Adaptive Situation-Aware Load Balance Scheme for Mobile Wireless Mesh Networks

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Abstract—**Mobile Wireless Mesh Networks (MWMNs) not only can provide high-bandwidth services for a large number of users, but also offers a good solution to the last-mile problems. However, the abundant net flow resulted from the great number of users may lead to the network traffic jam. To solve this problem, we proposed an Adaptive Situation-Aware (ASA) routing metric. We also designed a load balance scheme with Max-flow min-cut theory to route the network flow to the optimal path to achieve load balance among nodes in MWMNs.**

Keywords- Wireless Mesh Networks; Mobile Wireless Mesh Networks; Routing Metric; Load Balance

I. INTRODUCTION

With the rapid development of networks in recent years, people nowadays always want to access high-bandwidth network anytime and anywhere for enjoying ubiquitous network services. Owing to its high transmission rate, low deployment cost, and high coverage, Wireless Mesh networks (WMN) have replaced wired networks gradually and even performs well in residential areas that are incapable of line-of-sight transmissions.

In typical WMN, the constitution of the nodes can be divided into three layers. The first layer is composed of Internet Gateways (IGWs), which is responsible for connecting external wired networks and internal MR (Mesh Router) to provide network services. MR in the second layer takes the responsibility for connecting the Mesh Clients (MCs) in the third layer and the IGW in the first layer [1]. According to this constitution, WMNs can be classified into three kinds: Infrastructure WMNs, Client WMNs and Hybrid WMNs [2].

- *Infrastructure WMNs*: MR connects the IGW and MCs, and MR can form a backbone for MCs' transmissions.

- *Client WMNs*: This peer-to-peer structure is constructed by MCs. In such an Ad Hoc network, MCs manage the routing and the organization. Mesh Routers are not necessary.

- *Hybrid WMNs*: This hybrid architecture is composed of Infrastructure WMNs and Client WMNs as shown in Fig. 1. MCs can connect to MR or connect with one another through MCs.

The WMNs have a stable topology, which may changes due to MR failures, or new MR joints to WMNs. The components in WMNs usually have very low mobility, which is called Static WMNs. However, MCs usually are mobile between MRs which is called Mobile WMN (MWMN). In WMMNs, mesh node routes packets to destination with multi-hop. The most concerned traffic is oriented between MCs and IGWs to access Internet resource for users. The transmission efficiency may decrease owing to the lack of the bandwidth, packet loss or channel interference. Therefore, to optimize the transmissions, the routing metric is needed for selecting best path for nodes and distribute the flow to achieve the load balance of MWMN.

In WMNs, the nodes usually choose the shortest path or the path with the fewest hops for their transmissions, but this cannot guarantee the quality and efficiency of the path. For this reason, we need a routing metric for choosing the path of high quality and efficiency, and maintaining the optimal path whenever the net flow changes so that the load balance of the network can be guaranteed. In this paper, we propose the Adaptive Situation-Aware (ASA) routing metric to decide the optimal path for mobile MCs and increase the communication efficiency and decrease the interference impact. By analyzing
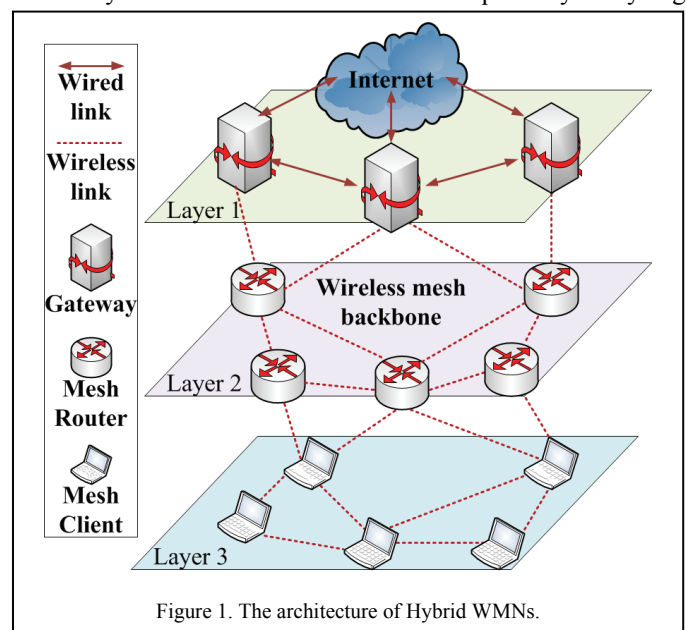

