A Proposal of CSMA Fixed Backoff-time Switching Protocol and Its Implementation on QualNet Simulator for Wireless Mesh Networks

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***Abstract*—As an inexpensive and scalable Internet access network, we have studied the architecture, protocols, and design optimizations of the *Wireless Internet access Mesh NETwork (WIMNET)*. WIMNET is composed of multiple access points (APs) that are connected through wireless links. Previously, we have proposed the concept of the *CSMA-based Fixed Backoff-time Switching (CSMA-FBS) method* for WIMNET to improve the performance by giving necessary link activation chances for multi-hop communications. In this paper, we propose a protocol for this CSMA-FBS method implementable on APs, and its actual implementation on the *QualNet* simulator for evaluations in realistic network environments. The simulation results in two network topologies confirm the effectiveness of our proposal.**

***Keywords*-Wireless mesh network, fixed backoff-time switching, CSMA-FBS, QualNet, simulation**

I. INTRODUCTION

Recently, a *wireless mesh network* has been extensively studied as a promising network technology to flexibly and inexpensively expand the service area by allocating multiple wireless mesh routers on a network field [1]–[3]. As a scalable access network to the Internet using this technology, we have studied the architecture, protocols, and design optimizations of the *Wireless Internet access Mesh NETwork (WIMNET)* [3], [4]. WIMNET is composed of multiple access points (APs) as mesh routers that are connected with each other through wireless links. At least one AP acts as a *GateWay (GW)* to the Internet. Any host in WIMNET can be connected to the Internet through multihop communications between APs to this GW.

WIMNET adopts *IEEE802.11 MAC (Media Access Control) protocols* for wireless communications [5]. To use a communication channel, a node in WIMNET employs the *CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) protocol*. In this CSMA/CA protocol, any node possessing a packet is on standby for a random time before the data frame transmission in order to avoid frame collisions while providing the fairness among nodes. This standby time is called the *backoff-time*, and is set a random value within the size of the *Contention Window (CW)*. When a node fails in the transmission, this CW size is increased to reduce the probability of the collision occurrence in the retransmission. When the node succeeds in the transmission, it resets the CW size to the initial one.

Unfortunately, the pure CSMA/CA protocol may cause several problems in WIMNET. The first problem is congestions of links around GW that can be bottlenecks of whole communications in WIMNET, because these links have to handle a lot of packets to/from GW for the Internet access. Thus, they should be activated with higher priorities than other links. The second problem is interferences among the links around GW that may not be resolved by the random backoff-time because of the limited CW size. We note that the initial value of the CW size is small. Multiple conflicting links can be activated at the same time by generating the same or similar backoff-time at the source nodes. Then, any link cannot complete the packet transmission successfully, and needs reactivations causing further conflicts.

To solve these problems in WIMNET, we have proposed the concept of the *CSMA-based Fixed Backoff-time Switching (CSMA-FBS) method* [4]. In this method, before starting communications, the *target link activation rate*, the *active backoff-time*, and the *passive backoff-time* are assigned for each link. The target link activation rate represents the frequency to activate the link to handle the traffics of the link properly. Different values are assigned to the two backoff-times by following the descending order of expected traffic loads of links. A larger value than any active backoff-time is set for the passive backoff-time so that the link should be preferentially activated by using the active backoff-time.

During communications, the *actual link activation rate* is observed by counting the numbers of link activation chances and actually activated times for each link, and taking their fraction. If this value is smaller than the target one, the active backoff-time is used for the preferential activation. Otherwise, the passive backoff-time is used. Because of different backoff-times assigned among the links, conflicts among interfered links can be avoided. However, only the concept of the CSMA-FBS method was presented, and was evaluated by our simple network simulator, where it was not implemented as a protocol.

In this paper, we propose a protocol of the CSMA-FBS method that is implementable on APs, and show its

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implementation on a well-known network simulator *QualNet* [6]. QualNet has been known to adopt a more realistic physical model than other simulators such as *ns-2* [7]. Before implementing the protocol on hardware, software evaluations using such a realistic network simulator is significant to refine the details of our proposal. We show simulation results using two network topologies, where they confirm the effectiveness of the CSMA-FBS protocol.

The rest of this paper is organized as follows: Section II reviews the IEEE 802.11 MAC protocol. Section III proposes the CSMA-FBS protocol. Section IV presents its implementation on QualNet. Section V shows evaluation results. Section VI concludes this paper with some future works.

II. IEEE802.11 MAC PROTOCOL

In this section, we briefly review the IEEE 802.11 protocol, and related studies of its modifications to this paper.

A. Overview of IEEE802.11 MAC Protocol

The IEEE802.11 MAC protocol enforces CSMA/CA to makes it possible for several nodes to share the same physical medium or channel by detecting or avoiding data frame collisions. Figure 1 illustrates the timing chart for the data transmission. After the channel becomes idle, the source node waits first for the DIFS period, and then, for the backoff-time that is randomly selected between 0 and the CW size. Then, if it does not detect any transmission from other node, it starts the transmission. The backoff-time is used to stagger the transmission timing among the ready nodes to avoid collisions. If a collision occurs, the CW size is doubled as the binary exponential backoff scheme to avoid further collisions. If the transmission succeeds, the CW size is reset to the initial one CW_{min}.

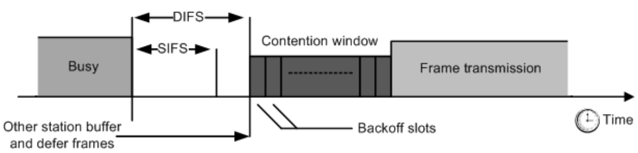


Figure 1: Timing chart for data transmission.

