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An adaptive load-aware routing algorithm for multi-interface wireless mesh networks

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Abstract In wireless mesh networks, the number of gateway nodes are limited, when the nodes access to the internet by fixed gateway node, different requirements of nodes lead to the dataflow shows heterogeneity. Many new routing metrics and algorithms existing in traditional wired networks and the Ad Hoc network, can not be directly applied to wireless mesh networks, so how to design a routing metric and algorithm which can dynamically adapt to current networks topology and dataflow changes, avoid bottleneck node, and select the most stable and least congestion link to establish a route is very important. In this paper, we presented a new dynamic adaptive channel load-aware metric (LAM) to solve the link load imbalance caused by inter-flow and inner-flow interference, designed a self-adaptive dynamic load balancing on-demand routing algorithm through extending and improving AODV routing method with the LAM, to achieve flow balance, reduce the high packet loss ratio and latency because congestion and Packet retransmission, and can increase Network Throughput.

Keywords Wireless mesh networks · Multi-channel · Routing metric · Load balancing · Load-aware routing

1 Introduction

In the routing protocol of Wireless mesh networks, the design of routing metric and algorithm must satisfy the dynamic requirements of operations on the multi-objective performance (such as delay, bandwidth, reduce congestion, reduce interference, and QoS guarantees).

Cognitive Radio Networks (CRNs) are being studied intensively. Routing in CRN is a challenging task due the diversity in the available channels and data rates [1]. The quality of wireless links would be affected or even jeopardized by many factors like collisions, fading or the noise of environment [2]. A wireless MANET is a collection of wireless mobile hosts that dynamically create a temporary network without a fixed infrastructure. The topology of the network may change unpredictably and frequently [3]. High quality multimedia forensics service is increasingly critical for delay-sensitive applications over heterogeneous networks [4]. A class of Delay Tolerant Networks (DTN), which may violate one or more of the assumptions regarding the overall performance characteristics of the underlying links in order to achieve smooth operation, is rapidly growing in importance but may not be well served by the current end-to-end TCP/IP model [5]. a computational intelligence approach -a reinforcement learning algorithm (RLA)-for optimizing the routing in asynchronous transfer mode (ATM) networks based on the private network-to-network interface (PNNI) standard is proposed [6]. Energy Saving IP Routing (ESIR), to be applied in an IP network. ESIR operation is integrated with Open Shortest Path First (OSPF) protocol and allows the selection of the links to be switched off so that the negative effects of the IP topology reconfiguration procedures are avoided [7].

Dataflow convergence on gateway nodes may cause load imbalance, thereby causing congestion, packet loss and buffer overflow. Breaking up existing routing strategies into a small number of common and tunable routing modules, and then show how and when a given routing module should be used, depending on the set of network

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characteristics exhibited by the wireless application [8]. The higher-layer nature of inter-domain routing requires reviewing the whole routing process in order to maximize performance at low decision making cost, a clear case for fuzzy set logic-based algorithms [9]. Quality of routing (QoR) games which always have Nash equilibria. Nash equilibria of QoR games give poly-log approximations to hard optimization problems [10]. The directional routing and scheduling scheme (DRSS) for green vehicle delay tolerant networks (DTNs) by using Nash Q-learning approach that can optimize the energy efficiency with the considerations of congestion, buffer and delay [11].

2 Routing metric modeling

2.1 Problem proposed

In the wireless Mesh network, load balancing is importance for efficient use of network capacity and improving network throughput. Network load imbalance will have the following main problems: (1) relay causes a decline of network capacity; (2) near the gateway area easily causes congestion; (3) the bottleneck node affects the entire network connectivity. Therefore, the network load balancing is a key factor to improve routing performance. Load balancing in Wireless Mesh networks differ from traditional wireless networks, the load balancing mechanism for wireless Ad hoc networks is suitable dynamic nodes. And the mechanism for wireless sensor network nodes are taken into account the capacity constraints of energy and computing. Relative to the relatively stable network topology and less mobile features in Wireless Mesh networks, the existing load balancing mechanism is not suitable, it is necessary to design an efficient load balancing algorithm to achieve optimal network performance for wireless Mesh network. In this paper, the ultimate goal is Solving a link load awareness routing metric and an adaptive dynamic load balancing on-demand routing algorithm, to maximize the channel utilization, balance the network traffic and achieve lower routing overhead.