Figure 1. The architecture of Hybrid WMNs.

the path load and the nodes' queue load, our proposed scheme can select the optimal path for nodes and distribute the flow to the MR with lower load. In this way, not only the load balance can be reached, but also the transmission efficiency of the network can be improved.

We have three major contributions in this work: 1) we classify the existing load balance routing metric and load balance scheme; 2) in order to achieve the load balance in MWMNs, we proposed an adaptive routing metric under the consideration of transmission efficiency and interference; 3) finally, we proposed a novel scheme based on our adaptive routing metric and Max-flow min-cut theory for improving the load balance in MWMNs.

This paper is organized as follow. Section II classifies existing load balance routing metrics and algorithms, and explains the advantages of ASA metric. Section III explains our proposed load balance scheme and routing metric. The performance and simulation of the proposed load balance scheme is elaborated in Section IV and the conclusion is given in Section V.

II. RELATED WORKS

Based on the different routing metrics and target of load balance, we can classify the load balance schemes into two categories: static load balance routing and dynamic load balance routing.

The static load balance routing aim at the balanced bandwidth allocation for users. It can improve overall network utilization and allow more traffic flow in MWMNs. The authors in [3] proposed the algorithm which constructs load-balanced backbone tree and balances traffic flows on each backbone tree. The authors in [4] proposed an approximation algorithm for NOC (Network Operation Center) to centralize management and balance the traffic load for nodes with different node weight. The authors in [5] proposed algorithm with lexicographic optimization to distribute the load in a min-max sense on each link in the network.

The dynamic load balance routing mainly provides efficient connection to destination. It solves the traffic congestion and improves overall network throughput, but it can't guarantee QoS (Quality of Service) requirement for each user in MWMNs. In [6], the authors proposed ETX (Expected Transmission Count) metric to provide efficient path by accounted the packet delivery ratio. However, ETX is only for single-channel environment. As the refinement of ETT (Expected Transmission Time), the authors in [7] proposed WCETT (Weighted Cumulative Expected Transmission Time) metric. Compared with ETX, WCETT accounts the transmission rate and the channel diversity to perform efficient routing for multi-radio environment. The Authors in [8] proposed IAR (Interference-Aware Routing) metric which accounts intra-flow and inter-flow interference based on the state time of the packet transmission to select an efficient path. The airtime metric proposed by [9] is to perform radio-aware routing by accounted channel access and protocol overhead, transmission rate and frame error rate. The authors in [10] proposed INX (Interference Neighbors Count) metric which

extends the ETT and accounts the interference by wireless links to select a path with less interference.

In this paper, the proposed ASA metric and routing scheme is belonging to the dynamic load balance routing. For MWMNs, we have two mainly advantages by using dynamic load balance routing scheme. First, In WMNs, the main traffic is from the user to IGW for accessing Internet resources. So, IGW becomes bottleneck for most of the situation, not Mesh Router. Based on ASA metric, the proposed scheme can select an efficient path to IGW. It has more benefit than balanced the bandwidth of links between the Mesh Routers. Second, the proposed scheme doesn't have to build a backbone tree in advance or manage by the centralized server, and focus on the flow which going to IGW. By utilizing ASA metric, it can adaptively route the most efficient path, even if the destination is not IGW or in the MWMNs.

