

Quality of Service (QoS)-based Hybrid Optimization Algorithm for Routing Mechanism of Wireless Mesh Network

Tao Huang¹ and Yuze Li^{2*}

¹School of Intelligent Manufacturing, Chongqing Three Gorges Vocational College, Chongqing 404155, China

²School of Languages and Media, Anhui University of Finance and Economics, Bengbu 233030, China

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A wireless mesh network (WMN) combines the advantages of the traditional wireless local access network (WLAN), such as low cost and easy deployment, with the multi-hop architecture of its wireless self-organizing network, and has significant advantages in adaptability and scalability. However, both the interference between wireless links and the fading of transmission signals can easily lead to the decline of link traffic, which will lead to major challenges in the data transmission process in the WMN. To solve this problem, a multipath routing algorithm is proposed to guarantee the quality of service (QoS). More specifically, data packets can be transmitted over multiple paths to improve overall network throughput performance. A multipath routing scheduling algorithm (MRSAs) is also proposed in this paper. On the basis of the currently available bandwidth information and the delay information introduced by the path, data packets can be divided into multiple segments and sent through different paths before transmission. The proposed scheduling policies can be adjusted and optimized on the basis of path delays so that data can be transmitted more efficiently over different paths. Simulation experiments verify the high performance of the proposed routing mechanism and scheduling strategy in terms of the average packet queuing delay, average delay jitter, and loss rate under different network loads.

1. Introduction

Wireless communication technology is developing at an unprecedented speed and is increasingly integrated into people's lives.⁽¹⁾ Cellular mobile communication network technology is relatively mature and its network coverage ability is high, but it is insufficient for data service support.⁽²⁾ In recent years, wireless local access networks (WLANs) have developed rapidly and become an effective means of wireless access, but their coverage is very limited.⁽³⁾ In what direction should next-generation wireless networks evolve? Although a conclusion has not yet been reached, the consensus is that a combination of high coverage, high data rates, and mobility support is urgently required.

*Corresponding author: e-mail: lyz@aufe.edu.cn
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The wireless mesh network (WMN), also known as a “multi-hop” network, is a recently developed wireless network technology that is completely different from the traditional wireless network.⁽⁴⁾ The core idea is that every node in the network can send and receive signals, thus solving the problems of low scalability and poor robustness that have always existed in the application of traditional WLAN technology.⁽⁵⁾ The WMN has attracted wide attention for its unique advantages and may become an important part of the next generation of wireless networks and the Internet. WMN technology has shown major advantages in many aspects, such as flexible networking, improved network coverage, increased network capacity, and reduced initial investment. It is especially suitable for broadband wireless access backbone networks. At the same time, with the continuous development and improvement of its technology, WMN technology is increasingly being used in urban emergency protection, public safety, traffic management, firefighting, rescue, disaster relief, forest management, television broadcasting, live events, marine communication, and resource exploration, with prospective applications in many other fields. At present, WMNs are attracting broad interest from international academia and industry and are being used increasingly widely.

The study of WMNs started from the aspects of channel assignment,⁽⁶⁾ link scheduling,⁽⁷⁾ the cache location decision and operation allocation scheme,⁽⁸⁾ the network energy consumption model and measurement,^(9,10) as well as routing and channel allocation.^(11,12) Although some multipath routing protocols and algorithms based on WMNs have been developed, such as the ad hoc on-demand multipath distance vector (AOMDV),⁽¹³⁾ temporary ordered routing protocol (TORA),⁽¹⁴⁾ split multipath routing (SMR) protocol,⁽¹⁵⁾ and energy-efficient clustering algorithm (EECA),^(16,17) multipath load balancing is still a key problem that is difficult to solve in routing protocols. On the one hand, the packet distribution strategy of the source node may lead to the problem of unfair rate allocation. On the other hand, due to the inherent properties of wireless communication, the advantages of multipath load balancing in WMNs may not be obvious. As discussed above, an efficient multipath routing protocol helps extend the life cycle of WMNs. Therefore, in this study, we propose a multipath routing algorithm and a multipath routing scheduling algorithm (MRSa) for the multipath routing protocol to guarantee the quality of service (QoS), and the routing mechanism and scheduling strategy have significant advantages under different network loads.