2.2 Network model

Channel assignment and load-balancing routing algorithms are based on the construction of wireless mesh network topology. To construct a wireless mesh network topology which is of high connectivity and is helpful for channel assignment and routing algorithm is a problem deserving of study, we have done related research work [12, 13]. When a given data stream increases in a network hotspot region, it can result in network congestion and network capacity reduced, by using load balance for uniformly distributed load, and choosing the lower flow path, to extend the network lifetime and improve the network throughput.

In the current research on the wireless Mesh network, multi-interface multi-channel approach can improve network nodes parallel transport on capacity and efficiency. This paper analyze the related problem from two perspectives of multi-channel Wireless Mesh nodes, and assume that each Mesh node is assigned a number of channels, The throughput improvement of the network relies heavily on the utilizing the orthogonal channels [14]. Through a typical distributed algorithm [15] implements the channel assignment of each node to avoid channel conflict possibilities. A weighted graph $G = (V, E)$ denotes the wireless Mesh network, where $V = \{v1, v2,\ldots, vm,\ldots, vn\}$ denotes non-empty set of Mesh nodes, n denotes the number of Mesh network nodes, m denotes the number of Mesh gateway nodes; E denotes the link communication assemble of public channel between a pair of mesh nodes connection,$|V|$ and$|E|$ respectively denote the number of network nodes and links. Showing in Fig. 1. In order to facilitate formal analysis, a series of definitions are given as follows:

Define 1 Link interference Loads: denote the process that node u and node v makes use of the channel i, may be affected link interference load arising from the interference of neighbor nodes.

Let l^i denote the link between node u and node v in the current channel i, $Q(l^i)$ denote interference load of l^i. Obviously, the load is mainly generated by the neighbor node u and node v competition for occupying the channel i. Formula is as follows:

$$Q(l^i) = \sum_{k \in N^i(u) \bigcup N^i(v)} Q_k^i \quad (1)$$

where $N(_u)$ and $N(_v)$ is the set of neighbor nodes which produced interference in channel i with node u and node v, Q_k^i denotes the packets average number of node u in the channel i corresponding to the interface queue in the cache.

Define 2 Link Load: denotes the link load level of node u and node v in the use of the channel i.

Let $LL(l^i)$ denote the link l^i load. Because of link interference, wireless link quality is affected, while the data packets is retransmitted in the contention channel, it may produce interface queue waiting, therefore, by introducing the ETT metric, to further define the link load calculation, formula is as follows:

$$LL(l^i) = ETT(l^i) \times Q(l^i) \quad (2)$$

where $ETT(l^i)$ is the expected transmission time of a data packed in link l^i. It can be seen from the above: $LL(l^i)$ not only considers the affection of packet transmission rate and

