selected.

Simulation results by ns-3 [10] show that the proposed RCA-HRP can help hybrid WMN achieve better performance in terms of average throughput, latency, and packet loss rate.

The rest of the paper is organized as follows. Section 2 introduces some related work about routing protocols designed for hybrid WMN. Section 3 presents the details of RCA-HRP. The simulation results and analyses are given in Section 4. Section 5 presents conclusions and future work.

2. Related works

There are only a few research results on routing protocols for hybrid WMN. These works concern a few different aspects, such as capacity [11], stability [12, 13], security [14, 15, 16, 17], and energy [18, 19]. Most of the research focuses only on reactive routing protocol. ALARM [20] uses time of emptying data queue to evaluate link condition during the process of route discovery. AODV-HM [12] makes use of the hop count of mesh clients as routing metric, choosing the route with least count of mesh clients. As mesh clients are mobile, AODV-HM can select a route with more stability. SafeMesh [21] selects links based on congestion and channel diversity. Multi-link discovery and node type-aware routing are used in SafeMesh. AODV-DF [22] reduces the number of route request (RREQ) packets and controls the flooding effectively. The occupancy of resources can be reduced, and heavy load caused by control packets is avoided. EPTR [23] considers expected throughput, interference and path length, which can maximum network throughput. EFMMRP [24] preserves network resource by using fuzzy logic. Delay, bandwidth and residual energy are considered in EFMMRP. NSR [25] takes network stability into account, and gateway selection and loop-free algorithm are proposed in NSR.

Reactive routing protocol cannot make full use of static mesh routers. Once some data packets need to be sent, static mesh routers also need to find routes to reach other mesh routers. High overhead may be caused in this case. In hybrid routing protocol, proactive routing protocol can help mesh routers transfer packets to gateway directly, and reactive routing protocol is just used for the route discovery between mesh clients. Therefore, hybrid routing protocol is more adaptive and could be more effective for hybrid WMN.

However, the existing researches of hybrid routing protocol for hybrid WMN are even less. HMesh [26] combines the proactive routing protocol OLSR [27] and reactive routing protocol AODV [28]. OLSR is used among mesh routers, and AODV is used among mesh clients. HDV [9] makes use of tree-based proactive routing for communication between mesh routers and gateway, and set reactive routing among mesh clients. Both HMesh and HDV only use the hop count as the routing metric. CHRP [29] improves the routing metric, considering interference, channel condition and energy of mesh clients. All the above existing hybrid routing protocols for hybrid WMN neglect the access process. When a mesh client wants to access a mesh router, this mesh router can be used unconditionally and replies RREP directly if it knows the way to the destination. Then this same access mesh router and proactive path may be used frequently, which will cause heavy load and congestion. LA-CHRP [30] can choose the mesh router with less load as the access node. However, LA-CHRP only considers load condition of the access mesh router, and neglects the condition of the whole proactive path. The access mesh router indeed has less load, but the condition of whole proactive path may not be the same. In addition, all existing hybrid routing protocols only consider the condition of the current node, neglecting the situation of nodes in the neighboring region. To overcome these weaknesses, a new approach is going to be proposed in the next section.

3. Regional condition-aware hybrid routing protocol

Unlike all existing hybrid routing protocols for hybrid WMN, the proposed RCA-HRP makes use of regional conditions to help mesh nodes make more effective route selection. In addition, both gateway-oriented traffic and client-oriented traffic are considered in RCA-

HRP. For gateway-oriented traffic, when a mesh client wants to access a mesh router, RCA-HRP considers the condition of the whole proactive path where this access mesh router is located. There are many factors which RCA-HRP considers for mesh routers in the proactive path, aiming to evaluate the condition of the whole proactive path more accurately. For these mesh routers, the number of neighboring mesh clients, neighboring mesh clients' load and speed are taken into account. In client-oriented traffic, regional network conditions such as neighbors' energy, speed and load are taken into consideration. During the process of obtaining regional information, the cross-layer approach [31] is used. The energy and speed of mesh clients can be collected from the application layer, and the queue length which reflects load condition at each radio interface of node can be obtained from the Media Access Control (MAC) layer.

