A Routing Metric Based on Available Bandwidth in Wireless Mesh Networks

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***Abstract*—The Wireless Mesh Network (WMN) is one of wireless communication technologies with a low cost and rapid deployment. WMNs should need metrics for optimal path selection in routing. Although a lot of routing metrics have been proposed for WMNs, they did not suitable to avoid the high traffic area. In this paper, we propose a new routing metric for high throughput and low average end-to-end delay while it occur high traffic area in networks. This metric is called the Expected Available Bandwidth (EQB). EAB is a metric which considers the available bandwidth and the successful transmission ratio. Our simulations are conducted by NS-2 and the result of those shows that EAB is better than the other metrics on the packet delivery ratio and the average end-to-end delay.**

***Keywords*— Wireless mesh networks, load balancing, routing metric, available bandwidth, ETX**

I. INTRODUCTION

As various wireless networks evolve into the next generation to provide better services, a key technology, wireless mesh networks (WMNs), has emerged recently.

A WMN is dynamically self-organized and self-configured, with nodes in the network automatically establishing and maintaining mesh connectivity among themselves (creating, in effect, an ad hoc network). This feature brings many advantages to WMNs such as low up-front cost, easy network maintenance, robustness, and reliable service coverage [1].

The draft standard defines a mesh network as two or more nodes that are interconnected via IEEE 802.11 links which communicate via mesh services and constitute an IEEE 802.11-based wireless distribution system (WDS). A mesh link is shared by two nodes who can directly communicate with one another via the wireless medium. The pair of nodes that share a link are neighbors. Any node that supports the mesh services of control, management, and operation of the mesh is a mesh point (MP). If the node additionally supports access to client stations (STAs) or non-mesh nodes, it is called a mesh access point (MAP). A mesh portal (MPP) is an MP that has a non-802.11 connection to the Internet and serves as an entry point for MAC service data units (MSDUs) to enter or exit the mesh (see Figure. 1). An MPP and MAP may be collocated on one device [2].

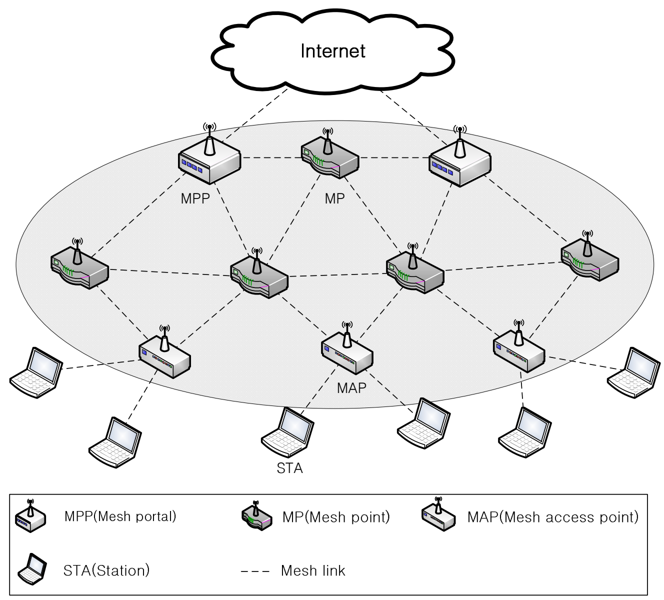

Figure 1. Configuration of WMNs

Although a wireless mesh network is one of the most hotspots in wireless network field, the routing protocol standardization of wireless mesh network is still on the way. The routing protocol of wireless mesh network is being used the algorithm in ad hoc network, AODV (Ad hoc On-demand Distance Vector). As a classical routing protocol for ad hoc network, AODV algorithm enables dynamic, self-starting, multi-hop routing between participating mobile nodes wishing to establish and maintain an ad hoc network. Most other routing protocols (e.g., DSR, DSDV and TORA) and AODV uses the shortest hops first algorithm. However, experiments and applications show that the shortest hops first algorithm is not appropriate for wireless mesh network because the number of hops from a source to a destination is used as an only routing metric. In fact, it is well-known that the path with minimal hops is not necessarily the best route. Due to the fact that routing protocols which only use hops as metric are not sensitive to the state of nodes and communication links, packet loss and transmission delay will increase dramatically even if only one node or link on the path with shortest hops becomes overload, and it become worse in wireless network because the throughput of wireless network declines far below the one in theory when network becomes overload [3].

