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A WCMAB Metric Providing QoS Gurantee with an Effective Methodology of Node to Node Available Bandwidth Estimation for Multichannel Multirate Wireless Mesh Networks

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Abstract— ***Wireless Mesh Networks, one of the most popular and promising wireless network which aim towards providing best effort broadband internet services while being fast, scalable and more essentially economical. Generally mesh clients, mesh routers and mesh gateways are hierarchically combined to establish a wireless mesh network. In case of practical applications, introduction of QoS provision in WMNs is highly reliant on node to node bandwidth. In this paper we present an effective methodology for computation of node to node available bandwidth and a Weighted Cumulative Maximum Available Bandwidth (WCMAB) metric with bottleneck bandwidth consideration. Experimental results verify the effectiveness and efficiency of the WCMAB metric derived from the proposed methodology for calculation of node to node available bandwidth.***

Index Terms— ***Avaible bandwidth estimation, Wireless Mesh Network, QoS, bottleneck, interference.***

I. INTRODUCTION

Recent years the rapid development and extensive research on Wireless Mesh Network have introduced a new paradigm that emerges towards providing seamless broadband internet access. Mostly static (in nature) mesh routers and mobile mesh clients are two types of nodes configuring the Wireless Mesh networks. Each mesh router can act as an access point and also as a relay node that forward data packet to other mesh routers. As WMNs combine the features of both infrastructure based network and Mobile Adhoc Network, throughput and bandwidth are the basic concerns in Wireless Mesh Networks in ensuring QoS provisions.

It is also evident that introduction of multiple channels causes a distinct increase in throughput but cannot eliminate interference. A number of researches have shown that interference has a significant impact on the performance of

multihop Wireless Mesh Network. Beside this, in case of real time data transfer, bandwidth bandwidth guaranteed routes are to be selected to diminish the amount of delay and jitter.

Accurate estimation of wireless channel bandwidth at a mesh node is a tough ask as it is affected by a number of parameters, mainly by congestion, link variability, nodes' transmission and reception range. Therefore, estimating bandwidth guaranteed paths also ensures load sensitivity, interference awareness, link variability and more essentially effective utilization of network resources.

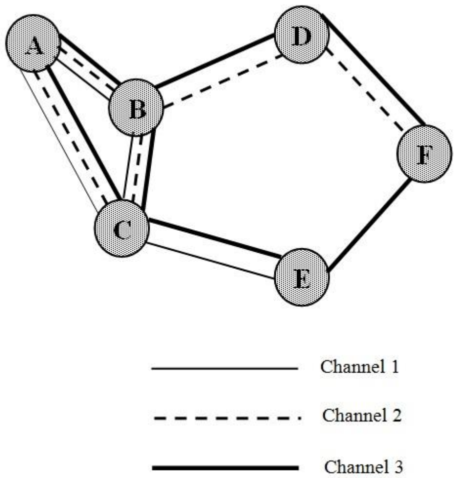

Fig. 1. Logical view of a typical multi radio mesh network

Traditional approach of bandwidth estimation through passive monitoring introduces extra overhead while involving several technical issues like deployment difficulty, resolving policy constraints of different network operators. Active researches have demonstrated the merits of active probing approach in establishing real time network services.

Our key contributions with this paper include:

- We establish a methodology for estimating node to node available bandwidth while computing the bandwidth consumption due to interflow and intraflow interference. The proposed methodology also grabs the influence of multiradio multihop mesh network.

- Based on the above methodology, we present a Weighted Cumulative Maximum Available Bandwidth (WCMAB) metric.
- Key features like isotonicity and finding bandwidth suitable path make it appropriate for routing real time data packets through loop free routes.
- Next, we present implementation of the proposed metric in the Optimized Link State Routing (OLSR) [10] protocol and perform extensive simulations in NS2 simulator [11] for a number of scenarios corresponding to different topologies.

II. ISSUES IN DESIGNING ROUTING METRICS

In order to provide desired performance, routing metrics must satisfy some criterions crucial to exploit fair throughput. Firstly, frequent route changes must be avoided. Secondly, designed metrics must reflect the changes in the network. Thirdly, metrics should posses isotonicity such that efficient algorithms with polynomial complexity can be applied. Finally, loop free routing must be ensured.