III. PROPOSED LOAD BALANCE SCEHEME

Setting up the routing metric is the first step of load balance scheme. However, the most existing routing metrics only concern some factors for their load balance goal. Hence we proposed an Adaptive Situation-Aware (ASA) metric under the fully consideration of the situation of MWMNs. Furthermore, we propose a load balance scheme based on ASA metric to select the path with good performance and decrease the effect by the interference, but also keeps the load balance of MWMNs. We detail the proposed metric and routing scheme as follow.

A. The Calculation of Adaptive Situation-Aware (ASA) Metric

In order to provide a situation-aware routing metric for MWMNs, our proposed metric is based on IAR metric [8] and Airtime metric [9]. The ASA metric can be defined by

$$ASA(p) = \sum_{i \in p} ASA(i), \tag{1}$$

where

$$ASA(i) = \left[O_{ca} + O_p + \frac{B_t}{r} \right] \frac{1}{1 - \alpha_{ub}}. \tag{2}$$

O_{ca} means the channel access overhead, O_p stands for the protocol overhead, and B_t symbolizes the bits of the test frame. Table I. shows the constant values of O_{ca}, O_p and B_t of 802.11a and 802.11b/g presented in [9]. r refers to the transmission rate, and α_{ub} represents the unproductive busyness resulted from calculating the state time of the transmission.

TABLE I.   REPRESENTATIVE CONSTANSTS OF AIRTIME METRIC

	802.11a	802.11b/g	Description
O_{ca}	75μs	335μs	Channel access overhead
O_p	110μs	364μs	Protocol overhead
B_t	8192bits	8224bits	Bits in test frame

In order to more accurately estimate the required resources of nodes for transmitting a packet that includes the backoff time, α_{ub} in IAR metric is adopted. In IAR metric, [8] defines α_{ub} as

$$\alpha_{ub} = \frac{T_{Wait} + T_{Collision} + T_{Backoff}}{T_{Wait} + T_{Collision} + T_{Backoff} + T_{Success}}. \quad (3)$$

The different states are defined as follow.

- $T_{Success}$: This state means that the node has successfully received the acknowledgement about the transmitted packet.

- $T_{Collision}$: This state means that the node has delivered a data packet but no acknowledgement about the packet is returned.

- T_{Wait}: This state means that when detecting that the medium is busy, the node keeps waiting until its turn.

- $T_{Backoff}$: This state means that when the node needs to communicate with others and the medium is also available. According to IEEE 802.11 standard, the node has to wait for a random time and the medium must keep being available during the waiting time.

When the node is going to transmit a packet to another one, or receives a packet that needs to be transferred, the node will experience a series of transmission states, including success, collision, wait and backoff, as shown in Fig. 2.

