A New Qos Aware Relay Node Selection Model For Wireless Mesh Networks

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ABSTRACT: *In Wireless Mesh Networks (WMNs), supporting Quality of Service (QoS) to enable a rich portfolio of applications/real-time multimedia applications is foreseen to be vital for the success of next generation networking technologies. However, today's cutting edge standards are not perfectly equipped to cater to this task. These standards come with an inherent complexity and suffer from innate problems with respect to QoS provisioning. Consequently, due to the limited resource of WMNs and increasingly demand of new applications, there is a need for devising innovative routing algorithms for supporting QoS on top of the existing standards. Thus, this paper presents a cross layer relay node selection scheme for routing protocols in order to offer optimal routes to real-time applications. Distinguished from guaranteeing a certain level of performance, our QoS scheme provides differentiated priorities and service levels to application with different needs. The scheme includes two parts. In the first part, we present an application priority model to update the application/ priority table from the gateway periodically. Secondly, a new routing metric combining application priority, channel busy level and hop count, is deployed to evaluate and select the best from plurality possible paths during the communication phase. Our simulation experiments confirm the superiority of the proposed scheme against a number of existing counterparts.*

Keywords: Routing Metrics, QoS, Wireless Mesh Network

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1. Introduction

Internet access has become a major avenue for everyday life, as it is used by billions of people worldwide [1]. It is anticipated that wireless applications will continue to grow including, but not limited to, Voice over Internet Protocol (VoIP), Video-on-Demand (VoD), online gaming, and real-time multimedia streaming. The provisioning of broadband access to citizens and communities has been a strategic objective for organizations and governments worldwide to avoid or mitigate the digital division and promote the quality of life. WMNs stand as a cost-effective ubiquitous broadband connectivity offering a wide range of services in a given geographical area and have been attracted tremendous research efforts [9], [12], [20], [23]. Due to the desirable characteristics of WMNs, including, but not limited to, multi-hop routing, auto-configuration, low cost, and easy deployment etc, they are perfect fit for the new users who are looking for a convenient and affordable internet access. Compared to the traditional fixed network and Mobile Ad-hoc Network (MANET) [2], WMN stands in the middle and combines wireless network with fixed characteristics, as the fixed network (backbone) is merged with mobile network (backhaul) in WMN [12].

There are various mesh devices including the personal computers, Smartphone, other smart devices such as smart TV etc. Although WMNs can offer broadband connectivity, it is obvious that the bandwidth is still not sufficient to satisfy the transmission of high-definition multimedia applications and real-time applications. In order to solve this problem, we observe that among a wide range of applications, real-time applications require low latency and high data rate, e.g. video chat application; other applications such as web browsing, then require fairly lower communication quality. Therefore, there has been an array of important works in providing QoS to end users in WMN, such as [11] [17] [24].

The selection of a relay node scheme plays an important role to ensure the quality of a route. In this respect, routing metrics are applied in the routing protocols to judge the quality and suitability of the available paths. Existing routing protocols use only number of hops, delay, interference, bandwidth, etc, omitting the variety of the application requirements/demands in WMNs. A relay node approach usually considers limited routing metrics while selecting the best path between the source and destination. Although there are a wide verity of relay nodes mechanisms that deploy different routing metrics, including the most recently proposed ones such as *IAR* [3], the selection of the optimal routes depending on the sensitivity of the applications to communication quality (not QoS). In other words, such mechanism selects a route with lowest cost. [16] describes new routing metrics are required to improve the performance by capturing more constraints in corporation with the properties and capability of WMNs. QoS aware relay nodes routing design is still in its infancy, besides the requirements of [16], QoS aware scheme should also provide different service level to applications. In an attempt to fill in this gap, this paper presents a new relay node scheme that maps the applications demands to the most capable relay node in the network. The aim is to select the optimal route depending on the sensitivity of the applications to real-time communication and routing conditions. This is achieved by combining our proposed application priority metric and channel busy level and the number of hops. This will enable cross layer routing to guarantee highest quality streaming for the WMN applications. The proposed model operates based on two new routing metrics, Packet Priority-Oriented routing metric (PPO) and the refinement Packet Priority-oriented QoS routing metric (PP-QoS) to enhance the QoS provisioning of WMNs.

To examine the new proposed model, we compare our proposed solutions PPO and PP-QoS with other relay node selection models that are based on Hop Count, ETX, and IAR 2 by applying the same parameters as [9], using intensive simulation experiments. The results confirm that both PPO and PP-QoS perform well, notably for real-time applications, PP-QoS outperforms other routing metrics in offering efficient routing under different network scenarios. Besides the real-time applications, for the overall network, PP-QoS reduces 82.5% of overall average end-to-end delay in heavy-loaded WMNs. The rest of this paper is organized as follows. Section II reviews the related routing metrics. Section III describes the proposed routing metrics and the implementation is described in Section IV. Section V presents the simulation and Section VI concludes the paper.

2. Related Work

In this section, we review some well-known routing metrics, and then present the functionality of each routing metric and their abilities to satisfy the requirements of efficient WMNs.

Hop Count is widely used in existing protocols such as AODV [4], DSR [5], and DSDV [6]. Simply a routing protocol applying the hop count routing metric always finds the routing path with the shortest distance in hop number. It does not consider other issues like transmission rates, interferences, packet loss ratios etc. Therefore, the hop count routing metric may result in poor performance, especially when it comes to real-time applications.