A. Ensuring stable routes

ETX Unstable routes with frequent changes can cause the overhead of excessive route updates and thus consuming the bandwidth unnecessarily. According to Yang *et al.*[12] and Draves *et al.*[13], in case of Wireless Mesh Networks(WMNs) topology dependent metrics are more suitable than load sensitive metrics as they assign path weights based on topological properties like hop count and link capacity.

B. Effective assignment of path weights to reflect actual network characteristics

In order to utilize the resources efficiently, routing protocols must select minimum weight paths. To achieve desired level of performance in terms of high throughput and low packet delay routing metrics must capture the characteristics of the mesh network. The key components that reflect the characteristics of the network are introduced in this section.

Number of hops

Path length itself can be treated as a routing metric. Though most of the MANET routing protocols introduces hopcount as the metric but in certain cases a path having higher hop count with high quality links is proved to produce significant improvement over a shorter path.

Link capacity

Measuring link capacity gives the rate of throughput that can be achieved for a given link (theoretically). Recently, most of the radios used are either cognitive or intelligent in nature which can automatically adjust their transmission rates to deal with lossy links.

Link quality

In order to find high quality links routing metrics basically depend on two parameters packet loss ratio and signal to noise ratio. More precisely a link with higher SNR and lower PLR can be considered as a good link and therefore must be preferred over lossy links with smaller hopcount.

C. Ensuring interference awareness

As the bandwidth of wireless links are shared, the nodes forwarding a flow face a strong competition of occupying bandwidth from its neighborhood in the form of interference.

Intraflow interference

When nodes of two or more hop distance engaged in a flow operate on same channel, the interference caused is termed as intraflow interference. Such interference increases bandwidth consumption and hence requires special consideration in design of a routing metric.

Interflow interference

Not only intraflow interference, a node also realizes interference caused by the neighboring nodes that are not in the same flow but operating in the same channel. Moreover involvement of multiple flows and routes make it much more tedious to encounter such interflow interference.

D. Computability by the efficient algorithms of polynomial complexity

The property that ensures the necessary and sufficient conditions for computing minimum weight paths with efficient algorithms [12] is called isotonicity. Sobrinho demonstrated [14],[15] that isotonicity is a sufficient and necessary condition for both the BellmanFord and Dijkstra's algorithm to find minimum weight paths. A nonisotonic metric is only computable by algorithms with exponential complexity.

E. Ensuring loop-free routing

Finally, the routing metrics must be designed such that no forwarding loops are formed by the routing protocols.

III. RELATED WORKS ON LINK AWARE METRICS

This section comprises of a brief study on the relevant link quality metrics specially proposed for mesh networks.

A. Expected Transmission Count

ETX proposed by [] estimates the expected number of transmission and retransmission required to sucessfulloy deliver a packet over a link. However, ETX doesn't measure delays asa result it suffers from self interference. ETX metric for a link l can be computed as

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

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Where, d_f is the probability that a data packet arrives at the receiving end

d_r is the probability that the corresponding acknowledgement is reached at the sending end.

B. Expected Transmissio Time

The authors in [] proposed a bandwidth adjustable form of Expected Transmission Count, termed as ETT (Expected Transmission Time) The ETT metric for a link l is defined as

$$ETT_l = ETX_l \times \frac{L_l}{R_l}$$

Where, ETX_l is the Expected Transmission Count for link l

L_l is the packet size for link l and R_l is the data rate for link l.

Introduction of link data rate makes it suitable to route using ETT in networks with heterogeneous data rates such as cognitive radio network.

This is the author to whom proofs of the paper will be sent. Proofs are sent to the corresponding author only.

C. WCETT

The weighted cumulative Expected Transmission Time metric is specially proposed for multi radio multi channel mesh network. WCETT metric for a path p is defined as

$$WCETT_p = (1-\beta)\sum ETT_l + \beta.\max_{1\le j\le k} X_j$$

$\beta \in [0,1]$ is a tuning parameter and X_j is defined as

$$X_j = \sum_{link\ l \in p\ is\ on\ channel\ j} ETT_l$$

With k being the total number of channels.

Though WCETT emphasizes on the most congested channel to track the imp-act of intraflow interference but it does not consider interflow interference explicitly. The authors in [] shown that WCETT is a non isotonic metric too.