2. Related Work

The dynamic source routing (DSR) protocol, a topology-based planar on-demand routing protocol, uses an active caching strategy and the extraction of topology information from source routes.⁽¹⁸⁾ Many optimizations based on active caching and topology information analysis are combined in DSR. Nodes can obtain the routes of all downstream nodes from the datagram header, and more topology information can be extrapolated by merging multiple pieces of information. Also, the nodes of the network interface mode, through monitoring the routing strategy of neighbor nodes, can obtain more topology information and store more interesting network topology information in the cache to improve the cache hit ratio of the routing lookup, meaning that the frequency of the route discovery process can be reduced and network

bandwidth can be saved. The routing discovery process adopts a flooding mechanism, which occupies a lot of network bandwidth and may become a new bottleneck.⁽¹¹⁾ The source routing information is carried in the data packet header, and the link utilization ratio outperforms that of other algorithms in terms of scalability when the network is large. There is no behavior related to timing, nor is there any explicit mechanism to invalidate an old route or select a newer route when there are multiple paths to choose from. For the on-demand-driven routing mechanism, the longer end-to-end delay caused by the routing algorithm makes it unsuitable for real-time applications.⁽¹²⁾ Only when the node that is transmitting a packet encounters a failed link will a routing error be generated and the transmitted packet returned to the original route. Only other nodes using the failed link on the path that the packet has gone through can be informed immediately, resulting in fewer routing packets and flooding of broadcast packets in the process of routing discovery.

In the improved link-state DSR (LSDSR) protocol, the link-state routing protocol is to use link information for efficient routing.⁽¹⁹⁾ In an ideal link-state routing protocol, the routing information is converted into link-state packets (LSPs) that contain the link and neighborhood information used for routing.⁽²⁰⁾ When the network topology changes, these LSPs update previous information on the network. In the process of routing, an efficient routing protocol is to avoid such low-speed links. For this purpose, an on-demand routing protocol that also considers link quality is needed. The DSR protocol is selected for link-state routing. In the LSDSR protocol, link-state information is used instead of the shortest path for routing.⁽²¹⁾ This protocol, based on link-state information, has its own metrics and can replace the skip counting method. In the process of protocol research, we must pay attention to the time synchronization of the protocol. However, if LSDSR is to be used in a real-world environment, the wireless sites need to be synchronized. LSDSR is based on the measurement of time delay, which requires time synchronization of the network.⁽²²⁾ Time synchronization is a key research focus in wireless networks. Different researchers have proposed a variety of synchronization algorithms that an Internet engineering task force needs to standardize. In this paper, a simple time synchronization method is proposed, which is based on hierarchical routing in mesh networks. To realize hierarchical routing selection, we assume that there is a virtual tree structure in the network topology.

3. Network Architecture and Problem Formulation

3.1 Network model

The WMN is a multi-hop, self-organizing, and self-managing wireless network architecture, which is composed of two types of nodes and takes the mesh as the basic topology. It is regarded as a wireless version of the Internet. Because the WMN technology varies considerably with the application, the network topology, node type, networking mode, and so forth will be different in different application scenarios and sometimes markedly different, making it difficult to give a unified and exact definition of this technology. The data communication network constructed using WMN technology has a mesh layout topology, as shown in Fig. 1. There are two types of