The key issue of routing protocols for wireless mesh networks is how to define a routing metric that discovers a high bandwidth path and think wireless link characteristics. Wireless link metrics such as expected transmission count (ETX) and expected transmission time (ETT) are early proposals that typically achieve better throughput than the shortest hop count metric [4]. However, they did not consider link condition for increasing throughput of the overall network. It is caused low throughput and high end-to-end delay time of the entire network.

In this paper, we present a new routing metric for high throughput and low average end-to-end delay that considers the available bandwidth and the successful transmission ratio. We evaluate the packet delivery ratio and the average end-to-end delay time performance of proposed routing metric in NS-2.

The remainder of this paper is organized as follows. Section II presents related work with routing metric and routing protocol. Section III describes the proposed routing metric and mechanism. Performance evaluation on the NS-2 is presented in Section IV. Finally Section V concludes this paper.

II. Related Work

A. Routing Protocol

Routing protocols are at the heart of Wireless Mesh Networks (WMNs) and control the formation, configuration and maintenance of topology of the network. Owing to their common features, routing protocols developed for ad-hoc networks are applicable for WMNs. Some of the commonly used routing protocols in WMNs are Ad-hoc On-demand Distance Vector (AODV) routing [5].

1) Ad hoc On-demand Distance Vector (AODV)

The AODV routing protocol is a reactive routing protocol; therefore, routes are determined only when needed. Hello messages may be used to detect and monitor links to neighbours. If Hello messages are used, each active node periodically broadcasts a Hello message that all its neighbours receive. Because nodes periodically send Hello messages, if a node fails to receive several Hello messages from a neighbour, a link break is detected.

When a source has data to transmit to an unknown destination, it broadcasts a Route Request (RREQ) for that destination. At each intermediate node, when a RREQ is received a route to the source is created. If the receiving node has not received this RREQ before, is not the destination and does not have a current route to the destination, it rebroadcasts the RREQ.

If the receiving node is the destination or has a current route to the destination, it generates a Route Reply (RREP). The RREP is unicast in a hop-by-hop fashion to the source. As the RREP propagates, each intermediate node creates a route to the destination. When the source receives the RREP, it records the route to the destination and can begin sending data. If multiple RREPs are received by the source, the route with the shortest hop count is chosen.

As data flows from the source to the destination, each node along the route updates the timers associated with the routes to the source and destination, maintaining the routes in the routing table. If a route is not used for some period of time, a node cannot be sure whether the route is still valid; consequently, the node removes the route from its routing table.

If data is flowing and a link break is detected, a Route Error (RERR) is sent to the source of the data in a hop-by-hop fashion. As the RERR propagates towards the source, each intermediate node invalidates routes to any unreachable destinations. When the source of the data receives the RERR, it invalidates the route and reinitiates route discovery if necessary [6].

B. Routing Metric

Various routing metrics have already been proposed. In this section, we discuss existing routing metrics for WMNs. Routing metrics have a decisive effect on the network performance. Good routing metric should carry enough information about the link quality so that a node can determine the best path to reach the destination. The already proposed routing metrics for WMNs consider hop-count, Expected Transmission Count (ETX), Expected Transmission Time (ETT) and etc.

1) Hop-count(HOP)

Hop count is the most commonly used routing metric in existing routing protocols such as DSR, AODV, DSDV and GSR. It reflects the effects of path lengths on the performance of flows. Since a hop count metric is isotonic, efficient algorithms can find loop-free paths with minimum hop count. However, hop count does not consider the differences of the transmission rates and packet loss ratios between different wireless links, or the interference in the network. Hence, using a hop count metric may not result in good performance [7].

2) Expected Transmission Count (ETX)

ETX measures the expected number of MAC layer transmissions (including retransmissions) needed for successfully delivering a packet through a wireless link. The path weight is the sum of the ETXes of all links along the path. ETX starts with measurements of the underlying packet loss probability in both the forward and reverse directions, i.e. df and dr, by using one-hop broadcast probe packets. Then it calculates the expected number of transmissions by:

$$ETX = \frac{1}{d_f \times d_r} \tag{1}$$

Since both long paths and lossy paths have large ETXs, the ETX metric captures the effects of both packet loss ratios and path length. However, it does not consider either available bandwidth or the fact that different links may have different transmission rates [7].