D. MIC

The Metric of Interference and Channel Switching tries to encounter the limitations of WCETT by introducing interference-aware resource usage unit (IRU) to account interflow interference. MIC involves channel diversity to track intraflow interference The MIC metric for a path p is defined as

$$MIC_p = \frac{1}{N \times \min(ETT)} \square \sum_{l \in p} IRU_l + \sum_{node\ i \in p} CSC_i$$

Where, N is the total number of nodes in the network and $\min(ETT)$ is the smallest ETT in the network

The IRU (Interference-aware Resource Usage) component for link l is defined as

$$IRU_l = ETT_l \square N_l$$

N_l is the number of neighbors with whom transmission on link l interferes

The second component Channel Switching Cost (CSC) is given as

$$CSC = \begin{cases} w1 \ \ if \ \ Channel(prev(i)) \neq Channel(i) \\ w2 \ \ if \ \ Channel(prev(i)) = Channel(i) \end{cases}$$

Where, $0 \le w1 \le w2$ and $prev(i)$ is the channel used in the previous hop of node i, $Channel(i)$ is the channel used in node i.

E. iAWARE

The iAWARE metric associates signal strength with Expected Transmission Time in order to increase the accuracy of finding minimum weight path. However the second component that is channel diversity remains same as that in WCETT. The iAWARE metric for a path p is defined as

$$iAWARE = (1-\alpha)\times\sum_{i=1}^{n} iAWARE_i + \alpha \times \max_{1\le j\le k} X_j$$

The X_j component is identical to that in $WCETT$. The first component for a link j is defined as

$$iAWARE_j = \frac{ETT_j}{IR_j}$$

Where, IR_j is the interference ratio for link j between nodes u and v, defined as

$$IR_j = \min(IR_j(u), IR_j(v))$$

Where, the Interference Ratio at a node u for a link j is computed as

$$IR_j(u) = \frac{SINR_j(u)}{SNR_j(u)}$$

Where, $SINR_j(u)$ is the Signal to Interference Noise Ratio and $SNR_j(u)$ is the Signal to Noise Ratio at node u.

F. CATT

CATT is derived according to IEEE 802.11 MAC layer based throughput model for shared wireless channel access. The CATT metric for a link l can be defined as

$$CATT^{L2D} = ETX_l \times \sum_{j \in N_l} \left(\left(\sum_{k \in N_l} \frac{L_k}{R_k} \right) . \tau_j . \frac{L_j}{R_j} \right)$$

Where, ETX_l is the expected transmission count value for link l. N_l is the set of interfering links. L, R and τ are the corresponding packet length, data rate, and packet transmission rate respectively.

IV. PROPOSED ROUTING METRIC

Introduction of QoS provisioning in WMNs actually upgrades throughput and minimizes latency, jitter. However, in case of real time data transmission, bandwidth is proved to be the basic factor in providing QoS guarantee.

A. Estimation of available bandwidth

A number of researches [21], [22], [23], [24], [25], [26] have been conducted in estimation of available bandwidth between a pair of neighbors. In the proposed idea every node calculates its own bandwidth usage caused due to the existing flows carried by it. Each node's measurement of bandwidth consumption is then wrapped into a hello message that is to be broadcasted in the interfering neighborhood.

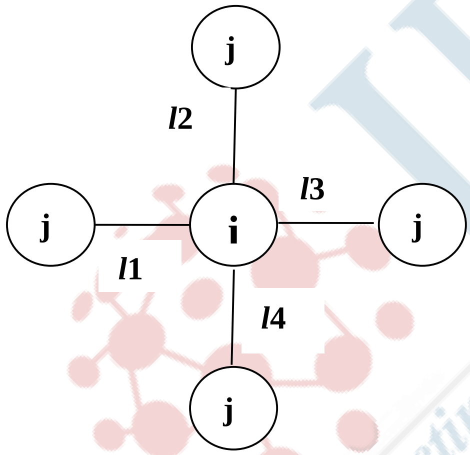

Fig. 2. A typical scenario of multiple link connecting a single node

Because of the sharing nature of the wireless channels, transmission failures due to collisions cannot be ignored. Even the presence of collision avoidance mechanisms such as CSMA/CA in the MAC layer cannot eliminate the interference caused by the hidden terminals. Hence, we have introduced the rate of unsuccessful transmissions (ρ_l) over a link l to reflect the packet losses in Wireless Mesh Network, which can be computed by calculating the rate of unsuccessful packet transmission (ρ_f) in forward direction and rate of loss rate the corresponding acknowledgement (ρ_r). The equation to compute ρ_l is given by

$$\rho_l = \rho_f \times \rho_r \tag{1}$$

Now, for any two nodes i, j communicating via link l, $\rho_i = \rho_j = \rho_l$. However, the value of ρ_i for a node i will be varied according to the link over which it is communicating (illustrated in Fig. 2).