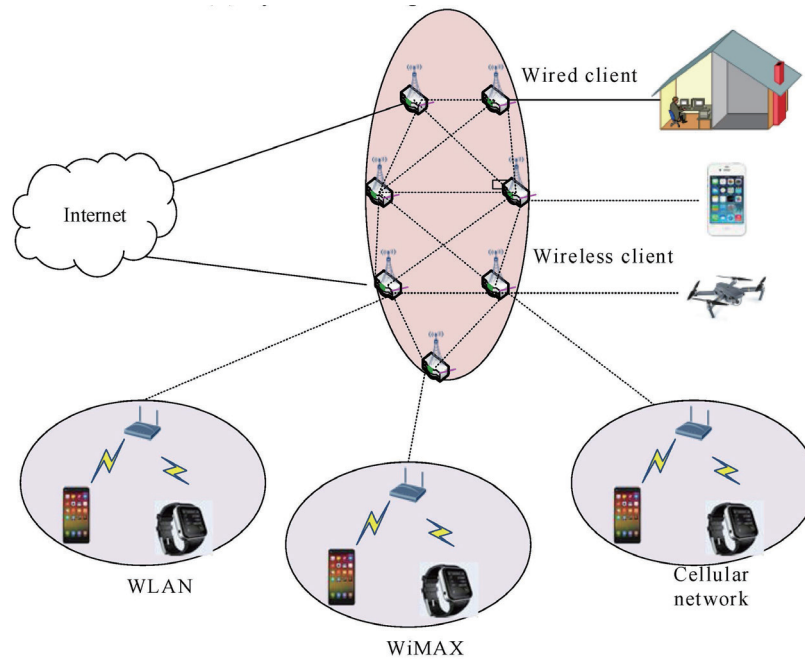


Fig. 1. (Color online) Architecture of WMNs.

nodes in the network: the wireless mesh router and wireless mesh end user. The latter can be a WLAN, cellular network, WiMAX network, sensor network, and so forth. In particular, in a wireless sensor network, the sensor acting as the sensing module first records some physical parameters of the monitored target, then processes the collected data and the data sent by other nodes, and forwards the processed data to the WMN through the mesh access node, then finally uploads the forwarded data to the Internet. The wireless mesh backbone network is connected by routers distributed in the mesh structure. A wireless mesh router with beamforming applies a certain algorithm to process the signals received by the multiple antennas and improve the signal strength at the receiving end of wireless equipment. Compared with other mature wireless networks, the WMN has the following five main characteristics: (1) the ability to learn the network topology dynamically, (2) communication in the multi-hop wireless mode, (3) multiple network interfaces and multichannel parallel communication, (4) the WMN node type determines its functional characteristics, and (5) dynamic integration with other wireless networks.

3.2 Key technology

At present, the latest generation of broadband ad hoc network radio with smart antennas is generally adopted in wireless mesh routers applied to mesh networks in daily life. The core technology is MN-MIMO, which is a multi-hop, uncentered, self-organizing wireless mobile network of smart antenna radio with multi-type, multi-input, multi-output technology.

The communication waveform with MN-MIMO technology is the most advanced waveform at present. It solves many problems faced by today's wireless communication, has

unprecedentedly high performance under critical harsh conditions, and provides long-distance, high-bandwidth, networked video and data communication for the most challenging environments in the world. This breakthrough waveform is a powerful mix of coded orthogonal frequency division multiplexing (COFDM),⁽²³⁾ MN-MIMO smart antennas,⁽²⁴⁾ and mobile ad hoc networks (MANET),⁽²⁵⁾ enabling digital communications with unmatched performance and flexibility. A comparison of the key technologies is shown in Table 1.

3.3 Problem formulation

Assume that an undirected graph $G(V, E)$ is used to describe a WMN containing N nodes, where V is the set of network nodes and E is the connection set composed of nodes in V . For each network node $v \in V$, the transmission range is $R_t(V)$ and the carrier sensing range is $R_c(v)$. Let e_{ij} represent the edge connecting node v_i to node v_j , where $v_i, v_j \in E$, and $1 \leq i, j \leq N$. If node v_i is within the transmission range v_j and v_j is also within v_i , then $e_{ij} \in E$.

The load $L(e) \in R$ on connection $e = (u, v) \in E$ represents the transmission of $L(u, v)$ on the connection, which is the sum of the traffic loads on all different paths through the link. For a connection $e \in E$ (e is the connection between two adjacent nodes u and v), let t_e be the traffic on link e , with link e on path p_m . If there are M paths through e , then the load on e can be expressed as

$$L(e) = \sum_{e=1}^M t_e. \quad (1)$$

Similarly, the load on p_m is

$$L(p_m) = \sum_{e \in p_m} L(e). \quad (2)$$

The transmission delay $d(e) \in R$ on the link consists of two parts: queue delay and transmission delay. In general, the delays between different links are independent of each other.