3) Expected Transmission Time (ETT)

ETT improves ETX by considering the differences in link transmission rates. It measures the expected MAC layer duration for a successful transmission of a packet on a given link. The path weight is simply the sum of all links' ETTs. The relationship between the ETT and ETX can be expressed as:

$$ETT = ETX \times \frac{S}{B} \tag{2}$$

where S denotes the packet size and B denotes the bandwidth (raw data rate) of the link. By introducing B into the path weight, the ETT metric captures the impact of link capacity on the performance of the path [8, 9]. However, it does not consider including available bandwidth in each link for selection of routing path.

III. Proposed Routing Metric

As mentioned in chapter Ⅱ, Hop, ETT and ETX have some problems. When the traffic of a network is increased, those metrics bring about low packet delivery ratio and high end-to-end delay time. In this paper, when the high traffic is concentrated into one area, we call the traffic concentration area.

The traffic concentration area is mainly occurred in intermediate nodes of a network when it has a heavy traffic load. However, other metrics does not find the path to avoid the traffic concentration area, because they do not consider the condition of the networks such as available bandwidth. It is cause of high drop ratio, low throughput and high end-to-end delay time. Therefore, we need to solve the problem as new routing metric.

Previous research is not considered with both available bandwidth of each link and successful transmission ratio. In our proposed scheme, the concept of available bandwidth of each link on a path and successful transmission ratio are combined and are used to avoid the traffic concentration area. We call this new routing metric Expected Available Bandwidth (EAB).

We need two elements for the calculation of EAB. One is the available bandwidth. We define the available bandwidth as the residual bandwidth of each link on all nodes. Each available bandwidth about all links can be calculated by a link capacity minus a link load on a node respectively. Under the proposed scheme, each available bandwidth is used to diagnose and understand the state of a link on a node. Available bandwidth value reflects the throughput of each link

The other is successful transmission ratio. It is defined as ratio of MAC layer transmissions needed to successfully deliver a packet from a sender to a receiver. In this paper, successful transmission ratio is used to estimate of the link quality.

A. Expected Available Bandwidth (EAB)

EAB is proposed to solve the traffic concentration area problem and is composed with two elements; available bandwidth and successful transmission ratio. The available bandwidth is computed as estimation with the total bandwidth minus the occupied bandwidth of each link on a node. If a link has a lot of available bandwidth, a node can transmits more data quantity through the link. In EAB, *AB(l,t)* is used to calculate the available bandwidth of link at certain time. *AB(l,t)* given by

$$AB(l,t) = BW_{total}(l,t) - BW_{occupied}(l,t) \tag{3}$$

,where l is link and t is time. $BW_{total}(l,t)$ is the total assigned bandwidth of an individual link and $BW_{occupied}(l,t)$ is the occupied bandwidth of each link.

In EAB, $P_{success}(l,t)$ is used to calculate the successful transmission ratio. $P_{success}(l,t)$ is given by

$$P_{success}(l,t) = d_f(l,t) \times d_r(l,t) \tag{4}$$

,where *l* is link and *t* is time. $d_f(l,t)$ is the forward delivery ratio and $d_r(l,t)$ is the reverse delivery ratio by using one-hop broadcast probe packets. The result of $P_{success}(l,t)$ is the probability value which means successful transmission ratio of each link at that time.

EAB's equation is as follows:

$$EAB(l,t) = AB(l,t) \times P_{success}(l,t) \tag{5}$$

,where *l* is link and *t* is time. *EAB(l,t)* is a metric to calculate an available bandwidth with successful transmission ratio. It means expected available bandwidth of each link at certain time on a node. This metric select a path which have low end-to-end delay and high delivery ratio.

B. Routing mechanism of EAB

In this section, we describe a routing mechanism of EAB. In ETX, every node sends out periodic probe message to compute the forward and reverse delivery ratios of the link. EAB uses this mechanism to calculate the value of available bandwidth and successful transmission ratio. Our routing metrics is computed during last 10 seconds by each node.

A source broadcasts a Route Request (RREQ) for that destination because it has to find a path when a source has data to transmit to a known destination. This procedure is called as route discovery. Each node sends a RREQ broadcast packet with computed EAB during route discovery until RREQ arrives at a destination.

In initial time, the value of EAB is set to infinity value when a source sends an RREQ to destination. At each intermediate node, a reverse link to the source is created in routing table of it when a RREQ with EAB is received.