In case, When node i communicates with node jx, over link lx; $\rho_i = \rho_{jx} = \rho_{lx}$, where $x = 1, 2, 3, 4$.

Thus, considering retransmissions, the total amount of bandwidth consumption due to single hop flows in a node i can be found as

$$Usg_{node\,i} = \sum_{\forall j \in F_i} \left(\tau_i^j \times (1 + \rho_i^j) \times T_{data}^j \times C_{ch} \right) \tag{2}$$

Where,

F_i is the set of existing flows carried by node i.

ρ_i^j is the rate of unsuccessful transmission of packets for node i while carrying flow j

τ_i^j denotes the packet sending rate of flow j for node i and C_{ch} is the estimated channel capacity.

T_{data} is the estimated channel time occupied by each data packet.

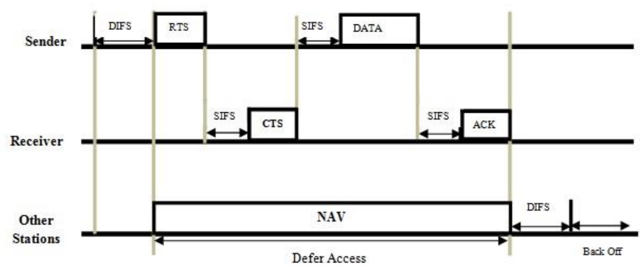

Fig. 3 DCF MAC operation scheme in IEEE 802.11

With consideration of four way handshake in IEEE 802.11 DCF shown pictorially in Fig. 3, the channel occupied time T_{data} can be given by the following equation:

$$T_{data} = T_{DIFS} + T_{RTS} + T_{CTS} + \frac{L+H}{C_{ch}} + T_{ACK} + 3T_{SIFS} \tag{3}$$

Where, $T_{RTS}, T_{CTS}, T_{ACK}$ are the transmission times taken for RTS, CTS, and ACK messages respectively. T_{DIFS}, T_{SIFS} represent the different interframe spaces. And L is the length of packet data and H is the total length of IP, MAC layer header. Table 1 summarizes different attributes for IEEE 802.11b/a/g.

Table 1: Important attributes in 802.11a, 802.11b and 802.11g

Parameter	Value		
	802.11b	**802.11a**	**802.11g**
SLOT	20 µs	9 µs	9 µs
SIFS	10 µs	16 µs	10 µs
DIFS(SIFS+2×SLOT)	50 µs	34 µs	28 µs
Physical Layer Header	192 µs	20 µs	20 µs
Minimum Data Rate	1 Mbps	6 Mbps	6 Mbps
RTS	20 Bytes	20 Bytes	20 Bytes
CTS	14 Bytes	14 Bytes	14 Bytes
ACK	14 Bytes	14 Bytes	14 Bytes
CWmin (units of SLOT)	31	15	15
CWmax (units of SLOT)	1023	1023	1023

After receiving the hello messages containing individual bandwidth consumption any node k computes the bandwidth usage in its interfering neighborhood using (2) as

$$Inter\ usg_k = \sum_{\substack{\forall i \in Inter_k \\ k \notin Inter_k}} \left(\sum_{\forall j \in F_i} \left(\tau_i^j \times (1+\rho_i^j) \times T_{data}^j \times C_{ch} \right) \right) \tag{4}$$

Where,

$Inter_k$ is the set of nodes causing interflow interference for node k (excluding k). Initially, populated with all nodes within the interference range carrying different flows.