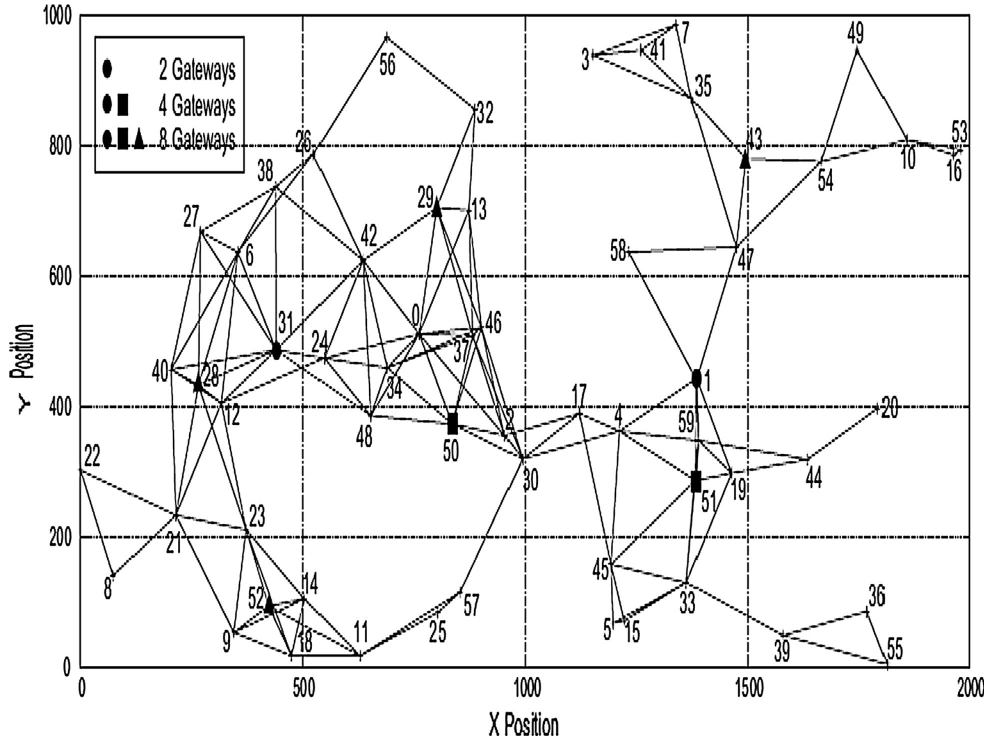

Fig. 1 Wireless mesh networks topology

transmission quality in link l^i,but also analyzes the inter-path interference.

In order to adjust the network load balance, avoid to produce bottleneck node causes congestion phenomenon, According to the size of the buffer queue in the nodes in the routing maintenance process, Choose lighter nodes to forward traffic load. A load factor of definitions are given as follows:

Define 3 node load factor: denotes the load of Node u divided by the load of its neighbors,if node u has k neighbors, the node u load factor can be expressed as follows:

$$loadfactor(u) = \frac{LL(l_u^i)}{\sum_{v=1}^{k} LL(l_v^i)} \quad (3)$$

In the process of routing maintenance, node u determine its load by saving and compare the queue length of neighbor nodes, when $loadfactor(u) \geq \beta$($\beta$is traffic overload threshold),it indicates the node u excess load.

Define 4 Gateway loads: denotes link loads of the gateway node g_m. Based on the define 2, the formula is as follows:

$$LL(g_m) = \sum LL(l_k^i), k \in neighbor\ of\ g_m \quad (4)$$

M is the number of gateway nodes.

$P = \{l_1^{i_1}, l_2^{i_2}, \ldots l_n^{i_n}\}$ denotes a path from source node s to destination node d. Where $l_k^{i_k}$ denotes the link while i_k is the number k channel in use of path p. Definition is given as follows:

Define 5 Channel path loads: denotes the total load links using the same channel in a path.

$$CL(j) = \sum_{k=1}^{n} LL(l_k^j) \quad (5)$$

$CL(j)$ denotes the channel path load when using the same channel j in the path p.

In order to take full advantage of the channel multiformity in wireless mesh network, to further reduce the inter-flow interference, we give the following definition:

Define 6 Load-aware metric: denotes the sum of channel path load and bottleneck load which is generated by the interference.

Let LAM denote load-aware metric. The formula is as follows:

$$LAM = (1 - \alpha) \times \sum_{j=1}^{m} CL(j) + \alpha \times \max_{1 \leq j \leq m} \{CL(j)\}. \quad (6)$$

where m denotes the number of available channels in the current path which has been chosen, α denotes the trade-off factor, its value is between 0 and 1.

Getting all channels load information in a path is LAM metric's design principle,in the first part of the formula is calculated all the channel loads of path *P* from the source node to current node, it is available by definition 5.2 that *CL (j)* not only reflect the path of end-to-end delay, and also reflect the corresponding channel interference of the path. Second part expresses maximal load valued of a channel in path *P*, namely the bottleneck load, this part reflects the different load on the different channel, that can avoid using the maximum load channel to data transmission.

The research background of LAM metric is use of multi-channel wireless Mesh network, and aims at the load influence by inter-flow and inner-flow interference, to solve the problem that only considers channel interference in the traditional channel allocation, achieve flow balance of data packet transmission during the routing selection process.

3 Load balancing routing algorithm

Combined with load balancing ideas in the previous section, we proposed a load-aware routing algorithm (LBRP). The algorithm may improve the current multi-channel routing algorithm on AODV-MR, the algorithm idea is composed by the routing request, routing answer and routing maintain. In the process of routing establishing, a node needs to establish a table in its cache to describe which channel has been used on its neighbor node. The table set up mainly through the following ways, when a new node join in, the channel allocation might be changed, the node periodically send HELLO packets to all neighbor nodes, and neighbor node can prompt reply a response packet which contains its usage channel information within the effective time. The node updates its neighbor nodes' usage channel table with the response packet of each neighbor node.