Expected Transmission Count (ETX) is proposed by De Couto et al. [7] [8] to estimate the expected number of MAC layer transmissions for the wireless links along with packet loss rate. The advantages of ETX are the reduced probing overhead and non self-interference as the delay is not measured. However, ETX cannot measure the cause of data rate in delivery ratio and it does not consider the transmission rate. Furthermore, unicast probing of ETX is not accurate especially in collective communication patterns.

Expected Forwarded Counter (EFW) [9] is proposed by Paris et al. It improves ETX by considering packet forwarding possibility of a relay node. Thus, EFW detects the misbehaving nodes. The relationship between ETT and ETX is shown as follow:

$$EFW_{ij} = ETX_{ij} \times \frac{1}{1 - p_{d,\,ij}} \qquad (1)$$

where $P_{d,ij}$ is *dropping* probability at the network layer of node *j* and there is a wireless link established between nodes *i* and *j*.

Interference-Aware Routing Metric (IAR) [3] is designed for WMNs to use the MAC layer information to detect the channel busy level. The IAR of a link is

$$IAR\,(l) = \frac{1}{1 - a_{ub}} \times \frac{S}{B} \tag{2}$$

$$\text{where } a_{ub} = \frac{T_{Wait} + T_{Collision} + T_{Backoff}}{T_{Wait} + T_{Collision} + T_{Backoff} + T_{Success}}$$

T_{Wait}, $T_{Collision}$, $T_{Backoff}$, $T_{Success}$ are the time spent in Wait, Collision, Backoff and Success states, respectively, in the MAC level whereas a_{ub} is the percentage of time spent in the Wait, Collision and Backoff State. Thus, the smaller IAR of a path represents the less busy level it has.

In [3]-[10] [19]-[21], the aspects such as path length, packet loss, and MAC level measurement were considered. However, none of the above aspects concentrates on the effects and requirements of various demands of different applications, i.e., there is no existing QoS routing metrics. Without QoS, transmissions of real-time applications may be routed in inappropriate and busy paths or other transmissions of non-real-time applications may be routed in an available and quite path. In fact, the gateway-orchestrating role in WMN is not considered in existing solutions either. Thus, in Section III, we introduce a new relay node mechanism using two QoS routing metrics able to provide differentiated services to the corresponding applications, by selecting a path based on the real-time priority.

3. The Proposed Solution

In WMNs, some applications such as safety and emergency applications are very strict in terms of communication quality. On the other hand, other applications such as file transfer applications have more relaxed constrains pertaining to delay/latency, jitter, etc. Unlike other relay node selection models, our QoS-aware scheme considers the possibility of having a relay node candidate running applications with fewer real-time communication demands over other candidates. For example, in Figure 1, when transmitting a file from *s* to *d*, the route s-node2-node3-d is chosen as the relay node by our proposal since node1 and node4 are engaged in the transmitting of high-priority video transmitting. In other words, the communication quality of broadband TV on node1 and node4 can be worsened if they were chosen as relay nodes.