Delay on path $d(p_m)$: For each path from source node i to destination node j , path p_m is represented by a set of nodes v_i, v_{i+1}, \dots, v_j with $\forall k, i \leq k \leq j, (v_i, v_{i+1}) \in E$, and all the nodes appear only once, such as in Eq. (3).

Table 1
Comparison of key technical performances.

Reference	Key technology	Core idea	Advantages
23	COFDM	S/P conversion of the high-speed data stream	Reliable long-distance transmission
24	MU-MIMO	Multipath effect	Enhanced throughput and reliability
25	MANET	Self-forming/Self-healing; Link adaptation/Adaptive routing/ Transparent IP networking/ Multicast traffic	Reliable mobile networking capability

$$d(p_m) = \sum_{e_{ij} \in p_m} d(e_{ij}) \quad (3)$$

The available bandwidth $b(p_m)$ on path p_m is determined by the lowest bandwidth among the links on the path, as shown in Eq. (4).

$$b(p_m) = \min \{b(v_k, v_{k+1})\}, i \leq k \leq j \quad (4)$$

End-to-end packet loss rate: The packet loss rate on a link is independent of those on other links. Let $dr(v_k, v_{k+1})$ be the packet loss rate of link (v_k, v_{k+1}) on path (i, j) . Then the packet loss rate on path (i, j) can be approximately expressed as

$$dr_m^{ij} = 1 - \prod (1 - dr(v_k, v_{k+1})). \quad (5)$$

3.4 Performance indicators

(1) Average delay: the ratio of the sum of all successful data packet delays to the number of data packets successfully transmitted:

$$\bar{D} = \frac{\sum_{i=1}^N D_i}{N}, \quad (6)$$

where D_i is the end-to-end delay of the i th data packet, mainly including the MAC queuing delay, packet transmission delay, and frame interval. N is the number of data packets successfully transmitted.

(2) Delay jitter: the difference between successive packets of data. For example, the delay jitter of node j on path m can be expressed as

$$J_m^j = |D_m^{j,i+1} - D_m^{j,i}|, \quad (7)$$

where $D_m^{j,i}$ and $D_m^{j,i+1}$ are respectively the delays of the j th node receiving the i th packet and the $(i + 1)$ th packet on path m . Here, we use the average value of multiple paths, so I_m is the number of packets on path m received by terminal router r .

$$J_m^r = \sum_{i=0}^{I_m-1} |D_m^{i+1} - D_m^i| \quad (8)$$

The average delay jitter of router r on path m can be expressed as

$$J_r = \frac{\sum_{m=0}^M J_m^r}{\sum_{m=0}^M I_m}. \quad (9)$$

(3) Loss rate: The ratio of the number of packets lost due to interference or conflict Num_{lost} to the total number of packets sent Num_{total} is

$$\eta = \frac{Num_{lost}}{Num_{total}}. \quad (10)$$

4. Multipath Routing and Scheduling Algorithm

4.1 Route discovery mechanism

For a WMN with N nodes, the neighbor node set of node v_i is denoted as $N(v_i)$, then $S_{ij} \in N(v_i)$ represents the child node set that reaches the target node v_j . We let $S_{ij}(k)$ represent the next-hop node set of node v_k on the data flow path of source node v_i and target node v_j .

During the initial network setup phase, all nodes can find multiple paths to arrive at gateway ω , which broadcasts a “Good Morning” message to its neighbors. After receiving this message, neighboring nodes at $N(\omega)$ will initiate “path discovery” to find the paths of all gateways and arrange them in ascending order of available bandwidth. These nodes further broadcast the “Good Morning” message and link information. Here, the “Good Morning” message contains all paths to ω and their sequences. Other nodes that receive a “Good Morning” message may receive a “Good Morning” message from a different path by the same sequence, which in turn determines the parent node on each path and adds it to the routing table. The node then unicasts a parent message to the selected parent node. The parent message contains all the paths that have been selected by the “Good Morning” message. At this point, its parent node is informed of the path used for transmission through the parent message, and the parent node records its child node in the routing table and updates the corresponding path. After that, the parent node single-casts a child message to notify all the corresponding nodes on the path, including gateway ω for the child node and the reachable path for the child node. Upon the receipt of child node information, each parent node registers its child node in its routing table and follows similar steps to register the multiple paths that the child node can reach. In this way, in the path from the gateway to the child node, each intermediate node, including the gateway, has one or more paths to the responding child node.