3.1 Routing request

The idea of routing request is similar to the classic AODV, routing setup is a process of on-demand launched. When the destination node D is not in the the source node's routing table, node S broadcasts RREQ packets to its neighbor nodes, the information of routing metric LAM on this node's current channels must be initialized as 0. When the intermediate node *X* receives the RREQ packet, it will update its information of available channels *CL*, get the *LAM* information from the first part in RREQ packet, and calculate the *LAM* value from the source node *S* to itself, write the updated value into the corresponding RREQ packets, and continue broadcast the updated RREQ packets to the backward node. When the upstream node receives RREQ packets of all neighbor nodes,it reads the *LAM* value from the RREP packets, and starts the operation in the algorithm. The routing request algorithm can be simply described as follows:

// Algorithm Route_request()

Input: $G=(V,E)$, Rhop, M, l_i'
Output: Rtable
//Initialize
NumGateway=N;
BLBFSP_Forest=Forest_BLBFSP(G,Rhop);
Ptable=GetPtable(G,Rhop);
CAtable=Channel_CSCA(BLBFSP_Forest，M);
//neighbor nodes with channel information
NCtable=CreateTable(BLBFSP_Forest, CAtable);
Rtalbe=Null;
Current_Send_Node=Null;
Current_Recieve_Nodetable=Null;
$LAM_{min}=\infty$;
//Source node S: Send RREQ packet to destination node D
If Current_Send_Node==S **Then**
 $CL(i)=0, \forall i \in \{1,\ldots,M\}$;
 Rtalbe={S};
BroadcastRREQpacket(NCtable);
Else
While GetlastRtable(Rtable)!=D **Do**
//Intermediate node : Receive RREQ packet
If Get(RREQ_ packet) **Then**
Current_Send_Node=GetlastRtable(Rtable);
Current_Recieve_Nodetable=GetNCTable(Current_Send_Node);
For i=1 to Size(Current_Recieve_Nodetable) **Do**
Channel_no[Current_Send_Node,Current_Recieve_Nodetable$_{[i]}$]=
CalculateCno (NCtable, $Min\sum_{l\in l'^{n}_{i}} R\times\delta_S$);
UpdateCL(Channel_no[Current_Send_Node ,Current_Recieve_Nodetable$_{[i]}$]);

$$LAM_{S,Current\_Recieve\_Nodetable[i]} = (1-\alpha)\times\sum_{i=1}^{m} CL(Channel\_no) + \alpha\times \max_{1\le j\le m}\{CL(Channel\_no)\};$$

  Send(RREP_packet);
EndFor
EndIf
//Intermediate node : Receive RREP packet
If Get(RREP_packet) **Then**
 For i=1 to Size(Current_Recieve_Nodetable) **Do**
  If $LAM_i < LAM_{min}$ **Then**
Candidate =i;
$LAM_{min}=LAM_i$;
 Else
  Candidate =min;
Continue;
EndIf
If $LAM_i == LAM_{min}$ **Then**
If SingleGateway(Current_Recieve_Nodetable)==0 **Then**
  Candidate =i;
  $LAM_{min}=LAM_i$;
 Else
  n=SingleGageway(Current_Recieve_Nodetable);
  For j=1 to n **Do**
   If $LL(g_j)+LAM_i < LL(g_j)+LAM_{min}$ **Then**
    Candidate =i;
    $LAM_{min}=LAM_i$;
  Else
    Candidate =min;
Continue;
    EndIf
   EndFor
  EndIf
  If $LAM_i > LAM_{min}$ **Then**
 Candidate =min;
Continue;
  EndIf
 EndFor
 EndIf
Rtalbe= Rtalbe ∪CurrentRecieveNodetable[Candidate];
Update_LAM（S，CurrentRecieveNodetable[Candidate]）;
Update_NCtable(CurrentRecieveNodetable[Candidate],candidate);
//Destination D: send RREP packet to source node S
If Current_Send_Node==D **Then**
Call Route_respose(Rtable);
Break;
 Else
Send(RREQ_packet);
 EndIf
EndWhile

By calling algorithm *Forest_BLBFSP()* [12] and algorithm *Channel_CSCA ()* [15], to provide input data for the algorithm. Function *CreateTable()* produce a neighbor node channel assignment table through the input data. Function *BroadcastRREQpacket ()* is the broadcast message process from source node to its neighbor nodes. Function *GetlastRtable ()* can get the last entered node in the routing table. Function GetNCTable () is used to retrieve all the neighbor node's channel allocation information of current sending node. The return value of function *SingleGateway ()* is an integer,When the node is only connected to a gateway node, the return value is 1, otherwise the return value is the number of gateway nodes connected. Function *UpdateCL ()* is used to update the channel path load values. Using *Update_LAM ()* function to update the criterion value between source node and new node. Function *Update_NCtable ()* is used to update channel table of the neighbor nodes.