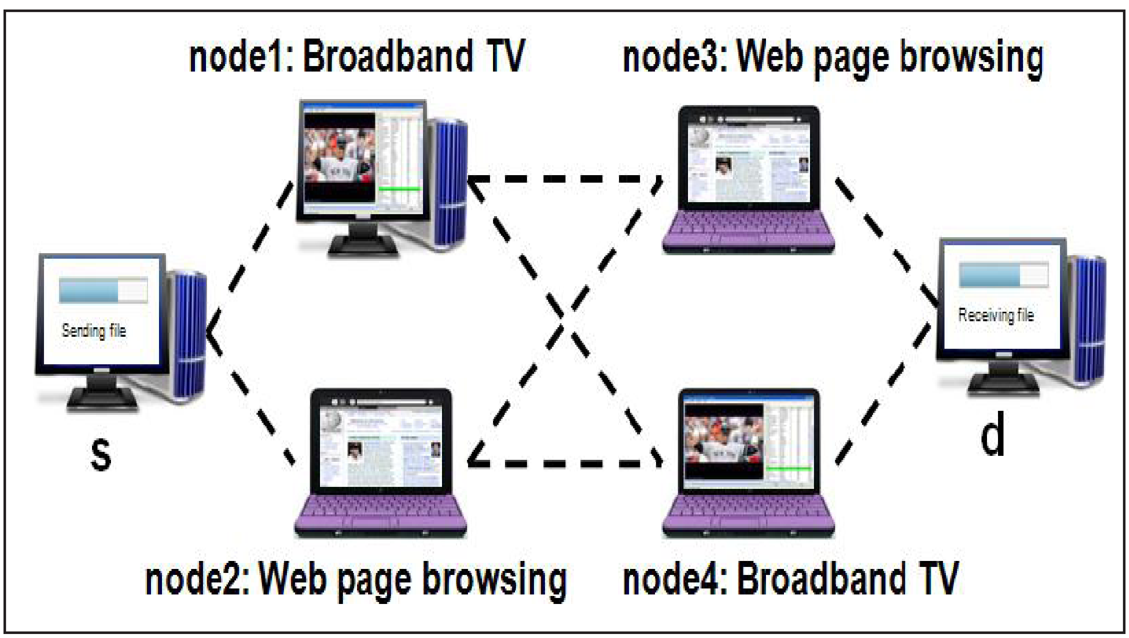


Figure 1. an example of proposed QoS relay node selection

To apply this new concept, our new relay node selection model is based on two new routing metrics, Packet Purpose-Oriented routing metric (PPO) and Packet Purpose-oriented QoS routing metric (PP-QoS) to provide different levels of QoS services to various applications. In our scheme, every application is assigned a real-time priority (*R*). For simplicity, we assume there is only one gateway for each WMN in charge of maintaining and distributing *R*. When a source node intends to find a path to a destination node, it first checks R of the application locally. If it does not have *R* value for the application, it asks its gateway to provide *R*. Then, the gateway assigns R for the application based on the communication requirements of the application. We set a value for the real-time priority between one and nine, where the real-time applications are assigned higher priority. In this section, we describe how our routing metrics work before discussing the implementation of assignment mechanism in Section IV. *PPO* is proposed by applying directly the idea of our new relay node selection model. *PPO* of a route *r* is as following:

$$PPO(r) = \sum_{l \in r} R_l, \; l \neq S, l \neq d \tag{3}$$

where R_l denotes the real-time priority factor of node *l*; *s* and *d* refer to the source and the destination of *r,* respectively. With PPO, the nodes forwarding data packets for real-time applications with high priority are avoided while selecting relay nodes. This ensures that a node is not involved in multiple transmissions generated by real-time applications.

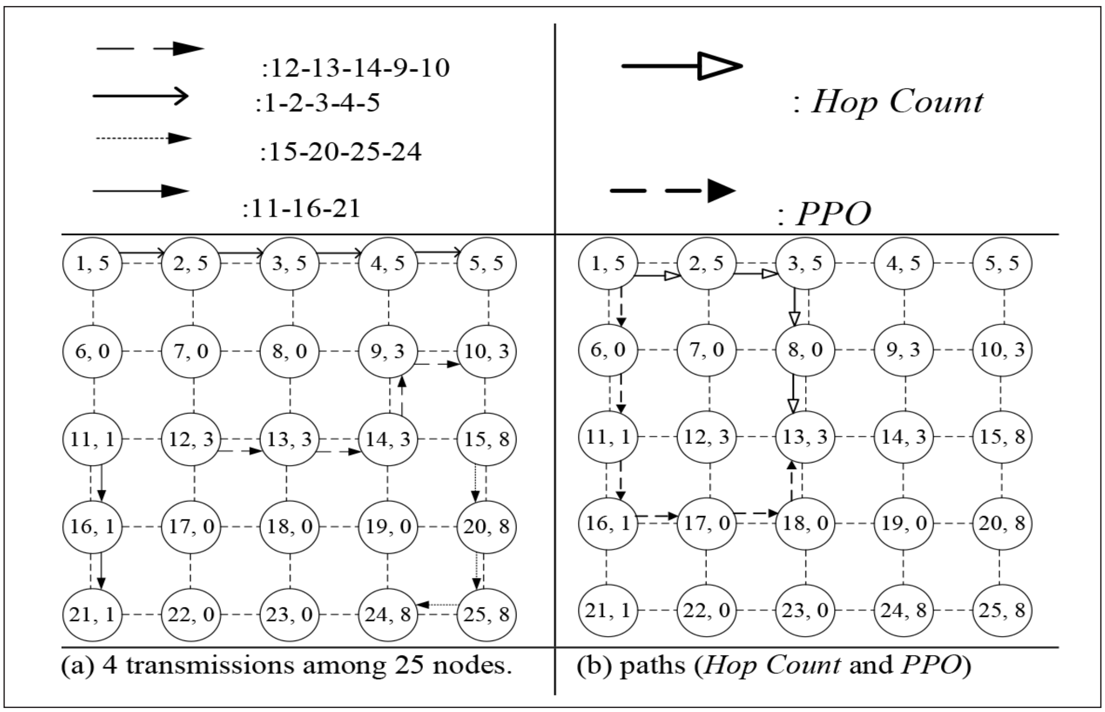


Figure 2. Compare PPO with Hop Count in AODV

Figure 2 shows an example of PPO during the route selection process in contrast with Hop Count. In Figure 2(a), each node is represented with node id and current aggregation of *R*, i.e. the total number of high priority application transmitted via this node. Apparently, there are four existing transmission paths from four applications generated. They are node1 to node5 (1-2-3-4-5), node11 to node21 (11-16-21), node12 to node10 (12-13-14-9-10), and node15 to node24 (15-20-25-24). The real-time priorities of these four applications are 5, 1, 3 and 8, respectively. Based on the four flows as background, for instance, an application with R set to 2 in node1 intends to find a path to node13 in Figure 2 (b). By applying Hop Count routing metric, a shortest path (1-2-3-8-13) is selected. In this case, the data packets are forwarded by the nodes that are currently involved in relaying packets for other applications with R valued 5, 5, 0, respectively, while PPO of this route is 16. Compared to Hop Count, a longer path (1-6-11-16-17-18-13) is selected with PPO routing metric of this route is lowered to 12. Further, when the packets follow the path of Hop Count, the transmission from node1 to node5 may exhibit higher delay and high packet loss rate as node2 and node3 relay packets of two applications. Therefore, a path with smaller sum of R is selected by using PPO. It bypasses the nodes engaging in transmitting packets for real-time applications. This ensures that the nodes currently forwarding packets for real-time applications are not selected as part of the route by another real-time application. A node may experience overloaded traffic due to relay packets for multiple low priority applications while using PPO. To overcome this issue, we involve the examination of channel usage and busy level. We provide and reform IAR with the real-time priority factor by proposing Packet Priority QoS-aware routing metric (PP-QoS). As the combination of PPO and IAR, PP-QoS of a route r is shown as follows:

$$PP\text{-}QoS\,(r) = \sum_{l \in r} ((1-p) \times IAR\,(l) + p\,R_l),\ l \neq S, l \neq d \qquad (4)$$

where p is a tuneable parameter subject to $0 \leq p \leq 1$ and $IAR\,(l) = \frac{1}{1-a_{ub}} \times \frac{S}{B}$ [1], [3]

In this routing metric, the smaller value of *PP-QoS* represents a better communication quality path for selection which also means the relay nodes on this path are engaged by fewer real-time data transmissions. We use an example of unicast to show the benefits of PP-QoS in Figure 3. In this example, a real-time application intends to find a route from node s to node d. We assign 0.5 to the parameter p. The path (s-4-d) is both the shortest path and the lowest sum of PPO selected by either Hop Count or PPO. In contrast, the path (s-3-2-d) is selected by *IAR*. However, the selection of these two routes does not consider both the required communication quality for applications and channel busy/occupancy level of forwarders.

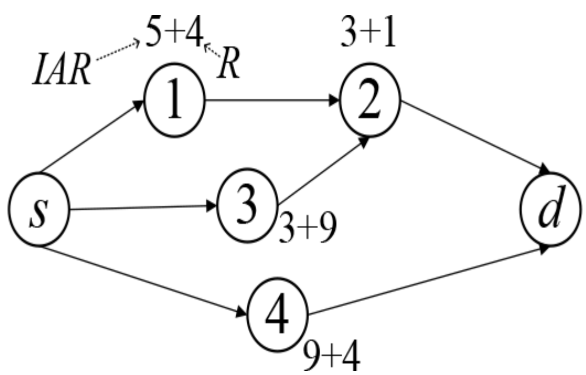


Figure 3. A unicast example of PP-QoS

Algorithm 1: Route Discovery by using *PP-QoS*

```
Dataÿ Sender: s , Receiver: r, intermediate node k
Result: Pbest: QoS guaranteed path
if s intends to send data packet to r
broadcast(Route_Request)
endif
for each node k recvd(Route_Request)
PP-QoSk = (1- p) ´ IAR(l) + p Rk
Route_Request.add(k, PP-QoSk)
if k = r
send(Route_Reply) to s
endif
end for
if i recvd(Route_Replynew_route)
if PP-QoSnew_route < PP-QoSold_route
P = new_route
endif
endif
```

If the path (s-4-d) is used to relay packets, it can force the real-time applications to lose high-quality performance, as the traffic load of node4 is comparatively high due to the remarkable IAR value. For the case of IAR path, a low IAR value of node3 indicates it is under light traffic load and a high R also determines the current transmissions on this node are from a real-time application. It is not an efficient option to allow a node to act as a forwarder of multiple real-time applications. Hence, to solve the above problems, the path (s-1-2-d) is selected by PP-QoS. Algorithm 1 shows the proposed relay node scheme with applying PP-QoS in on-demand routing paradigms.

4. Implementation

As presented in Figure 4, the gateway node maintains the Application vs. Real-time Priority table, which contains all the existing network applications and corresponding real-time priority levels (communication demand level of applications). The gateway node is responsible for distributing the real-time priority based on the mesh clients. For example, an ISP provider maintains the real-time priorities of applications at the gateway in order to provide the efficient routing of real-time applications. The network managers of ISP provider will evaluate the R value for each application.