3.1. Gateway-oriented traffic

3.1.1. Regional condition-aware weight value of proactive path

When a mesh client wants to access a mesh router, the condition of the whole proactive path where the access mesh router is located is considered in RCA-HRP. For the mesh routers in the proactive path, RCA-HRP considers the number and detailed condition of neighboring mesh clients to reflect the condition of the proactive path.

For each mesh client, its load condition is considered. As the load condition can be indicated by queue length [21], queue length is used to evaluate the weight of a mesh client. In addition, the number of neighboring mesh routers is also an important factor which can influence the performance of routes. More neighboring mesh routers can provide more stable routes and chances of communication. For instance, if a mesh client has several neighboring mesh routers, when a route between this mesh client and a mesh router is broken, the mesh client can connect to another neighboring mesh router to communicate. The weight value of mesh client i (denoted as W_c^i) can be expressed as

$$W_c^i = \begin{cases} \dfrac{queue\_length_i}{m}, m \neq 0 \\ queue\_length_i, m = 0 \end{cases} \tag{1}$$

where $queue\_length_i$ is the queue length of mesh client i, and m is the number of neighboring mesh routers of mesh client i. W_c^i indicates the situation of packet forwarding and load of mesh client i. Based on the above expression, for a mesh client, when its queue length is longer which means it has heavier load, then the weight value calculated by equation (1) will become bigger to reflect such a fact. On the other hand, when the number of the neighboring mesh routers is bigger which means the mesh client has more resource to communicate and as a result its relative load is lower, then the weight value calculated by equation (1) will become smaller to reflect such a fact. In other words, the weight value defined in (1) gives a comprehensive and balanced measure of the load for a mesh client.

As mesh clients can access their neighboring mesh routers at any time, mesh clients with packets to forward near a mesh router can indeed influence the condition of this mesh router. Thus, for each mesh router, the queue length of its neighboring mesh clients is considered in RCA-HRP. Here, the queue length condition of neighboring mesh clients can be represented by weight value W_c^i. In addition, for each mesh router, the speed of neighboring mesh clients can also influence the condition of this mesh router. High-speed mesh clients may access mesh routers frequently and irregularly, which causes instability of route and decreases network performance. Therefore, the speed of neighboring mesh clients is also taken into consideration in RCA-HRP.

In short, the regional condition of a mesh router includes the weight and speed of its neighboring mesh clients. Therefore, the weight of mesh router j (denoted as W_r^j) in the proactive path can be expressed as

$$W_r^j = \begin{cases} \dfrac{queue\_length_j}{queue\_length_{\max}^r} + \dfrac{\sum\limits_{client\ i \in N_j} W_c^i}{queue\_length_{\max}^c} + \dfrac{\sum\limits_{client\ i \in N_j} v_i}{n \times v_{\max}},\ n \neq 0 \\ \dfrac{queue\_length_j}{queue\_length_{\max}^r},\ n = 0 \end{cases} \tag{2}$$

where v_i is the speed of mesh client i, $queue\_length_j$ is the queue length of mesh router j, and N_j is the set of neighboring mesh clients of mesh router j. $queue\_length_{\max}^r$ and $queue\_length_{\max}^c$ are the maximum lengths of queue that are allowed for mesh routers and mesh clients, respectively. $v_{\max}$ is the maximum allowable speed of mesh clients in the whole network. n is the number of neighboring mesh clients of mesh router j. The weight defined in (2) represents the operation condition of a mesh router. The smaller the weight is, the better the condition is for the router.

As the proactive route is composed of mesh routers, the condition of the whole proactive path is related to each mesh router located in this path. Therefore the weight value of the whole proactive path (denoted as $Weight_p$) in RCA-HRP can be expressed as

$$\mathrm{W}eight_p = \sum_{j=1}^{k} W_r^j + \frac{k}{hop_{\max}} \tag{3}$$

where k is the hop count of the proactive path, and $hop_{\max}$ is the maximum hop count of all proactive paths. Based on the measure defined in (3), smaller $Weight_p$ means better condition of the given proactive path.

To clearly explain how to calculate the weight value of a proactive path in RCA-HRP, a simple example is shown in Figure 2.