In order to include the bandwidth consumption due to existing local flows in node k to grab the impacts of self interference, (4) can be modified as

$$Inter\ usg_k = \sum_{\forall i \in (Inter_k \cup \{k\})} \left(\sum_{\forall j \in F_i} \left(\tau_i^j \times (1+\rho_i^j) \times T_{data}^j \times C_{ch} \right) \right) \tag{5}$$

The two types of work status actually causing the channel busyness time are transmit and receive. In general, any existing flows in the interfering neighbors can be considered as a single hop flow and can be computed without any complexity by (2). Based on the above assumption, with the information of total bandwidth consumption in the interfering neighborhood (in order to capture the influences of interflow interference and self interference) the available bandwidth of a given node k can be computed by subtracting the usage bandwidth of the interfering neighbors from the channel capacity.

$$AvB(k) = C_{ch} - \sum_{\forall i \in (Inter_k \cup \{k\})} \left(\sum_{\forall j \in F_i} \left(\tau_i^j \times (1+\rho_i^j) \times T_{data} \times C_{ch} \right) \right)$$

Now, with consideration of intraflow interference, the bandwidth requirement for a given node k to drive a given multihop flow m can be found as

$$Intra\ usg_k = \sum_{\forall j \in (Intra_k \cup \{k\})} \tau_j^m \times (1+\rho_j^m) \times T_{data}^m \times C_{ch} \tag{6}$$

Where,

$Intra_k$ is the set of nodes causing intraflow interference for node k (excluding k) along the flow path and initially, populated with the nodes within the interference range along the flow path.

Based on the above, the estimated available bandwidth for a node k incorporating the impacts of interflow interference, self interference and intraflow interference can be written as:

$$AvB(k) = C_{ch} - Inter\ usg_k - Intra\ usg_k$$
$$= C_{ch} - \sum_{\forall i \in (Inter_k \cup \{k\})} \left(\sum_{\forall j \in F_i} \left(\tau_i^j \times (1+\rho_i^j) \times T_{data}^i \times C_{ch} \right) \right) - \sum_{\forall l \in (Intra_k \cup \{k\})} \left(\tau_l^{cf} \times (1+\rho_l^{cf}) \times T_{data}^{cf} \times C_{ch} \right) \tag{7}$$

B. Metric structure

The proposed metric finds an optimal path to drive a flow while satisfying the bandwidth requirement for transmission of real time data with a special consideration of the bottleneck of the routes. The bottleneck of a path p can be found by the following

$$btneck(p) = \min_{\forall node\ i \in path\ p} (AvB(i)) \tag{9}$$

The $WCMAB$ metric for a path p is defined as $WCMAB(p) = \alpha \times btneck(p) + (1-\alpha) \times rmAvB(p)$ (9)

Where, α is the tuning parameter and $0 \le \alpha \le 1$, $rmAvB(p)$ is the remaining total available bandwidth for a path p excluding the bottleneck bandwidth from source to destination calculated as

$$rmAvB(p) = \sum_{node\ i \in p\ and\ i \neq bottleneck\ node} AvB(i) \tag{10}$$

Where, $AvB(i)$ is the available bandwidth for node i, computed by (7).

The strength of the proposed metric lies in its isotonic, agile behavior and special consideration of hotspots. Moreover, due to its isotonicity, $WCMAB$ also prevents formation of forwarding loops during route calculation with efficient algorithms of polynomial complexity.

V. PERFORMANCE EVALUATION

Optimized Link State Routing protocol (upcoming in IEEE 802.11s) provides the necessary infrastructure to include link quality information while computing the optimal weight paths with Dijkstra's algorithm. Being proactive in nature, OLSR enhances the scope of introducing QoS provision while routing in Wireless Mesh Networks.

OLSR protocol with ML, MD, ETX metric is available in

[27] and OLSR module covering most of the link aware metrics is available in [28]. We have implemented the proposed Weighted Cumulative Maximum Available Bandwidth (WCMAB) metric in OLSR and conducted extensive simulations with NS2.34 simulator.

A. Simulation setup

CATT, iAWARE and MIC are the popular metrics recently applied to route selection in Wireless Mesh Networks. We have chosen these three link quality metrics for evaluation with WCMAB. The above stated metrics along with WCMAB were evaluated in NS2 simulator with respect to different parameters: throughput, packet loss ratio, jitter and delay under varying loads. Different parameters used during simulation are listed in Table 2.