In order to decide minimum value of EAB, each intermediate node has to compare the current value of its EAB with the EAB value in RREQ received from previous node. That is why minimum EAB value influences mainly the overall throughput on the path. Subsequently a node records the minimum EAB values in routing table. Each node has to create and send RREQ with minimum EAB. Its process repeats to arrive at the destination.

When RREQ packets arrive at its destination, a destination finds the maximum EAB value among a lot of received EAB value. It is to select the path having the maximum throughput among candidates. Although intermediate nodes in RREQ procedure find the minimum EAB values of each link, the destination selects the maximum EAB value for maximum throughput in overall path. We present the following two pictures for more details about mechanism of EAB procedure.

In figure 2, we illustrate how to find minimum ABLQ. In Figure 2, (a) is illustrated the calculation process of EAB related with each link. Circle labelled by 'S' is a source node and other circles are intermediate nodes. In Figure 2, (b) shows initial EAB value and process of finding a minimum EAB in a node. In Figure 2, (c) and (d) display the comparison process between node's EAB value and EAB value in RREQ and the RREQ sending procedure.

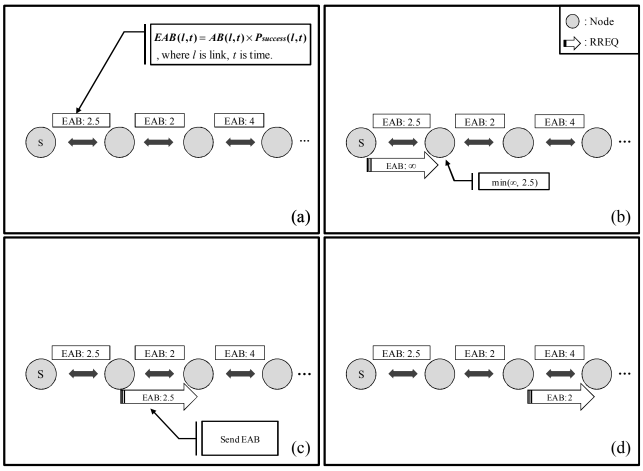

Figure 2. Procedure for finding a minimum ABLQ

Figure 3 is illustrated the RREP sending procedure with EAB. In Figure 3, (a) and (b) is illustrated RREQ sending process about each link. Circle labelled by 'D' is a destination and other circles are intermediate nodes Figure 3(c) represents finding maximum EAB value. A destination uses maximum value finding function and selects the maximum EAB among all of EAB values in received RREQ.

As shown Figure 3(d) which represents RREP sending procedure, a destination generates a Route Reply (RREP) with a computed result. The generated RREP is sent in a hop-by-hop fashion to the source. As the RREP propagates, each intermediate node creates a route to the destination.

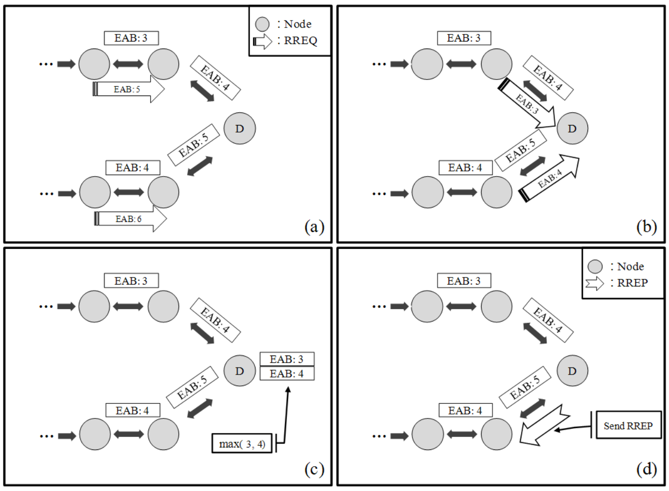

Figure 3. An example of RREP sending procedure in ABLQ

RERR sending and the other operation process is same to original AODV.

IV. PERFORMANCE EVALUATION

The performance of the proposed EAB is compared with other routing metrics such as HOP, ETX and ETT by NS-2 simulator. We evaluated the performance in terms of the packet delivery ratio, the average end-to-end delay and the number of control message. In the case of WMNs, the efficient energy saving on mesh node is not an issue [1], and therefore we have not discussed it in this paper.