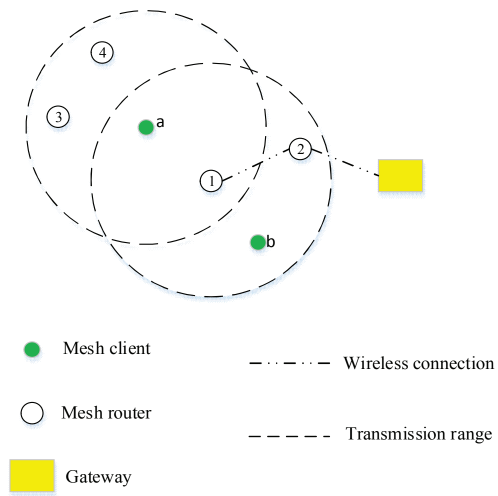


Figure 2: An example for calculating the weight value of proactive path in RCA-HRP

In Figure 2, the dotted circles denote the transmission ranges of mesh client a and mesh router 1. We can see that mesh client a has three neighboring mesh routers. Thus, the value of m is 3. Mesh router 1 has two neighboring mesh clients, so the value of n is 2. Assuming that the queue length of mesh client a (i.e., $queue\_length_a$) is 6, then according to formula (1), the value of W_c^a can be calculated, which is 2. Mesh client b can get the value of W_c^b in the same way, and we assume that the value is 3 here. Assume the speed values of mesh client a and b are 1m/s and 2m/s respectively, and the queue length of mesh router 1 (i.e., $queue\_length_1$) is 5 here. The maximum queue lengths set for mesh routers and mesh clients (i.e., $queue\_length^r_{\max}$ and $queue\_length^c_{\max}$) are 20 and 10 respectively. The maximum speed of mesh clients (i.e., $v_{\max}$) which is allowed in the network is 10m/s. Based on formula (2), the value of W_r^1 is 0.9. Similarly, the value of W_r^2 for mesh router 2 can be calculated and is assumed to be 1.5 here. Further, $hop_{\max}$ is set as 5 in this example. Then based on the formula (3), the value of $Weight_p$ for this proactive path is the sum of W_r^1, W_r^2 and 2/5, which is 2.8.

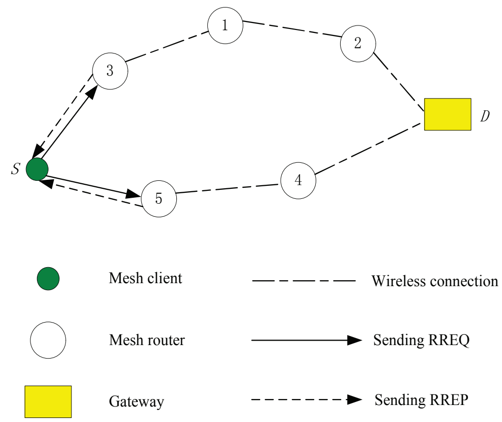


Figure 3: An example of the access mechanism in RCA-HRP

3.1.2. Access mechanism

When a mesh client needs to access its neighboring mesh router j, the weight value for the whole proactive path of this router will be calculated, that is, $Weight_p$ is obtained. After calculating all weight values for all neighboring mesh routers for the given mesh client, that is, calculating all $Weight_p$, the mesh router with the smallest $Weight_p$ will be selected. That is, the router and its corresponding proactive path with the best condition will be used to transport packets. An example to illustrate such an access mechanism is shown in Figure 3.

In Figure 3, mesh routers are connected to gateway D according to the proactive routing protocol. When mesh client S wants to communicate with gateway D, it broadcasts RREQ message, and both mesh routers 3 and 5 can receive this message. In RCA-HRP, each of mesh routers 3 and 5 will check whether they have valid routes to D in their proactive routing tables. If both of them have the valid routes, they will send RREP message to mesh client S. We assume that the $Weight_p$ of path 3-1-2-D is 2.1 and the $Weight_p$ of path 5-4-D is 1.9. Because $Weight_p$ for the corresponding path of router 5 is smaller, S will select mesh router 5 and its corresponding path 5-4-D to transmit data packets.