3.2 Routing response

Routing answer of LBRP algorithm is relatively simple, and the same as AODV-MR process, it is achieving the acknowledgement and response of routing from destination node *D* to source node *S*. The routing response algorithm can be simply described as follows:

```
//Algorithm Route_respose()
  Current_Send_Node=GetlastRtable(Rtable);
  //Destination D: send RREP packet to source node S
  If Current_Send_Node==D Then
  Current_Send_Node =Locate_pre-hop (D,Rtable,NCtable) ;
  Add_Route(D,Rtable,NCtable);
  Send(RREP);
  EndIf
  //Intermediate node X: receive RREP packet
  Whlie Current_Send_Node≠S Do
  Current_Send_Node =Locate_pre-hop (X,Rtable,NCtable) ;
  Add_Route(X,Rtable,NCtable);
  Send(RREP);
  //Source node S: manage RREP packet
  If Current_Send_Node==D Then
  Senddata(Rtable);
  Break;
      EndIf
  EndWhile
```

Function *Locate_pre - hop ()* find the pre-hop neighbor node and available channel from routing table and channel assignment table in the local cache, send the RREP packets. Function *Add_Route ()* join the current node information into the RREP packets. Function *Senddata()* represents data transmission from the source node according to the established route.

3.3 Routing maintain

The backbone network nodes is relatively stable, so the routing maintenance mainly consider the maintenance process of node failure or link overload.

Node *r* periodically sends the HELLO packet to its neighbors, to monitor the activity and exchange of information between the neighbor nodes. When a node didn't accept the information of neighbor node *v* within a prescribed time, that is link failures between them. When found $loadfactor(u) \geq \beta$,it is also regarded as link failure, when the above two cases in the network routing maintenance program is started. The routing maintain algorithm can be simply described as follows:

```
// Algorithm Route_maintain()
  If  r not get(v_HELLO_packet) or loadfactor(v)≥β  Then
  BroadcastRERRpacket(Nctable,(r,v));
  If Exist(backuprouting) Then
       Senddata(backup_routing);
     Else
  S=r;
  Call Route_request(RCtable⊄v);
     EndIf
  EndIf
  If Current_Recieve_Node∈ GetNCTable(r) Then
  If Get(RERR) Then
     If Check(Rtable ,v) ==1 Then
        BroadcastRERRpacket(Nctable,(r,v));
     Else
      If Exist(backuprouting) Then
          Senddata(backup_routing);
        Else
  S= Current_Recieve_Node;
  Call Route_request(RCtable⊄v);
        EndIf
    EndIf
  EndIf
```

Function *Check ()* is used to Check whether the current upstream nodes in the routing table contains a node. Function *Exist ()* is used to judge whether has a backup path to the destination node in the current node's routing table.

4 Simulation and comparison

4.1 Simulation environment

To evaluate the effectiveness of our LBRP algorithms from different aspects, we perform a simulation in the NS3, and compare with two algorithms which based WCETT metric and Hop-cont metric. Simulation environment is as follows:

In the simulation environment, 60 nodes are randomly and independently distributed in rectangular network domain of 1,000 m × 1,000 m, there are 8 mesh gateway nodes with fixed static mode, the others are all mesh nodes, these nodes use Random Waypoint Model mobility model, the specific network topology shown in Fig. 1. By changing the parameters of the pause time, to change the characteristics of the experimental scene file in the experimental process, In the start stage, the non-gateway nodes maintain the stability network structure within the prescribed time, after that select a destination node in the rectangular area randomly, then move with a definite speed to it. When it reaches the node, it remains in a pause time again, and then randomly select another destination node, repeats the above steps at the set time. All nodes in the network communication range are 100 meters. Wireless channel capacity is 2 Mb/s. Buffer capacity of a node in the MAC layer is 35 packets. The lowest layer uses IEEE 802.11 Distributed Coordinated Function (DCF) access control mode, DCF mechanism allows nodes to share the wireless channel, provides collision avoidance (CSMA/CA) for Channel competitive mechanism, provides RTS/CTS/ACK mechanism for unicast. At the beginning of the experiment, chosen 20 nodes as source nodes send data to a random destination node, packet size is 512 bytes. In this paper, each mesh gateway node is equipped with 802.11b/g wireless card, which has twelve available channels, and the Mesh nodes are equipped with 802.11a wireless card, which has three orthogonal channels. In this paper we use a typical channel assignment algorithm for all nodes assign channel.