Finally, ASA sums the cost of nodes on path p by (1), then we can get the ASA metric cost of path p. Fig. 3 is a path selection example by using the proposed ASA metric. When the Node A wants to transmit data to the Node D, even the Link AD is only one-hop distant, the Link AD is not the optimal path according to the calculation of the ASA metric. The ASA metric chooses three paths with the minimum total metric cost to reach the Node D. Therefore, our proposed metric will choose the Link AC and the Link CD to reach the Node A.
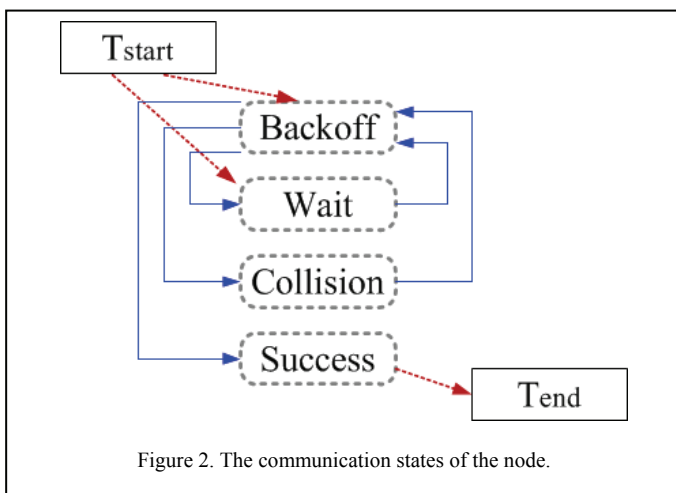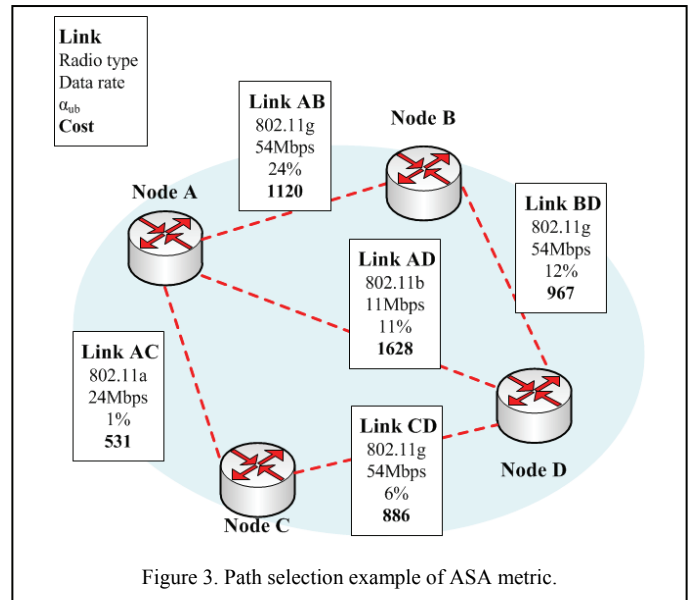

Figure 3. Path selection example of ASA metric.

B. The Concept Of Max-flow Min-cut

However, it is not enough to choose the path with minimum ASA metric cost. Because the path might be chosen with uneven metric cost that cause the packet loss increasing. In order to decrease the packet loss and further achieve load balance, we adopt the concept of Max-flow Min-cut. In [11], the max-flow min-cut theorem is defined as following.

Theorem. For any network $N = (G, c, v_s, v_t)$, the maximum value $|f|$ of any flow f in N is equal to the minimum capacity $c(C)$ of any v_s-v_t-cut C in N.

In the situation that several paths have the same ASA metric cost when the distribution of the links' cost is different. It means that the transmission rate of the link is disproportionate and the load of some nodes on the path would be rather heavy. As shown in the Fig. 4, although the ASA metric costs of these two routing path from the Node A to the Node D are the same, the load distribution on Link ABD is different from the Link ACD. Because of the load of the Link BD is more heavily than the Link AB. It might cause lots of

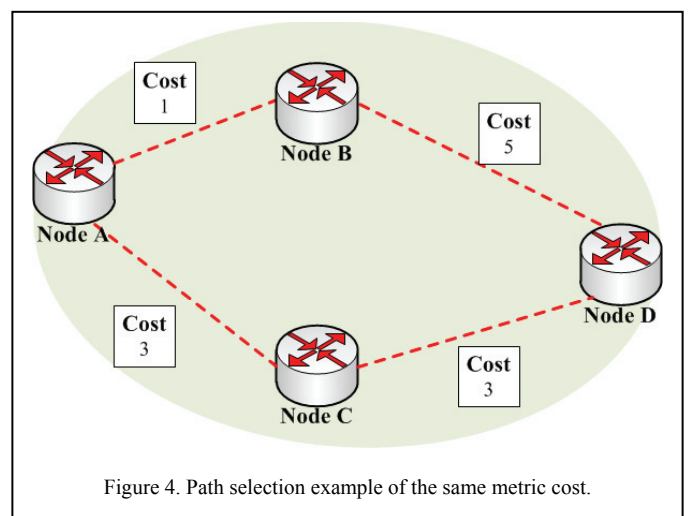Figure 2. The communication states of the node.