4.2 Route maintenance mechanism

In WMNs, the routing protocol must be updated and maintained when new nodes are added or existing nodes exit the network. When looking for a new path or a new node, one node updates its routing table and notifies neighbor nodes of this information. The affected node

updates its routing table with this information and further broadcasts the routing table in a timely manner. A node can only be added to the mesh network after it has gained gateway admittance. Once in the network, each new node sends a Find message and finds a route to the gateway, which in turn responds to an admission or denial message.

4.3 QoS-based MRSA

We split the data stream into fragments that are transmitted along multiple paths. To overcome the limitation of traffic congestion, we propose a new adaptive scheduling scheme based on multipath load sensing. Firstly, the robustness of multipath transmission is improved by overload detection. For a WMN with M paths, it is initially possible to find a multipath set. Assume that path p_m has a maximum delay $d(p_m)$. The target node will cache all packets from the path with a delay less than p_m . We propose the use of the MRSA to determine the distribution of the data flow on each node, as shown in Fig. 2.

As can be seen from Fig. 2, given M paths, $P = \{p_1, p_2, \dots, p_M\}$, the corresponding delays are $\{d(p_1), d(p_2), \dots, d(p_M)\}$. A data source is divided in time into fragments t_1, t_2, \dots, t_k , where k is the number of paths, the delay on each path is $d(p_1) < d(p_2) < \dots < d(p_k)$, and each fragment is transmitted in parallel along these paths.

This approach places the beginning of the data stream on a path with a shorter delay, so that the data stream can be recovered earlier at the receiving end. To ensure continuity of the data flow, t_i is expressed as

$$t_i = \frac{\sum_{l=1}^i b(p_l)(d(p_{l+1}) - d(p_l))}{B}, \tag{11}$$

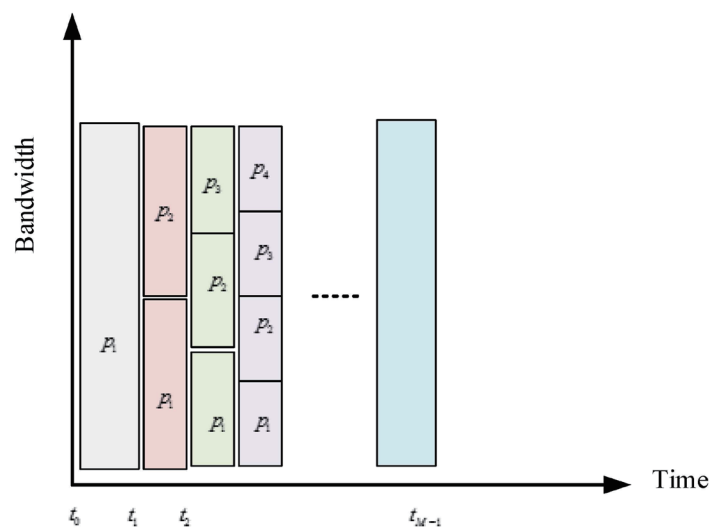


Fig. 2. (Color online) Multipath scheduling of video stream.

where B is the total bandwidth of the M paths, $b(p_i)$ is the bandwidth on path p_i , and $d(p_i)$ is the delay on path p_i . To avoid overloading a link, traffic is distributed proportionally to the remaining capacity of the bottleneck. When the multiple paths are independent of each other, load balancing can effectively suppress congestion and achieve a higher data transmission rate. Therefore, by using the MRSA, when the loads on different paths are different and the same data segment is sent along different paths, it will arrive at the target at the same time, thus ensuring the continuity of data flow.

5. Results and Discussion

5.1 Parameter setting

The simulation is based on NS-3 network simulation software (version NS-3.33). The network topology is shown in Fig. 3. All nodes are in a $1 \text{ km} \times 1 \text{ km}$ square area. The input of the data source is a constant bit rate (CBR) video stream service with a rate of 128 kbps. The video stream is input to a WMN and transmitted to the target node through multiple paths, and the target node demodulates and recovers the received data stream. The WMN has six nodes, including a source node S and a target node R. The channel bandwidth is set as 2 Mbps and the main simulation parameters follow the IEEE 802.11b protocol.