A. Simulation Environment

In this section, we describe the simulation environment of our proposed scheme. We used C++, TCL language, and NS-2, which is one of the famed for network simulator. We also adapted routing metrics including our EAB as well as Hop, ETT, and ETX to NS-2. We applied IEEE802.11 and AODV for performance measurement of routing metrics. Both protocols are used as the underlying MAC protocol in a small-scale WMN.

All simulations run for the duration of 100 seconds. Routing pairs in simulation are performed with seven flows. In each flow, a source node and a destination node in routing pairs is randomly selected among nodes. Packets created by a source node have the size of 512 bytes and are sent at a deterministic rate. Table 1 shows the detailed parameters of performance analysis in simulation.

Table 1. Simulation Parameter

Parameter	Value
Mac type	IEEE 802.11
Routing Protocol	AODV
Transmission range of node	150m

Map size	600m×600m
Simulation time	100s
Propagation model	Two-ray ground
Traffic type	CBR(UDP)
Packet size	512byte
Packets/second	1 ~ 10
Number of nodes	50
Routing pairs	7

Figure 4 shows our simulation topology. We make the topology of a mesh network which consists of 50 nodes.

They are randomly deployed in 600m x 600m square area.

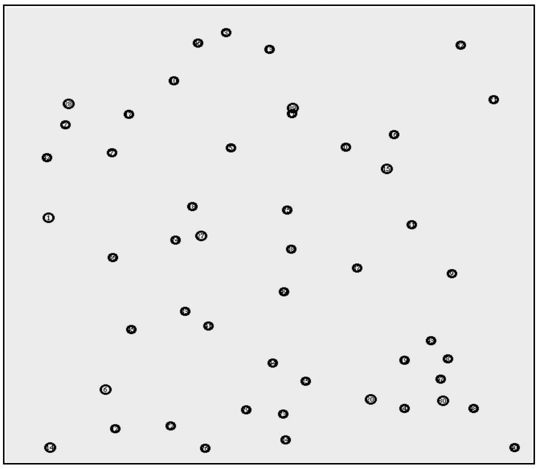

Figure 4. Topology in our simulation

B. Simulation Result

We measure packet delivery ratio and average end-to-end delay between a source node and a destination node according to increasing the traffic load in overall network. The results are presented in Figure 5 and Figure 6 respectively. There are seven routing pairs in simulation. Each routing pairs generate traffic from a source node to a destination node and are sent at a deterministic time. Figure 4 shows delivery ratio of all traffic flows.

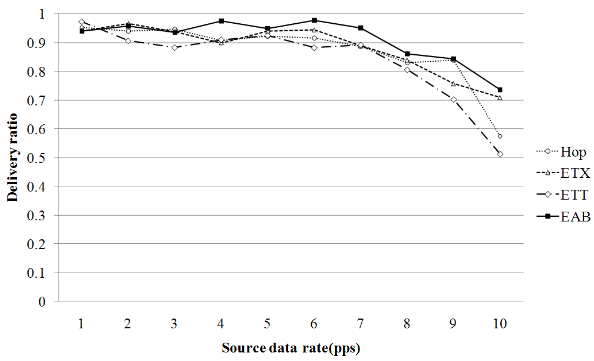

Figure 5. Delivery ratio of all flows

The traffic load in our simulation is increased only about 1-10 packets per second. Although traffic load is increased, EAB is still showed better performance than other routing metrics. The reason is simply that EAB selects a certain path with a lot of available bandwidth and high successful transmission ratio. Therefore it can avoid nodes in the traffic concentration area on mesh network.

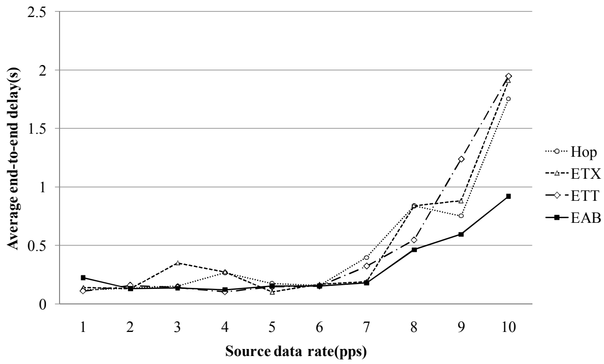

Figure 6. Average end-to-end delay

When traffic is increasing on a network, we can see that EAB has the lowest average end-to-end delay in Figure 6. That situation is why overall throughput of network is affected by the available bandwidth and success transmission ratio.