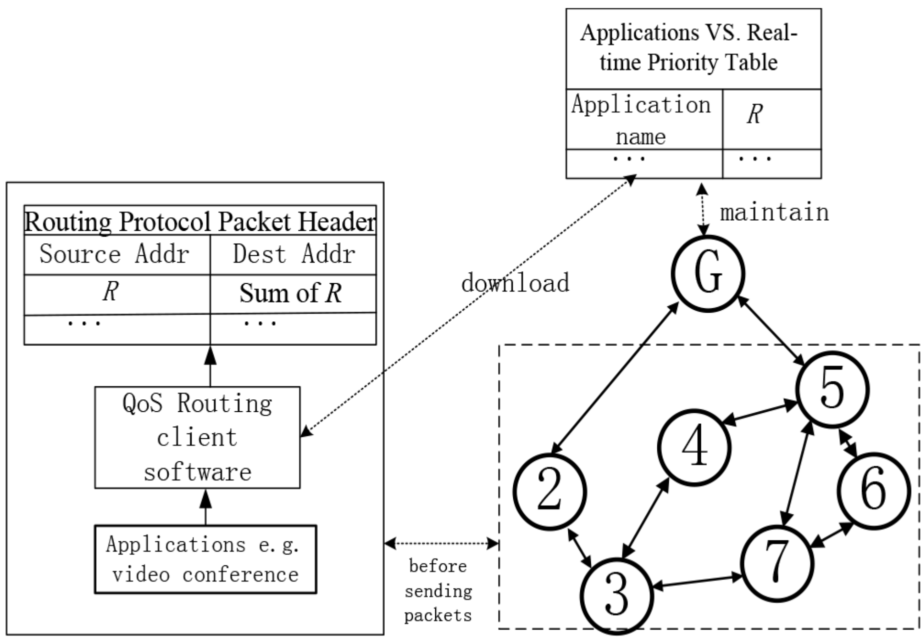


Figure 4. The implementation of PPO and PP-QoS

As illustrated in Figure 4, the QoS Routing monitor software of each mesh client node has to download the Application vs. Real-time Priority table from its gateway when it joins a WMN. Besides, the QoS Routing monitor software of each mesh client node is also requested to update the table when the gateway has a new one. This guarantees that mesh client nodes have fresh table. When the application of a mesh client node intends to send data packets, the packets will be captured by the QoS Routing monitor software locally and priority field e.g. „*R* will be added to the packet header. If the priority cannot be found in the table of the QoS Routing monitor software, the application is set as non-real-time by default and its real-time priority is set to 1. This is because in our scheme we only give the registered application higher priority. If there is no existing route, real-time priority from application layer packet will be applied to set the real-time priority field in the Route Request packet in networking layer. After setting the sum of real-time priority field to zero in the packet header, Route Request packet is sent out. By modifying the Route Request packet, both PPO and PP-QoS are compatible with the existing protocols such as AODV [4], DSR [5]. Each node receives the Route Request packet, increments the current sum of real-time priority, channel busy level (if PP-QoS) in the packet header. When the Route Request arrives at the destination, the best path is selected depending on the combination of the sum of real-time priority and channel busy level (if PP-QoS). Then, a Route Reply packet with real-time priority is sent back to the source node following this best path. Each forwarder in the best path increments local current sum of real-time priority by the value of real-time priority in the Route Reply packet, and records the real-time priority, source node, destination node in the current multicast forwarding table. As the Route Reply propagated back to the source, the source records the route and starts sending packets. When the path is no longer used by an application in the source, every relay node decrements the current sum of the real-time priority by the value of the real-time priority of this application only if it is forwarding packets for the application with the same source and destination in the current forwarding table.

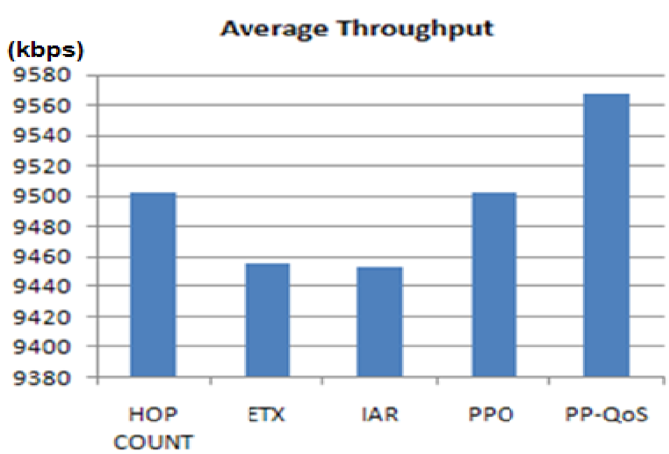
5. Simulation Results

We evaluate the performance of the proposed model using NS2 simulator [18]. The simulation aims to examine whether the proposed relay node scheme, based on the two new routing metrics can provide high communication quality to real-time applications. PPO and PP-QoS are both single channel and there is no other existing QoS routing metric. Therefore we compare our metrics to non-QoS single-channel metrics, Hop Count, ETT and IAR by implementing them with AODV. However, it is worth indicating that PP-QoS can be converted into multi-channel routing metric such as IAR. The performance metrics, average throughput and average end-to-end delay are used to evaluate the experimental results because these performance metrics are common performance metrics in examining the capability of a relay packet selection model or routing algorithm in previous studies such as [9]. The average throughput is the average rate of successful packet delivery in a time interval. The average end-to-end delay is determined by the average time a packet travelled from a source to destination. In this paper, in addition to the analysis of the overall network performance, we particularly examine the average end-to-end delay to study the effects of proposed routing metrics on real-time applications.

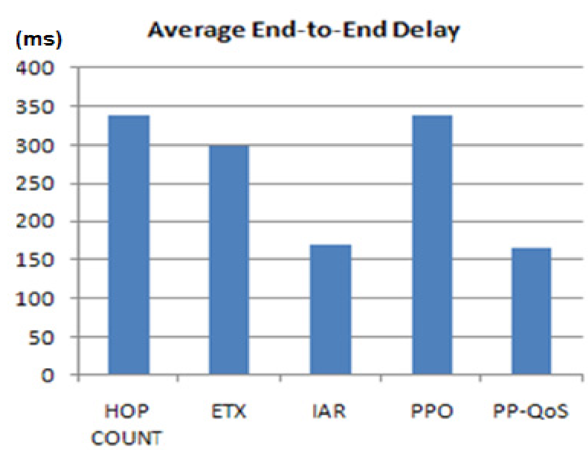
As previous setup in [9], our simulation models a network of 50 wireless routers distributed over a 1000 m × 1000 m area. There is one node designated as the gateway in the middle of network. Beside 40 stationary nodes, there are also 10 mobile nodes with various speeds during the simulation to create real WMN scenarios. This also evaluates the ability of the metrics in handling mobility. We simulate the mesh networks with both grid topology and random topology node deployment. The sources send Constant Bit Rate traffic (CBR) over User Datagram Protocol (UDP) as transport protocol, consisting of 1024-byte packets with sending rate of 50 packets per second. The interference range is set by default 500m. Therefore, the packet size and data rate are large enough to assess whether our solutions are capable of driving real-time applications.