Table 2: Parameters used in simulation

Parameters	Values
Number of nodes	50
Simulation area	1000×1000m^2
PHY/Mac	IEEE 802.11b/g
Channel data rate	2/11 Mbps
No. of non overlapping channels	3
Transmission range	250m
Interference range	500m
Tuning parameter α	0.5

B. Simulation results

Fig. 4 shows the comparison results in terms of delay. It shows that with the increasing load, end to end delay of MIC and iAWARE metrics increase rapidly. As compared to iAWARE and MIC, WCMAB and CATT provide reasonable performances but with higher values of load WCMAB employs a distinct less in delay than CATT.

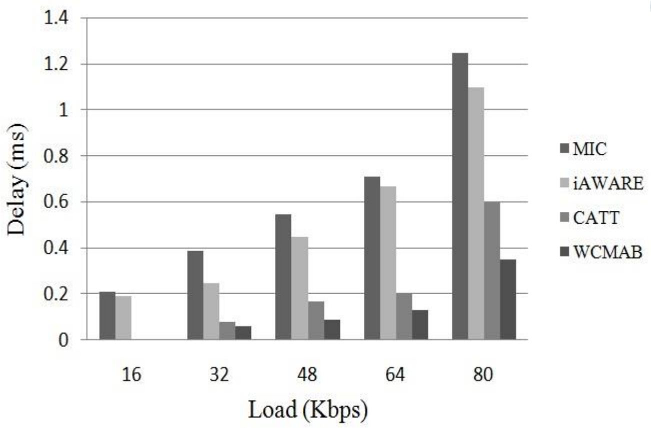

Fig. 4: Comparison of performance in terms of delay against varying load

Fig. 5 depicts the comparison result in terms of average flow throughput. It can be clearly observed that provides the best performance with a high margin as compared to other three metrics.

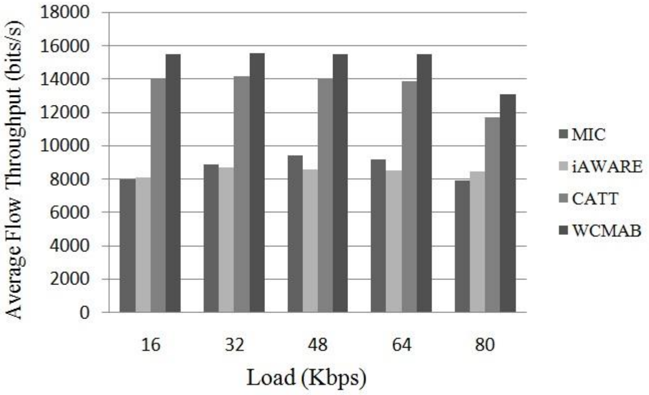

Fig. 5: Performance results in terms of Avg. flow throughput

We measured the jitter for the chosen metrics along with WCMAB and compared the evaluation results. Fig. 6 pictorially describes the performance comparison in terms of jitter.

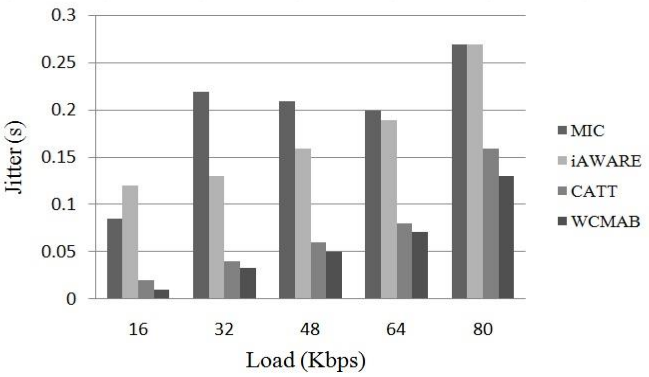

Fig 6: Results in terms of jitter for different values of load

VI. CONCLUSION

We have presented a novel and effective methodology for calculation of node to node available bandwidth and thereafter derived a bottleneck aware bandwidth based routing metric WCMAB for IEEE 802.11 based Wireless Mesh Networks (WMNs). We also have discussed the key aspects of designing routing metrics. Introduction of bottleneck awareness have significantly reduced the packet losses. Our simulation results demonstrated the accuracy of the proposed methodology and metric toward finding the bandwidth suitable paths for ensuring QoS service provisions in WMNs.

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