The number of control message is depicted in Figure 7. Control message in our simulation means AODV's routing control message such as probe (hello), RREQ, RREP and RERR. The great number of control messages means routing overhead because control messages is also traffic on the network. Therefore increasing control messages can give the network burden.

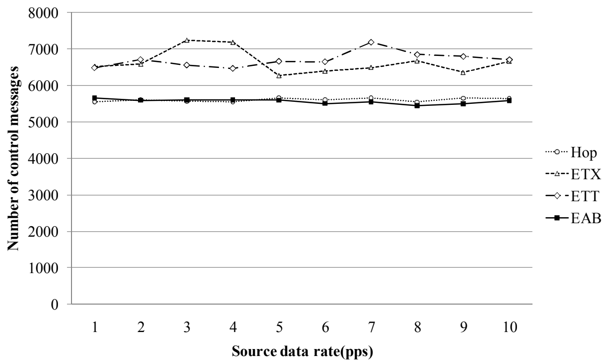

Figure 7. Number of routing control messages

In Figure 7, EAB is the lowest value which is the number of all control messages for establishing a certain path. ETX, ETT and EAB use probe messages for evaluation of link state so that there are a lot of control messages.

Although EAB use a lot of control message for a path selection and maintenance, it has lower quantity in control message than the others.

We compare our proposed metric with the others based on the packet delivery ratio and the average end-to-end delay time through extended simulations, and we show the superiority of our metric. We have simulation results of EAB with high delivery ratio in high traffic situation. We created arbitrary seven flows in network, and we checked only one flow's packet delivery ratio and average end-to-end delay. Figure 8 shows packet delivery ratio of one flow.

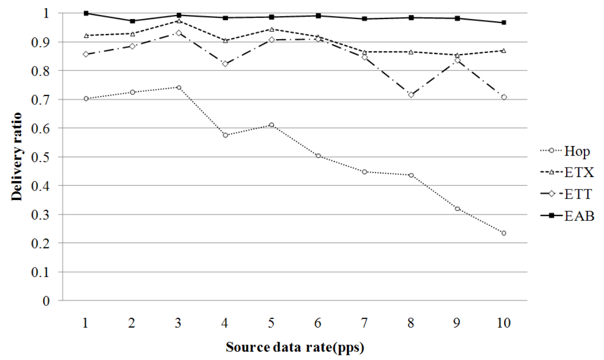

Figure 8. Delivery ratio of one flow

As shown in Figure 8, EAB shows high packet delivery ratio than other metrics in situation of high traffic. Because EAB considers available bandwidth, it selects a path through low traffic region.

Figure 9 shows average end-to-end delay of one flow, and we can observe the lowest average end-to-end delay time in EAB.

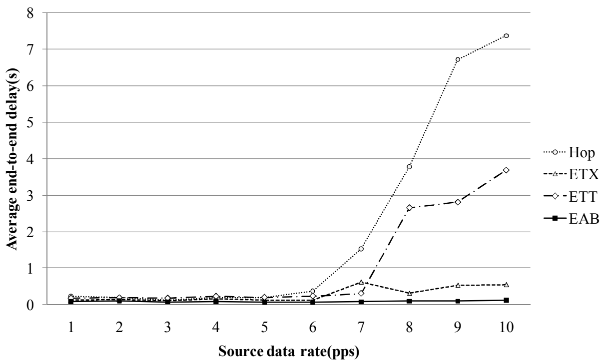

Figure 9. Average end-to-end Delay of one flow

On the other hand, we can see that other metrics have the increased average end-to-end delay time when traffic is increasing on a network. This situation is why the high average end-to-end delay of network is affected by the low throughput among links.

V. Conclusion

In this paper, we introduce new routing metric to solve the problem of high drop ratio, low delivery ratio and high end-to-end delay time in traffic concentration area. We call this new routing metric Expected Available Bandwidth (EAB).

The performance of the proposed EAB is compared with other routing metrics such as HOP, ETX and ETT by NS-2 simulator. We measure throughput ratio and average end-to-end delay between a source node and a destination node according to increasing the traffic load.

Our simulation results show that EAB has better performance than other routing metrics, regarding throughput ratio and average end-to-end delay. The reason is simply that EAB selects a certain path with a lot of available bandwidth and high successful transmission ratio. Therefore it can avoid nodes in high traffic region on mesh network.

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