3.2. Client-oriented traffic

In the client-oriented traffic, W_r^j is still used here to set the weight of mesh router j. For a mesh client, as its weight value W_c^i is used to measure the effect of itself to other neighboring mesh routers, W_c^i only measures the load condition from the point of view of both the queue length and the number of its neighboring mesh routers as the communication resource. The calculation of W_c^i overlooks the residual energy of mesh client i. Because the energy of mesh clients is limited, energy is actually also an important factor needed to be considered during the process of routing. The remaining energy percent of mesh client i (denoted as P_{energy}^i) is

$$P_{energy}^i = \frac{R_{energy}^i}{I_{energy}^i} \tag{4}$$

where R_{energy}^i and I_{energy}^i are the remaining and initial energy of mesh client i respectively.

The improved weight of mesh client i (denoted as $Weight_c^i$) is then expressed as

$$Weight_c^i = W_c^i + (1 - P_{energy}^i) \tag{5}$$

Based on the above weigh, the reactive routing metric of RCA-HRP (denoted as $Metric_{reactive}$) is

$$Metric_{reactive} = \sum_{client\, i \in q} Weight_c^i + \sum_{router\, j \in q} W_r^j \tag{6}$$

where q represents the path which is formed by all mesh clients and routers on the path. Thus, the route with smallest $Metric_{reactive}$ will be chosen to forward packets. As a result, the mesh routers whose neighboring mesh clients have lower speed and less packets to be transported will be chosen. At the same time, the mesh clients with more neighboring mesh routers and more residual energy will be selected.

When a node receives a RREQ, the process mechanism is shown in Figure 4.

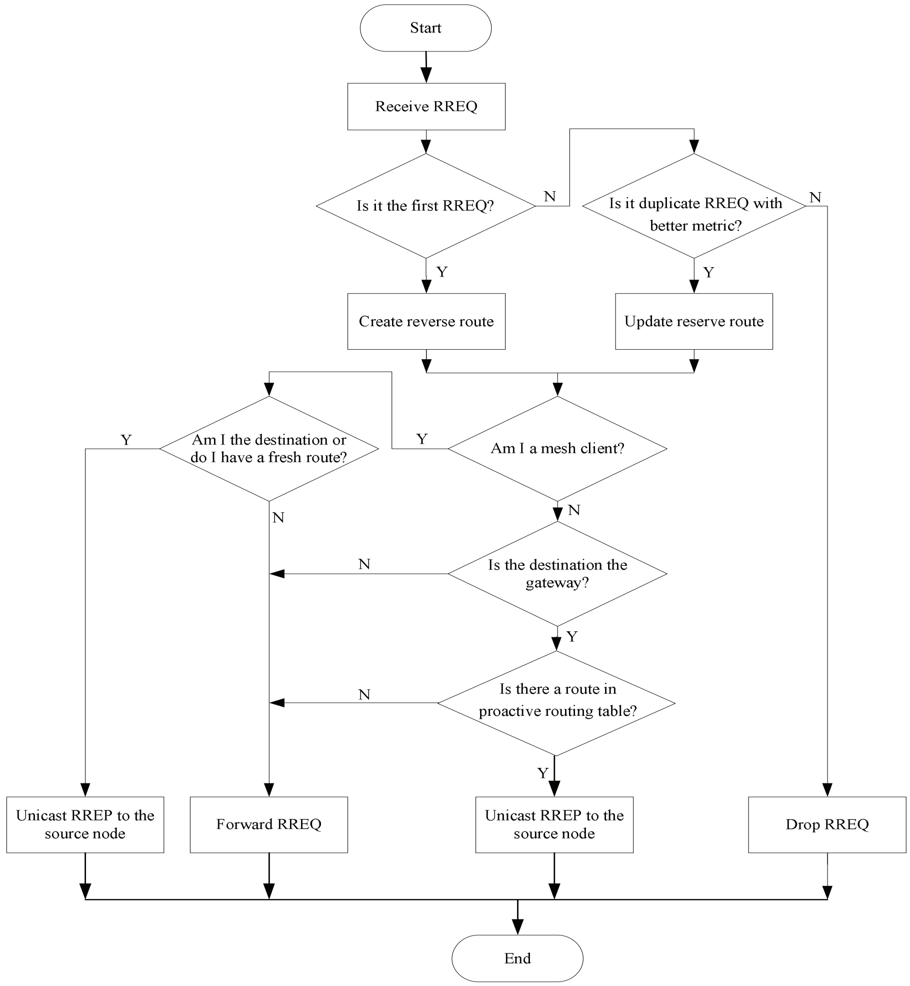


Figure 4: The process mechanism of RREQ

4. Performance evaluation

The detailed simulation environment, performance metrics, simulation results and analyses are given in this section.