Figure 4. Path selection example of the same metric cost.

packets congested at the Node B and lead to the packet loss when flows go through the Link ABD. On the contrary, the transmission rate of the path via Node C is rather uniform and the packet loss thus can be decreased when the flows go through the Link ACD.

This load balance situation is just like water flow in water pipe. Because the maximum flow of overall network is limited to the link capacity, and the node before the link will become the bottleneck. Consequently, we choose the path with the load more uniformly based on the concept of Max-flow Min-cut theorem to reduce the probability of packet loss. It can be define as

$$V = \frac{1}{n}\sum_{i=1}^{n}\left(ASA(i) - \overline{ASA}\right)^2 . \tag{4}$$

We use V to calculate the load distribution on each path. It is assumed that there are n links of the path, $ASA(i)$ is the ASA metric cost of the i-th link of the path, and $\overline{ASA}$ is the average ASA metric cost of the path. We also set up the range for initiating this calculation. If the difference between the minimum metric costs is under 10%, then the calculation of load distribution is trigged. It makes the proposed scheme don't be impacted too much with the ASA metric, but can chose the path with uniform load in reasonable. When the metric cost of some paths is close to the minimum one, we use (4) to calculate the V of the ASA metric cost on the path, and select the path with the minimum V. The bigger V refers to the more seriously congested the node is. To decrease the packet loss caused by the heavy load, we therefore have to choose the path with the minimum V.

C. Load Balance Scheme

Nevertheless, the quality of the paths changes from time to time. If the load of the nodes on the path increases seriously, the transmission efficiency of the original optimal path will decrease. Moreover, to change the paths too frequently might lead to an unstable network. For this reason, we need a scheme to measure the metric cost of the paths periodically so that the nodes' transmissions can be maintained on the optimal path and the changes of the paths will not too frequently. Hence we design a load balance scheme to periodically update the metric cost of the nodes and delete the data of left nodes in the MWMNs.

In our proposed scheme, we set the time threshold δ of the periodically update. The scheme updates the metric cost on each path when the time of last update is over δ. However, δ may have different value with different environment (like topology, number of flow or flow rate). We can change δ to achieve the best performance with different environment.

The following table shows the algorithm of the above-mentioned scheme in pseudo code. The source node periodically updates the metric cost of all possible paths, and compares the current metric cost with the minimum one. As long as the current path is still with the minimum metric cost from other possible paths, our scheme regards the current path load balanced. On the other hand, once the other path has the minimum cost in the next periodically update, the flow will

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Algorithm Load Balance Scheme with ASA Metric

Initialize wireless mesh network
STEP1.
Source node S calculate $ASA(p)$ of each possible path;
if (the $ASA(p)$ of some path $\approx$ the minimum $ASA(p)$)
　　{ **select the path with minimum V ;** }
else
　　{ **select the path with minimum $ASA(p)$;** }

STEP2.
Set $i = 1$;
while (the current time of S > the start time of $S + \delta * i$)
　　{ **update $ASA(p)$ of each possible path;**
　　　$i = i + 1$; }

STEP3.
When Source node S updata $ASA(p)$;
if ($ASA(p)$ of current path $\leq ASA(p)$ of the other path)
　　{ **Load keep balanced at current path;** }
else if ($ASA(p)$ of current path $>> ASA(p)$ of the other path)
　　{ **Switch path to the path with minimum $ASA(p)$;** }
else if ($ASA(p)$ of current path $\approx ASA(p)$ of the other path)
　　{ **Select the path with minimum V ;** }

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change the current path to the other path on next periodically update. We use this scheme to maintain the path on the optimal path and avoid the situation that changes the path too frequently.

IV. PERFORMANCE ANALYSIS

In this paper, NS2 simulation tool is adopted to evaluate the throughput of our proposed load balance scheme. We compare our proposed load balance scheme with WCETT, Airtime, and Hop count.