5.2 Simulation results

To evaluate the simulation results, the proposed MRSA in this paper is compared with the traditional algorithm (no-MRSA).⁽¹⁹⁾ Figure 4 shows the average packet delay curve, where each point is the mean of 50 iterations in the simulation. When the network traffic load is greater than 600 kbps, the proposed MRSA can significantly reduce the packet transmission delay. As the network traffic continues to increase, the MRSA greatly improves the network performance.

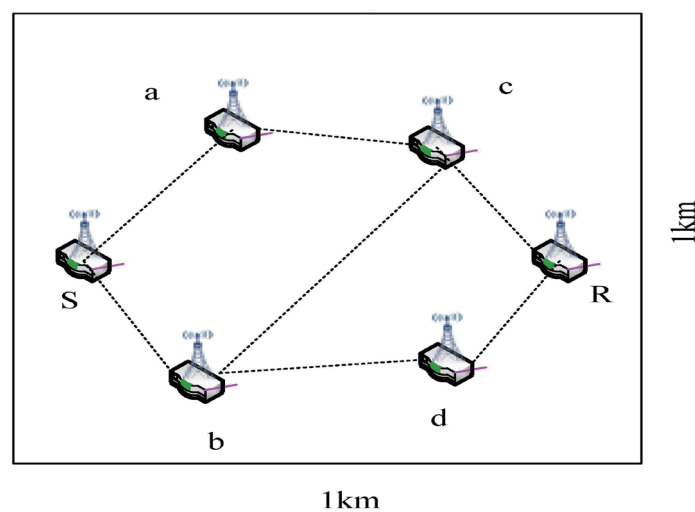


Fig. 3. (Color online) Network topology in simulation.

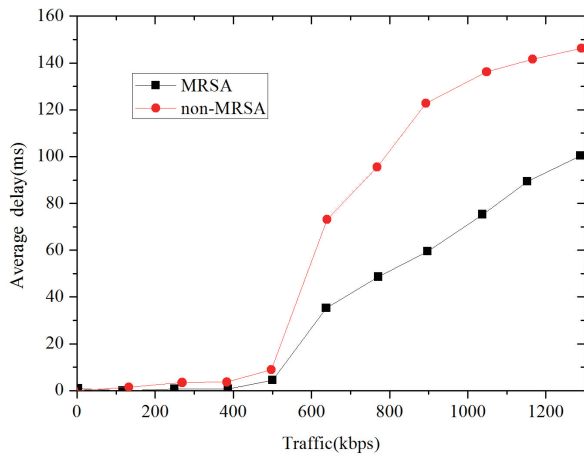


Fig. 4. (Color online) Average packet queuing delay.

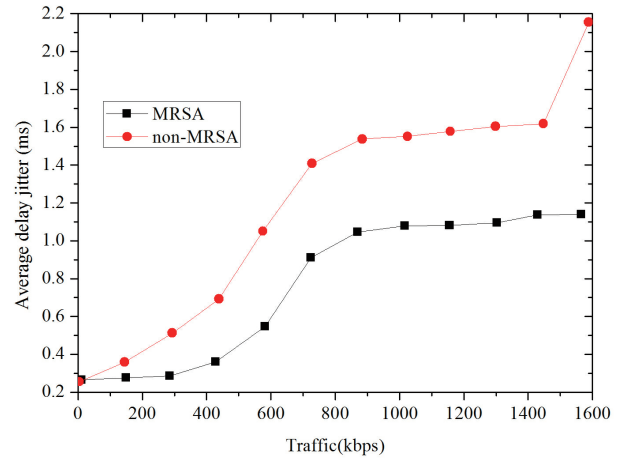


Fig. 5. (Color online) Average delay jitter.