4.1. Simulation environment

Network simulator ns-3 is used to evaluate the performance of RCA-HRP in multi-radio multi-channel hybrid WMN. There are 25 mesh routers and 50 mesh clients in the area of 1000m×1000m. Mesh routers are deployed randomly and into a grid respectively. Mesh clients can always move arbitrarily in the network, and the MRMC environment is used. The Constant Bit-Rate (CBR) traffic flows are conveyed in the simulation. Both gateway- and client-oriented traffic exist simultaneously, and they are half and half. Details of simulation parameters are shown in Table 1.

4.2. Performance metrics

Average throughput, average latency, and average packet loss rate defined as below are used as metrics to evaluate the network performance.

- Average throughput is the number of bits which are received successfully by the destination node every second.
- Average latency is the average delay of each packet delivered in success.
- Average packet loss rate is a ratio, that is the number of lost packets divided by the total number of packets sent by source node.

4.3. Simulation results and analyses

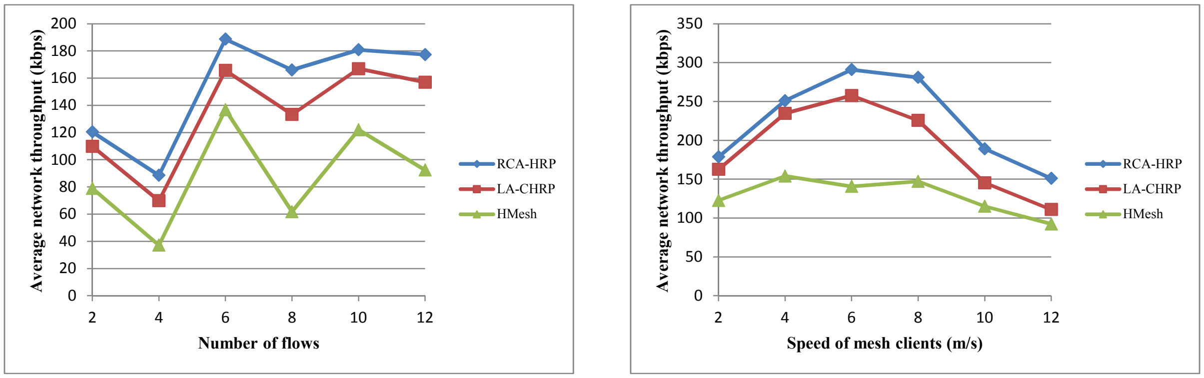
4.3.1. Hybrid WMN with grid backbone

Mesh routers are deployed into a 5×5 grid here, and mesh clients move randomly. There are two simulation cases. One is that the speed of mesh clients is fixed to 2m/s and the number of data flows is changed. The other is that the flow number is 8 and the mesh client speed is different. Simulation results are shown in Figures 5, 6 and 7.

From Figure 5, we can see that the average network throughput of RCA-HRP is always higher than LA-CHRP and HMesh. As the regional condition of mesh routers and mesh clients are considered comprehensively in RCA-HRP, during the process of route discovery,