In MWMNs, the main traffic is from mesh nodes to gateway. In order to simulate the real situation, we set up heavy network traffic in our designed MWMNs scenario. In the scenario, there are three CBR flows named Flow1, Flow2 and Flow3 randomly generated to the same gateway. The Flow1 starts at the beginning of the simulation, while the Flow2 and the Flow3 starts at the 200th second. The three flows will interact with each other. We use the three flows to produce heavy load scenarios. According to the result from our experiment, we set the δ to 4 seconds.

The other simulation parameters are shown in the Table. II. We simulated our MWMNs scenarios with 20 times to get the result from the three CBR flow. Each random topology will reset their position from random nodes, and it will perform with different metrics and schemes respectively. Finally, we compare the throughput of each scheme to prove the load-balancing ability of our proposed scheme.

TABLE II.   SIMULATION PARAMETERS

Parameter	Values
Scenario Size	500 m*500 m
Nodes	Generated 49 nodes randomly Generated 1 gateway on the corner
Transmission Range	250 m
Carrier Sense Rage	550 m
Flows	3 CBR flows
CBR Rate	1 Mbps
Packer Size	1500 bytes
δ	4 sec
Simulation Time	600 sec

Moreover, Hybrid Wireless Mesh Protocol (HWMP) [12] is the default routing protocol of IEEE 802.11s. We select HWMP for our routing protocol with Hop count, Airtime and ASA. WCETT has its' own routing protocol. Then, we compare three results with different schemes to present the performance.

- Total throughput

- Average end-to-end delay

- Route overhead

First, the total throughput of each scheme is shown in the Fig. 5 and we can compare the average throughput of each flow with Table. III. At the beginning, the throughput of ASA is higher than WCETT. Because Hop count only considers hops, Airtime and WCETT only considers the packet error rate in the time instantly when the packet have send out. But our ASA considers not only the time include the packet haven't send out, but also chose the path with uniform load distribution. So, ASA metric can keep higher throughput then other scheme from 0-200 sec.

At 200th, the Flow2 and Flow3 will start to transmit. Because Hop Count, Airtime and WCETT can't change path when the network traffic load become heavy, the three flows will interfere with each other. So, it will reduce the throughput seriously. But our proposed ASA load balance scheme will update the load status on the path periodically. It can calculate the metric cost of paths and change to the path with the minimum load so that the total throughput can be improved.

Our proposed ASA load balance scheme not only provides higher throughput at beginning. In the heavy load situation with three flows, ASA still can keep higher total throughput. Even the average throughput of flow1 in ASA is lower than Airtime, ASA can decrease the effect of interference by period update. Hence the throughput of each flow in ASA is more stable than Airtime.

The average end-to-end delay of each scheme is shown in the Fig. 6. The average delay of ASA is the lowest than other schemes. Because ASA can chose a path which transmit more efficiently than other schemes. When the network traffic become congestion and the performance of the current path decrease, ASA can change the current path to the path with lighter load. So that it can get better performance and keep stable by periodically update.

Finally, the route overhead of each scheme is shown in the Fig. 7. We can see that ASA has more overhead after 200 sec. Because ASA has period update mechanism which produces more control messages to update the metric cost on each path. However, the total route overhead of ASA is still in reasonable and better than WCETT. In the simulation results, our proposed ASA load balance scheme provides the highest throughput and lowest end-to-end delay, but produces slightly route overhead than Airtime and hop count.