5.1 Grid topology networks with heavy traffic load

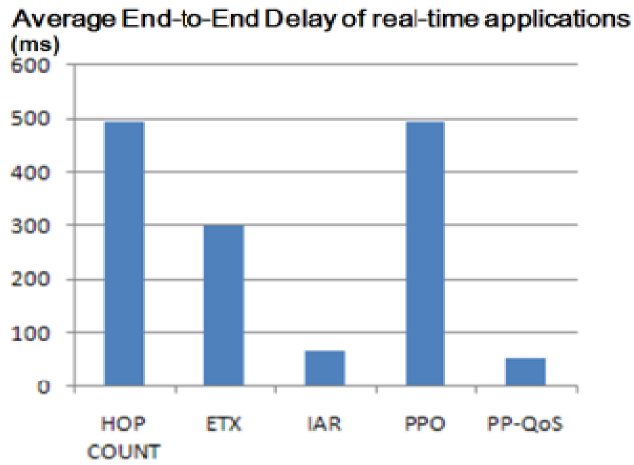
In this part, there are 30 out of 50 nodes, each with an application, sending out data packets in simulating a busy network, which is in order to test the performance of PPO and PP-QoS in the heavy-loaded scenarios. In Figure 5 (a), the results show the average throughput of PP-QoS is the highest in the heavily loaded grid topology. However, PP-QoS outperforms others by bypassing the paths or partial paths, which are forwarding packets for real-time applications. Compared to PP-QoS, PPO performs poorly in average throughput as it does not consider the effects of traffic overload caused by low priority applications. Figure 5(b) represents PP-QoS surpasses other routing metrics in terms of the average end-to-end delay, which further implies that PP-QoS can provide low latency communication for variety QoS demands in grid topologies. Figure 5(c) accommodates the outputs of the experiments regarding the average end-to-end delays of transmissions from real-time applications in a busy grid WMN topology. We consider the transmissions from applications with priority greater than 5 as real-time communication. PP-QoS particularly attains the lowest delay time for real-time applications with 22% less delay than the second best routing metric, IAR, in order to demonstrate the key behaviour of PP-QoS while providing better paths to real-time applications.