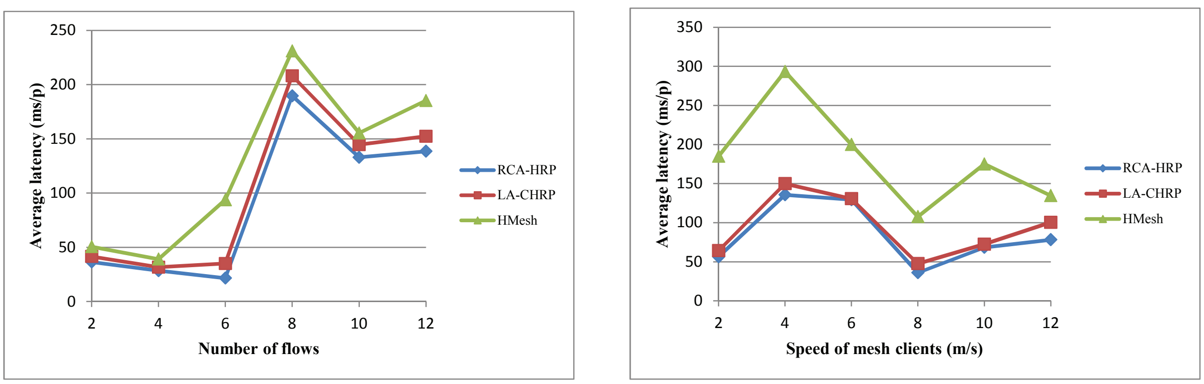
Table 1: Simulation parameters

Simulation Parameters	Values
Simulation time	100 s
Traffic type	UDP
Packet size	1024 bytes
Packet rate	80 kbps
Number of radio interfaces in each router	3
Number of channels in each router	3 channels (1, 6, and 11)
Number of radio interfaces in each client	1
Number of channels in each client	1 channel (1)
Initial energy of each router	10000J
Initial energy of each client	500J
Transmission range	250 m
Interference range	550 m
Propagation model	Two Ray Ground
Mobility model of mesh clients	Random direction 2d mobility model
Antenna	Omnidirectional



(a) Different number of flows (b) Different speed of mesh clients

Figure 5: Average network throughput of hybrid WMN with grid backbone

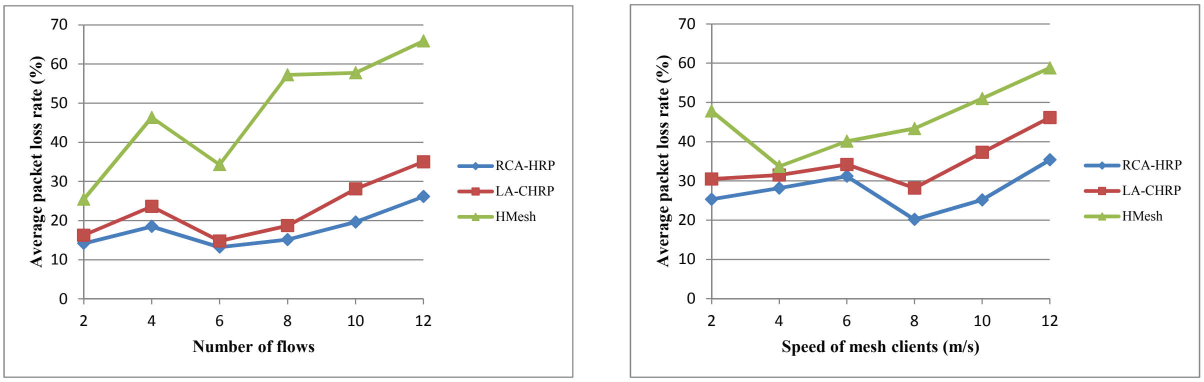


(a) Different number of flows (b) Different speed of mesh clients

Figure 6: Average latency of hybrid WMN with grid backbone

the situation of all neighbors is considered. The area with heavy load and congestion can be avoided, and the node with better regional condition will be selected. Not only the condition of an individual node itself, but the condition of its neighbors is also taken into account. Then, the whole network performance has been improved, which makes RCA-HRP achieve higher average network throughput.

Figure 6 demonstrates that the average latency of RCA-HRP is lower than LA-CHRP and HMesh. HMesh only uses the hop count as the routing metric. Route with the least hop count may have heavy load and congestion, and as a result the performance of HMesh is not