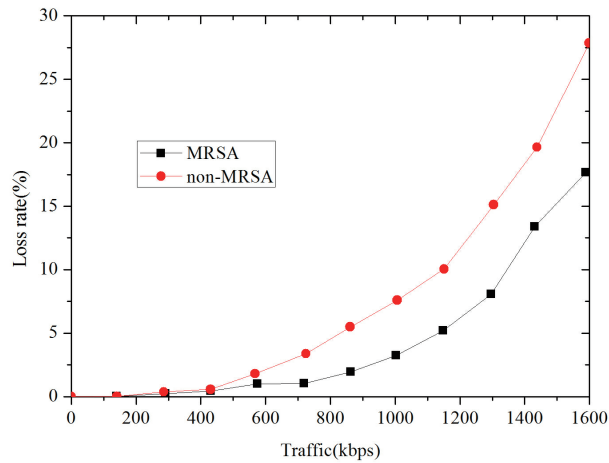


Fig. 6. (Color online) Loss rate.

Figure 5 shows the average delay jitter performance in the simulation. When the network traffic is greater than 400 kbps, the packet delay jitter of the network is significantly reduced by using the MRSA, with an average reduction of about 30%. Note that when the traffic volume is greater than 1400 kbps, the delay jitter increases sharply when the MRSA is not used. This shows that the MRSA can achieve efficient load-balancing performance.

Figure 6 shows the relationship between the packet loss rate and network traffic load. With increasing network traffic load, the packet loss rate gradually increases. For non-MRSA, when the network traffic load increases to 600 kbps, the packet loss rate increases by about 3.4%. When the network traffic load gradually increases, the packet loss of the two algorithms monotonically increases, and the packet loss rate gap between non-MRSA and the MRSA monotonically increases. In particular, when the traffic is 1600 kbps, the gap is 10%. This shows that the MRSA can adaptively divide the data into different paths.

6. Conclusions

The interference between wireless links and the fading of transmission signals may easily reduce link traffic, which will lead to major challenges in the process of data transmission in WMNs. To solve these problems, we propose an MRSA based on mesh networks. Moreover, in the multipath routing protocol, on the one hand, it is very important to develop a more effective congestion control and rate adjustment strategy. On the other hand, it is also important to evaluate load balancing and congestion control plans to develop appropriate path quality evaluation indexes for multipath routing protocols. According to the bandwidth and delay of different paths, the data packets are divided into data streams of different sizes and distributed to the corresponding paths. The data flow through multiple paths to reach the target, thus improving the total throughput of the mesh network. The proposed MRSA can be applied to densely deployed network environments, such as 5G networks.

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References

- 1 Y. Liu, C.-X. Wang, J. Huang, J. Sun, and W. Zhang: IEEE Trans. Veh. Technol. **68** (2019) 2077. <https://doi.org/10.1109/TVT.2018.2866414>
- 2 D. Raychaudhuri and N. B. Mandayam: Proc. IEEE **100** (2012) 824. <https://doi.org/10.1109/JPROC.2011.2182095>
- 3 S. Aust, R. V. Prasad, and I. G. M. M. Niemegeers: IEEE Commun. Surv. Tutorials **17** (2015) 1761. <https://doi.org/10.1109/COMST.2015.2429311>
- 4 J. Hu, L. Yang, and L. Hanzo: IEEE Trans. Veh. Technol. **66** (2017) 8495. <https://doi.org/10.1109/TVT.2017.2678167>
- 5 W. Tu, C. J. Sreenan, S. Jha, and Q. Zhang: IEEE Trans. Mob. Comput. **16** (2017) 3431. <https://doi.org/10.1109/TMC.2017.2691706>
- 6 L. Yang, Y. Li, S. Wang, and H. Xiao: IEEE Access **7** (2019) 67167. <https://doi.org/10.1109/ACCESS.2019.2918355>
- 7 H. -T. Roh and J. -W. Lee: J. Commun. Networks **18** (2016) 884. <https://doi.org/10.1109/JCN.2016.000123>
- 8 W. Xu, W. Wu, H. Wu, J. Cao, and X. Lin: IEEE Trans. Comput. **63** (2014) 860. <https://doi.org/10.1109/TC.2013.20>
- 9 M. Li, H. Nishiyama, N. Kato, Y. Owada, and K. Hamaguchi: IEEE Trans. Emerging Top. Comput. **3** (2015) 420. <https://doi.org/10.1109/TETC.2014.2386135>
- 10 C. Luo, S. Guo, S. Guo, L. T. Yang, G. Min, and X. Xie: IEEE Trans. Parallel Distrib. Syst. **25** (2014) 3211. <https://doi.org/10.1109/TPDS.2013.2297922>
- 11 Y. Chai and X.-J. Zeng: IEEE Syst. J. **14** (2020) 4119. <https://doi.org/10.1109/JSYST.2020.2966795>
- 12 S. S. A. Gilani, A. Qayyum, R. N. B. Rais, and M. Bano: IEEE Access **8** (2020) 136769. <https://doi.org/10.1109/ACCESS.2020.3011651>
- 13 G. Pathak and K. Kumar: J. Commun. Inf. Networks **2** (2017) 123. <https://doi.org/10.1007/s41650-017-0012-z>
- 14 Y. Wu, N. Sun, Y. Fang, and D. Liang: IEEE Trans. Syst. Man Cybern.: Syst. **49** (2019) 1186. <https://doi.org/10.1109/TSMC.2017.2723478>
- 15 Y. Cheng and X. Jia: IEEE/ACM Trans. Networking **28** (2020) 846. <https://doi.org/10.1109/TNET.2020.2971587>
- 16 M. Y. Arafat and S. Moh: IEEE Access **9** (2021) 18649. <https://doi.org/10.1109/ACCESS.2021.3053605>
- 17 J. Leu, T. Chiang, M. Yu, and K. Su: IEEE Commun. Lett. **19** (2015) 259. <https://doi.org/10.1109/LCOMM.2014.2379715>