TABLE III.   AVERAGE THROUGHPUT OF EACH FLOW

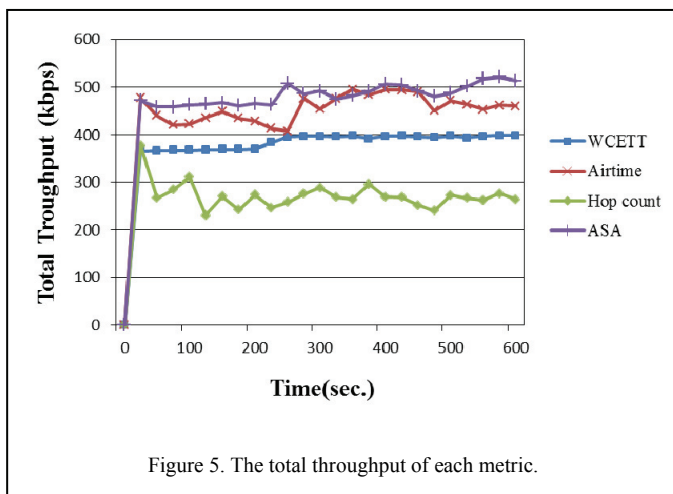|	0-200 sec	201-600 sec		
	Flow1 (kbps)	Flow1 (kbps)	Flow2 (kbps)	Flow3 (kbps)
Hop count	281.8	83.2	82.3	101.4
WCETT	368.0	125.1	151.5	118.7
Airtime	384.8	160.6	147.5	155.3
ASA	463.7	143.8	184.0	167.3

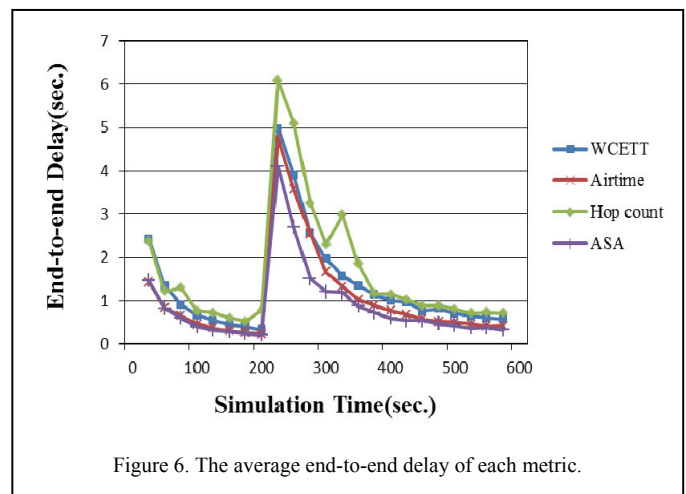Figure 5. The total throughput of each metric.

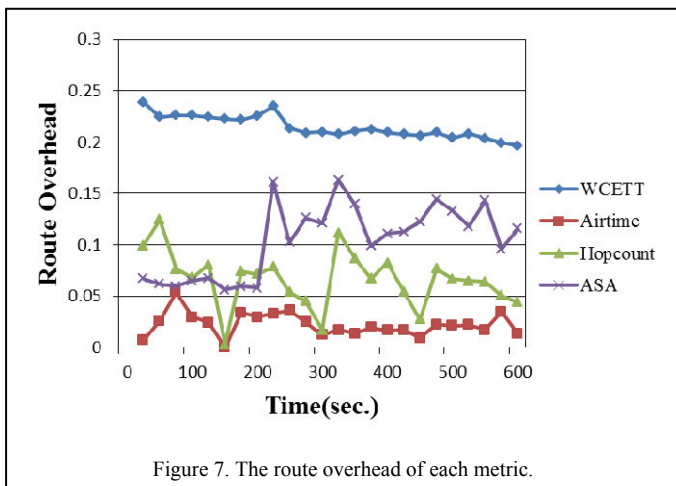Figure 6. The average end-to-end delay of each metric.

Figure 7. The route overhead of each metric.

V. CONCLUSION

This paper proposes an adaptive situation-aware load balance routing scheme that suit for MWMNs. In order to maintain the optimal path during the transmissions, we also propose a routing metric for judging the situation of routing paths. The simulation results indicated that our proposed ASA scheme with routing metric not only achieves the load balance but also improve the total throughput and end-to-end delay.

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