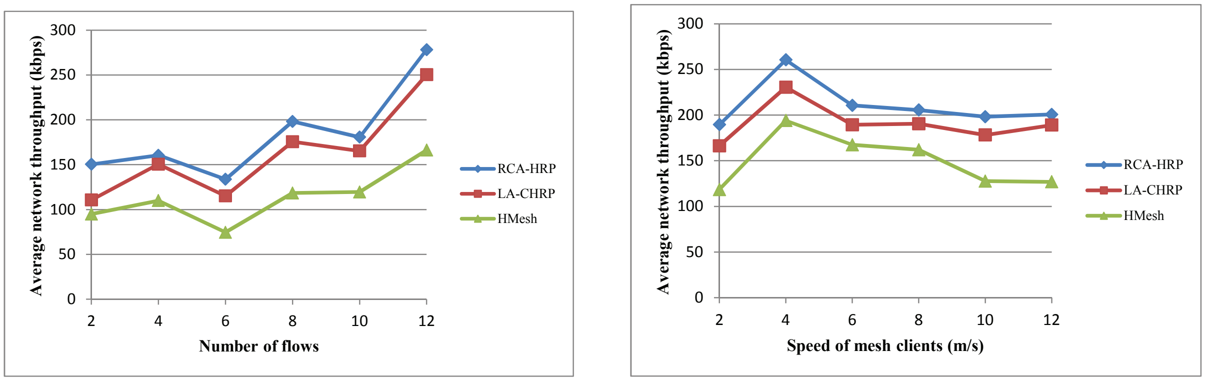
(a) Different number of flows

(b) Different speed of mesh clients

Figure 7: Average packet loss rate of hybrid WMN with grid backbone

good. LA-CHRP is a load-aware routing protocol, but it only considers the load condition of the access mesh router. Although the mesh router with less load and better condition will be selected as the access node, the condition of the whole proactive path is neglected and as a result the selected path is often not a good one. To avoid this situation, during the access process, in addition to the condition of the access mesh router, the situation of whole proactive path is taken into account in RCA-HRP. Then the proactive path with low load and better condition is chosen to transfer packets, which helps RCA-HRP choose better path effectively and get lower average latency.

Figure 7 shows that RCA-HRP can always obtain lower average packet loss rate than LA-CHRP and HMesh in different cases. RCA-HRP considers the different features of mesh routers and mesh clients. For mesh routers, the queue length of themselves, the speed and queue length of neighboring mesh clients are taken into consideration. For mesh clients, as they have limited energy, the energy condition of them is also considered in the process of route discovery. In addition, gateway- and client-oriented traffic are processed respectively and properly in RCA-HRP. In gateway-oriented traffic, the situation of whole proactive path



(a) Different number of flows　　(b) Different speed of mesh clients

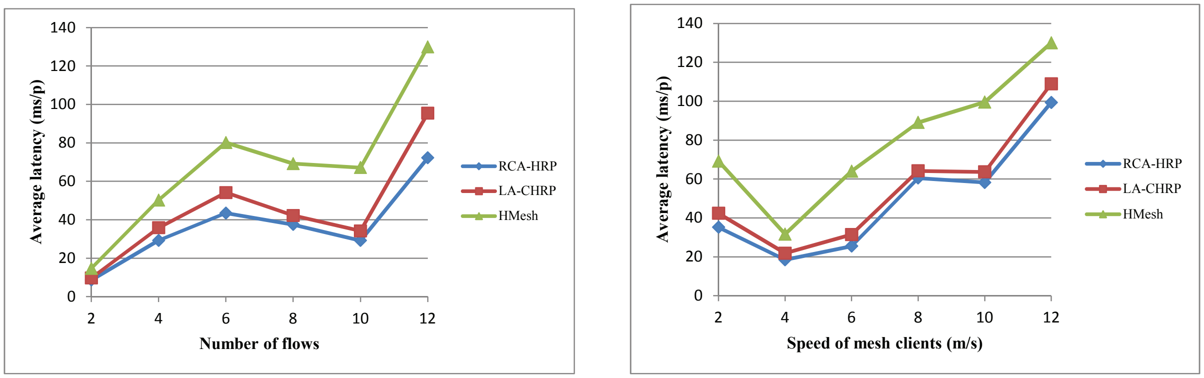
Figure 8: Average network throughput of hybrid WMN with general backbone

is considered during access process. The more stable path with less load and congestion will be selected. In client-oriented traffic, besides the condition of node itself, regional condition is also considered. The node with better own and regional condition will be selected. As heavy load and congestion can be avoided in both gateway- and client-oriented traffic, the packet loss rate of RCA-HRP is lower than others.