- 18 B. Blywis, M. Günes, D. J. H. Gutzmann, and F. Juraschek: *Wireless Days (2010 IEEE IFIP)* 1–5.
- 19 J. Xu, Y. Zhang, J. Jiang, and J. Kan: *Ad Hoc Networks* **116** (2021) 102470. <https://doi.org/10.1016/j.adhoc.2021.102470>
- 20 H. Geng, H. Zhang, X. Shi, Z. Wang, X. Yin, J. Zhang, Z. Hu, and Y. Wu: *J. Commun. Networks* **22** (2020) 46. <https://doi.org/10.1109/JCN.2019.000056>
- 21 G. Robertson and S. Nelakuditi: *IEEE Trans. Netw. Serv. Manage.* **9** (2012) 293. <https://doi.org/10.1109/TNSM.2012.12.110172>
- 22 L. Wang, V. Lehman, A. K. M. M. Hoque, B. Zhang, Y. Yu, and L. Zhang: *IEEE Access* **6** (2018) 10470. <https://doi.org/10.1109/ACCESS.2017.2789330>
- 23 J. Choi: *IEEE Wireless Commun. Lett.* **8** (2019) 536. <https://doi.org/10.1109/LWC.2018.2878820>
- 24 C. Chen, Y. Yang, X. Deng, P. Du, and H. Yang: *IEEE Open J. Commun. Soc.* **1** (2020) 943. <https://doi.org/10.1109/OJCOMS.2020.3009386>
- 25 Q. Zhang, L. Ding, and Z. Liao: *China Commun.* **16** (2019) 24. <https://doi.org/10.23919/JCC.2019.08.003>

About the Authors



Tao Huang received his B.S. degree in electronic information engineering from Chongqing Technology and Business University, China, and his M.S. degree in electronic and communication engineering from Chongqing University of Posts and Telecommunications, China, in 2005 and 2013, respectively. He was a visiting scholar focusing on applications of electronics at Chongqing University and on communication engineering and electrical, media, and information technology at Technische Hochschule Deggendorf (Deggendorf Technical University) in 2015 and 2018, respectively. He is currently a lecturer at the School of Intelligent Manufacturing, Chongqing Three Gorges Vocational College. His research interests include electronics, communication, and automation. (13884897@qq.com).



Yuze Li was born in Bengbu, Anhui province, and received his B.S. degree from Anhui Normal University, China, and his M.S. degree from Nanjing Normal University, China, in 2001 and 2008, respectively. Currently, he is a Ph.D. student at Assumption University, Thailand, and a senior experimenter at the School of Languages & Media, Anhui University of Finance and Economics. His research interests include the theory and practice of educational technology. (lyz@aufe.edu.cn)