(a) Average Throughput

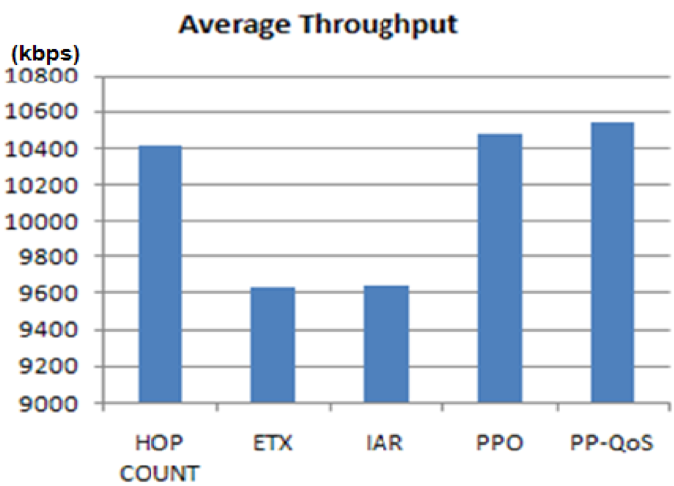


(b) Average End-to-End Delay

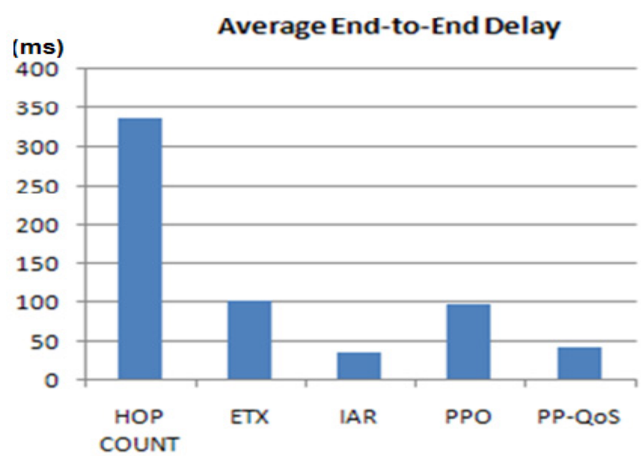


(c) Average End-to-End Delay of real-time applications

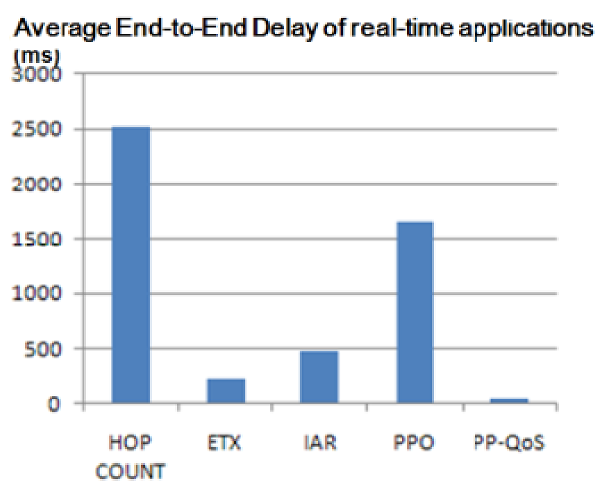
Figure 5. (a) (b) (c) in heavy-loaded grid topology networks



(a) Average Throughput



(b) Average End-to-End Delay



(c) Average End-to-End Delay of real-time applications

Figure 6. (a) (b) (c) in heavy-loaded random topology networks

5.2 Random topology networks with heavy traffic load

We study the performance of proposed metrics in random topology WMNs under busy traffic load as much as 30 CBR flows. Figure 6(a) shows that PP-QoS exhibits the best throughput performance in the random topologies, while PPO is the second best among these metrics. The results of average end-to-end delay are also are shown in Figure 6(b), where PP-QoS marks the second best performance in overall average end-to-end delay among the routing metrics. The advantage of PP-QoS for real-time applications is clearly shown in Figure 6(c). PP-QoS minimizes the communication delay for real-time applications as much as an average reduction of 10 times of delay. To sum up, PP-QoS and PPO outperform other routing metrics, especially when providing services to real-time applications for both regular and irregular topologies of heavy-loaded WMNs.

5.3 Grid topology networks with light traffic load

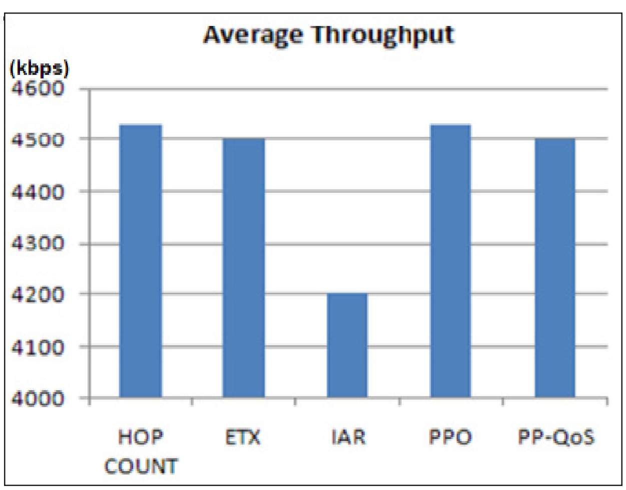
We simulate the scenarios of light traffic WMNs to evaluate the performance of our routing metrics. We first deploy the nodes in grid topology with only 10 CBR flows randomly generated from 10 different nodes, in order to model light traffic load scenarios. In this case, as shown in Figure 7, PP-QoS ranked the third best in terms of the average throughput and second best in the other two performance metrics. Hence, there is only limited number of nodes forwarding packets for them when there are few applications at the transmission phase. The value of the real-time priority is not enough to help PP-QoS to calculate the best path in this case. Comparatively, IAR is more sensitive when selecting appropriate paths in the lightly loaded networks.

5.4 Random topology networks with light traffic load

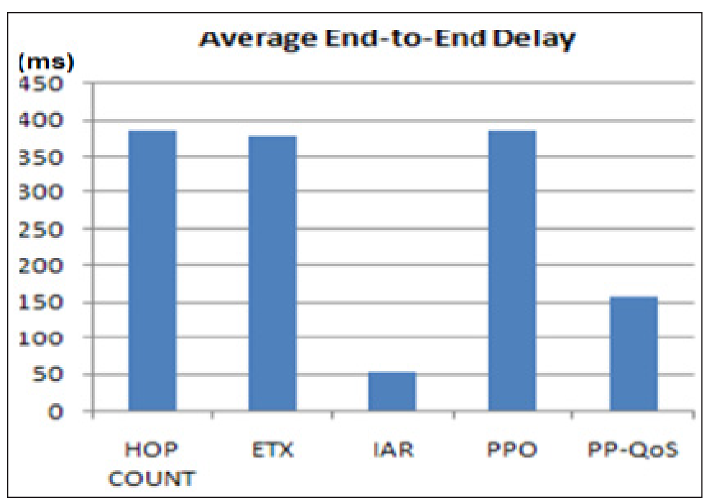
To study the performance in light traffic, i.e., 10 CBR, random topologies have been considered. Although the overall average throughput result of PP-QoS is the second worst in the light traffic in Figure 8(a), PP-QoS still acquires the best result in terms of the overall delay time with saving at least 11% communication time as illustrated in Figure 8(b). In addition, PP-QoS is the second best after IAR pertaining to the delay time of the real-time applications. Furthermore, the overall network performance also demonstrates the good adaptability of PP-QoS and PPO, while they keep providing efficient routing for data packets even in a quite network.