4.3.2. Hybrid WMN with general backbone

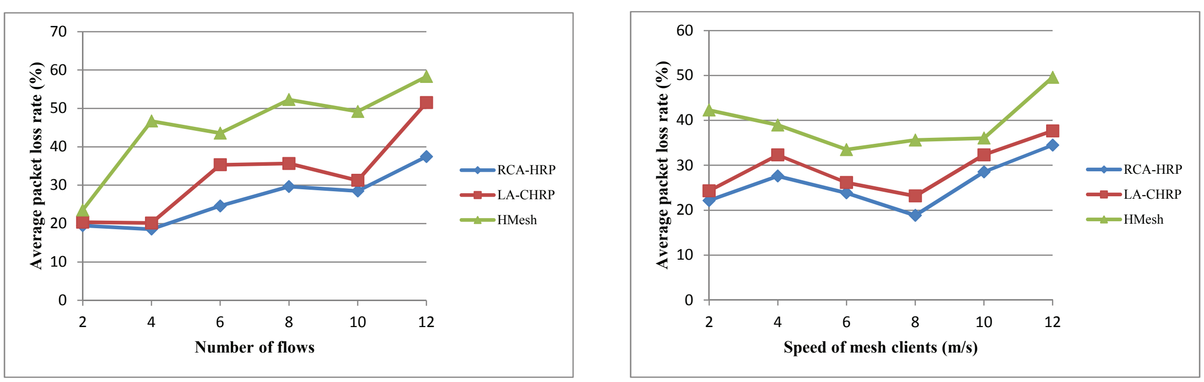
In this part, mesh clients also move randomly, but mesh routers in backbone are deployed at random. Simulation results in terms of average network throughput, average latency and average packet loss rate are shown in Figures 8, 9 and 10.

From Figures 8, 9 and 10, we can see that, similar to the simulation results in hybrid WMN with grid backbone, average network throughput, average latency and average packet loss rate by RCA-HRP are also better than LA-CHRP and HMesh, as RCA-HRP considers the condition of whole network more completely and comprehensively. Both gateway- and client-oriented traffic is considered, and regional condition is taken into account in these two kinds of traffic. A node in a more stable region, whose neighbors are with less load



(a) Different number of flows (b) Different speed of mesh clients

Figure 9: Average latency of hybrid WMN with general backbone



(a) Different number of flows (b) Different speed of mesh clients

Figure 10: Average packet loss rate of hybrid WMN with general backbone

and congestion, can be selected in priority. Thus, the region with high congestion will be avoided effectively. Besides, gateway- and client-oriented traffic is processed separately. For gateway-oriented traffic, when a RREQ arrives at an access mesh router, this mesh router can reply a RREP directly if it has a valid proactive path to the gateway. The delay cost by finding paths can then be decreased. The performance of whole proactive path is also considered during the access process. Then RCA-HRP can select paths effectively according to the holistic condition. For client-oriented traffic, besides queue length and load condition, energy is also considered for mesh clients. The disconnection caused by running out of energy of one overused mesh client can be avoided. Due to these advantages, RCA-HRP can help hybrid WMN obtain better network performance.

5. Conclusions and future work

A right routing protocol can improve the performance of whole network dramatically. There are two different kinds of nodes (i.e., static mesh routers and mobile mesh clients) in hybrid WMN. Reactive routing protocols do not consider the different features of mesh routers and mesh clients, which cannot adapt well to hybrid WMN. Hybrid routing protocols combining both proactive and reactive routing protocols are more effective for hybrid WMN. However, current research about hybrid routing protocols is quite limited and few. Further, all of these hybrid routing protocols overlook regional condition of mesh nodes, and do not consider the situation of whole proactive path in the access process. RCA-HRP proposed in this paper has overcome these weaknesses. Regional condition of mesh routers and mesh clients are taken into account respectively. For mesh routers, queue length of themselves, speed and queue length of neighboring mesh clients are considered. For mesh clients, the number of their neighboring mesh routers, queue length and energy of themselves are all taken into consideration, and both gateway- and client-oriented traffic are considered in RCA-HRP. In gateway-oriented traffic, when a mesh client wants to access a mesh router, the condition of whole proactive path where the access mesh router is located is considered. In client-oriented traffic, a node with better own and regional condition will be selected to transport packets. Simulation results have shown the advantage of RCA-HRP in terms of average network throughput, average latency and average packet loss rate.

As the resource of a wireless network is constrained [32], making full use of resource is very important. To transport as many data packets as possible with limited resource and guarantee the quality of service (QoS) request [33] [34] is a goal in a wireless network. To do resource allocation in an effective and balanced way is our future work.

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