To compare the LBRP algorithm with WCETT metric routing algorithm and Hop count metric routing algorithms on packet delivery fraction, routing load, average end-to-end delay of data packets. The mesh node packet sending rate is gradually increase from 0 to 30 packet/s,. Each simulation costs 1,000 s, the last result is the average of the three experiments values. We focused on the impact of network load on the algorithm, to evaluate the effectiveness of LBRP algorithm from the following three simulation parameters:

1. Packet delivery rate: packet delivery rate is the probability of successful delivery packet from a node. This parameter can be observed packet loss rate, and also reflect the support network throughput, is the indicator for protocol validity.
2. The average end to end delay: delay cost is time of packet from the source node to destination node, including route discovery, queuing, and transmission delay and so on.
3. Normalized routing cost: Routing overhead is an important performance indicator to measuring different protocols, for the wireless channel, the performance is particularly important. Protocol control cost includes routing request, route reply, route error and other control group.

4.2 Simulation results analysis

The simulation environment is described as above, by changing the Mesh nodes' sending packets speed, to observe the different performance on LBRP algorithm, WCETT routing metric algorithm and Hop-count metric algorithm.

Figure 2 shows packet delivery rate by Varying sending packet rate of three routing algorithm between a pair of nodes. On the whole, with the source node sending packet rate increasing, the network needs to forward packets increasing, then the network load gradually increases, it is clear that the packet delivery rate of three algorithms gradually reducing, especially when the sending rate is equal to or less than 5packets/s, the network is under the lighter load, the packet delivery rate of three methods can achieve at 100 %; and when the transmission rate is equal or greater than 30packets/s, the network is on the maximum load, the three algorithms' packet delivery rates drop below 58 %. But LBRP algorithm's packet delivery ratio is higher than other algorithms at least 10 %. Leading to such phenomenon is that, the LAM metric of LBRP algorithm reduces interference of inter-flow and inner-flow in the multi-channel environment, it can reasonable assign channel to multi interface for network nodes, dynamic adaptively select node which Channel path load is lighter as the next-hop added to the selected path, reduces the unreliability due to the link quality, avoid packet loss because of using ETT criterion, improves the packet delivery ratio as much as possible in the packet delivery process, and that two other algorithms do not consider node load, it may be cause serious packet loss in each cache queue. The Hop-count metric algorithm is designed to find the path which has the least number of hops, and ignores load bearing capacity of the node in the path. Although WCETT metric algorithm considers the link bandwidth utilization rate, packet forwarding error rates and the diversity of the channel, but also ignores load imbalance based reasonably channel assignment.

Figure 3 shows the average delay cost from different source nodes sending rate of three algorithms. As shown, as the sending rate increase, average delay cost is also increasing in the three algorithms obviously, due to the data sending packets overload, it causes data packets congestion in some nodes, makes long queuing delay in each channel queue IFQ, and thus these packets increase the transmission delay in the forwarding process. Hop-count metric algorithm is the maximum delay cost, WCETT metric algorithm delay cost is the second, and the LBRP algorithm delay cost is minimized. The reasons for this situation is similar the analysis in Fig. 2, it mainly that LBRP algorithm has a strong processing power when network load is too high, to avoid forwarding packets on overload nodes, minimize data packet's waiting delay in the intermediate nodes, and reduces delay which cost finding the available channe due to the inter-flow and inner-flow interference in multi-channel environment.