6. Conclusion And Future Work

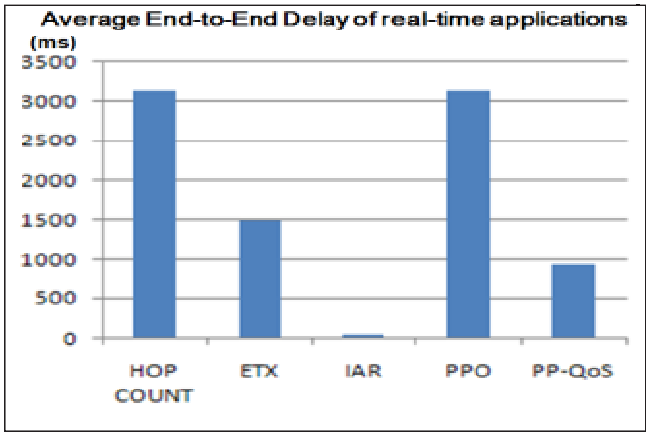
This paper presents a new relay node scheme to handle QoS-aware applications in WMNs. The new scheme is based on two new routing metrics PPO and PP-QoS, to promote the efficiency of WMNs with the aim of facilitating more efficient real-time applications delivery. To the best of our knowledge, our scheme is the first that enables the routing protocol to select the paths based on the sensitivity of the application to the required level of QoS provisioning. In our simulation experiments (not all our experiments are shown due to space limitation), our scheme has been compared to those based on the metrics of with Hop Count, ETX and IAR. Thus, for future research, we plan to investigate the capability of the proposed scheme at a higher data-carrying capacity. We anticipate that our scheme can be implemented in group-communication patterns, which could provide a concrete basis for a number of interesting extensions.



a) Average Throughput

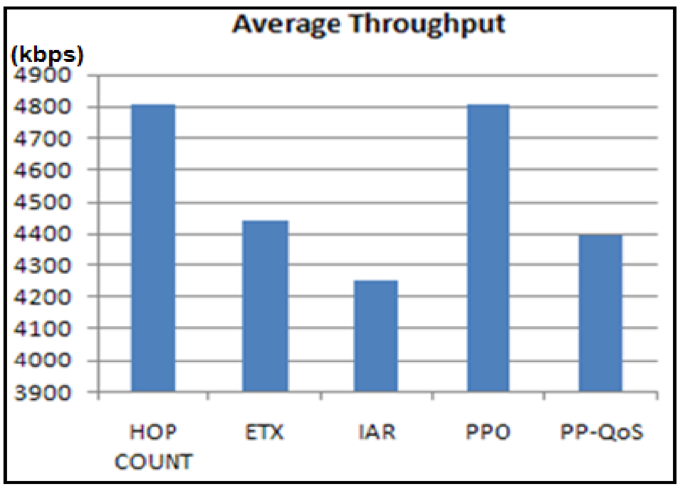


(b) Average End-to-End Delay

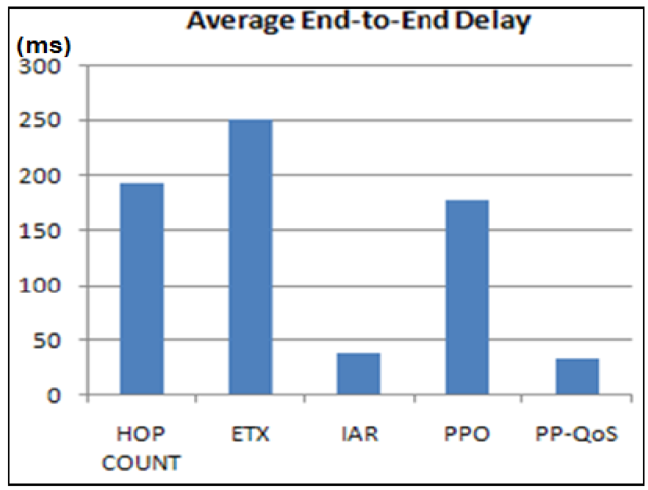


(c) Average End-to-End Delay of real-time applications

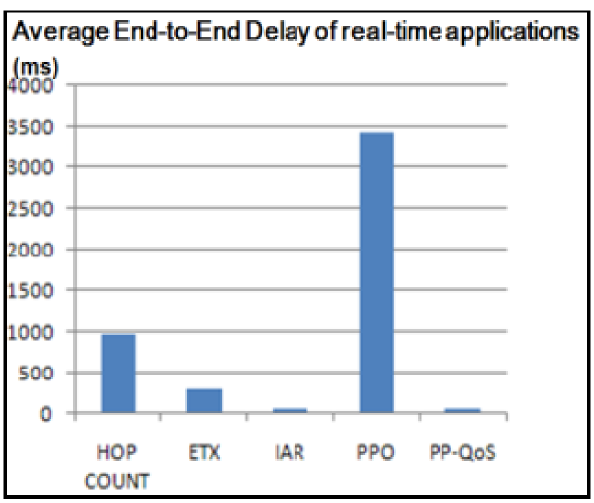
Figure 7. (a) (b) (c) in light traffic grid topology networks



(a) Average Throughput



(b) Average End-to-End Delay



(c) Average End-to-End Delay of real-time applications

Figure 8. (a) (b) (c) in light traffic random topology networks

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