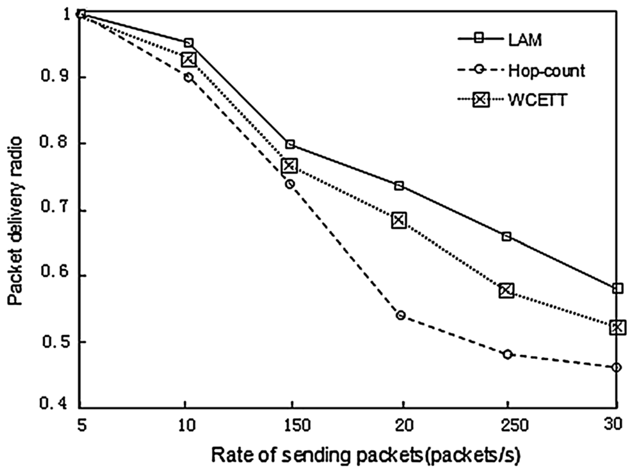

Fig. 2 Packet delivery rate by varying rate of sending packet

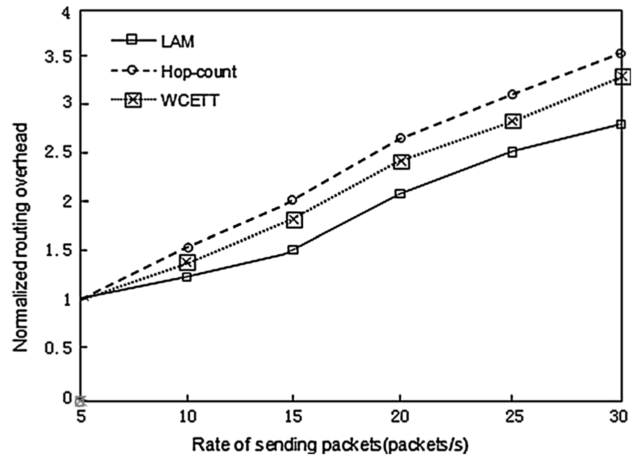

Fig. 4 Average end-to-end delay by varying rate of sending packet

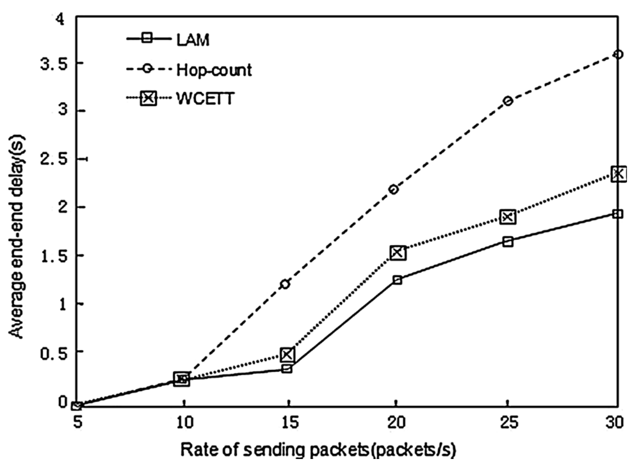

Fig. 3 Average end-to-end delay by varying rate of sending packet

To further validate the three algorithms routing overheads in the route establishment process. We compared routing overheads of the three algorithms with the same simulation environment in Figs. 2 and 3.

Shown in Fig. 4, under different transmission rates, the three algorithms' routing overheads have shown an increasing trend. However, WCETT metric algorithm and Hop-count metric algorithm routing overheads are high, and LBRP algorithm routing overhead is low. The main reason exists that LBRP algorithm in the routing establishing process, it can adaptively get the load information of each node, particularly when the link load is changed in the same channel, reduce data packet loss during the multi-flow transmission interference, and avoid resources wasted of network bandwidth and energy which could generate routing break, thus reduce the cost of the entire routing maintenance. But two other algorithms in this feature is limited, due to excessive load, need to re-initiate establishing routing to avoid the overloading node is selected again, therefore, increases routing overhead.

5 Conclusion and future work

In this paper, based on the study of multi-interface multi-channel Wireless Mesh Networks, we solve the link load imbalance which caused by the inter-flow and inner-flow interference, propose a new dynamic adaptive load-aware metric, design load balancing routing algorithm LBRP based on AODV-MR algorithm, and evaluate the algorithm implementation and performance verification, compare the simulation results with other classical routing algorithm: the algorithms using WCETT metric and Hop-count metric. Simulation results show that LBRP algorithm's performance have been significantly enhanced better than other algorithms. In future work, we will focus on considering QoS service guarantees, extensions of multi-path routing protocols and multicast routing protocols. We will further to verify the affection of this metric to network performance.

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