B. Related Studies of Protocol Modifications

In [8], Xu et al. raised the question: can the IEEE 802.11 work well in wireless ad hoc networks ? They concluded that the protocol was not designed for multihop networks. Although it can support some ad hoc network architecture, it is not intended to support the wireless multihop networks such as ad hoc networks and wireless mesh networks, where the connectivity is one of the most prominent features. The reason is that RTS/CTS exchange will block all wireless terminals in the neighborhood.

In [9], Nakamura et al. examined the fixed backoff-time for wireless LANs. By simulations, they showed that it can reduce collisions and idle duration to improve the throughput and delay performance. However, their method is based on PCF, whereas WIMNET is based on DCF.

In [10], [11], Minooei et al. and Wu et al. proposed an efficient backoff mechanism for ad hoc networks using DCF and modifying the backoff time by considering the frame collision probability of each node for multihop ad hoc networks. For this purpose, the backoff-time bt is given by:

$$bt = rand\left[CW_{\min} \times 2^{m-1}, CW_{\min} \times 2^{m}\right] \qquad (1)$$

where CW_{min} represents the initial contention window size, m does the number of consecutive transmission failures, and the function $rand[x, y]$ returns a uniformly randomized integer between x and y. The simulation results show the higher end-to-end throughput than the conventional IEEE 802.11 MAC protocol.

III. PROPOSAL OF CSMA-FBS PROTOCOL

In this section, after briefly reviewing the overview of the CSMA-FBS method, we propose the CSMA-FBS protocol that can be implemented on APs.

A. Overview of CSMA-FBS Method

The CSMA-FBS method uses the two fixed backoff-times. Specifically, the *active backoff-time* and the *passive backoff-time* are adopted for each link to avoid the simultaneous activations of conflicting links. Either of them is used by comparing the *target link activation rate* and the *actual link activation rate*. Any backoff-time is assigned a different fixed value from each other so that no pair of conflicting links may be activated at the same time. Besides, the backoff-time for a link with the larger traffic load is assigned a smaller value than that for a link with the smaller load, so that congested links can be activated more frequently than less-congested links. Furthermore, any active backoff-time is assigned a smaller value than a passive one, so that links using active ones have larger priorities in activations than links using passive ones.

During communications, every time an AP holding packets detects the channel clearance, it updates the target activation rate and the actual activation rate. If the actual one is smaller than the target one, it selects the active backoff-time, judging that the activation rate of this link is not enough to handle the traffic. On the other hand, if it is larger, it selects the passive backoff-time so that other links selecting active backoff-times can be activated with higher priorities. The link with the passive backoff-time can be activated only if any conflicting link with the active backoff-time does not hold packets.

B. Target Link Activation Rate

The target link activation rate rt_{ij} for the link from AP_i to AP_j for $i = 1, \cdots, N$ and $j = 1, \cdots, N$ (let us call link l_{ij}) can be calculated by:

$$rt_{ij} = \frac{tn_{ij}}{an_{ij}} \tag{2}$$

where tn_{ij} represents the target number of activating link l_{ij} per second, and an_{ij} does the average number of link activation frames per second. tn_{ij} can be given by:

$$tn_{ij} = \frac{rb_{ij}}{fb_{ij} \times (1 + fe_{ij})} \tag{3}$$

and an_{ij} can be calculated by:

$$an_{ij} = \frac{1}{ft_{ij}} \tag{4}$$

where rb_{ij} represents the number of bits per second that link l_{ij} needs to transmit, fb_{ij} does the average number of bits in one transmitted frame, fe_{ij} does the rate of causing the frame transmission error, and ft_{ij} does the average duration time of transmitting one frame.

Among the parameters of the target link activation rate, rb_{ij} should be calculated from the communication requests and the routing path in WIMNET. The others fb_{ij}, fe_{ij}, and ft_{ij} should be updated during communications by the following equations:

$$fb_{ij} = \frac{sb_{ij}(t)}{sf_{ij}(t)} \tag{5}$$

$$fe_{ij} = \frac{ff_{ij}}{sf_{ij}(t) + ff_{ij}(t)} \tag{6}$$

$$ft_{ij} = \frac{t}{sf_{ij}(t) + ff_{ij}(t) + of_{ij}(t)} \tag{7}$$

where $sb_{ij}(t)$, $sf_{ij}(t)$, $ff_{ij}(t)$, and $of_{ij}(t)$ represent the total number of successfully transmitted bits, the total number of successfully transmitted frames, the total number of failed frames, and the total number of transmitted frames of interfered links for link l_{ij}, when t seconds have passed since the communication started in WIMNET, respectively.

C. Actual Link Activation Rate

The actual link activation rate for each link is obtained by dividing the number of actually transmitted frames with the number of possibly activating chances for the link:

$$ra_{ij} = \frac{sf_{ij}(t)}{ac_{ij}(t)} \tag{8}$$

where ra_{ij} represents the actual link activation rate for link l_{ij}, and ac_{ij} does the number of possibly activating chances of link l_{ij}.

In the CSMA/CA protocol, ac_{ij} is hard to be obtained. One reason is that unlike the TDMA protocol where the link activations are synchronized by a single clock, the timing of counting the number of activating chances is not clear in the CSMA/CA protocol. Another is that the link activation chances resulting in transmission failures should not be counted, because they are not considered in the calculation of the target link activation rate.

D. Active/Passive Backoff-time

The two fixed backoff-times for each link are calculated. First, the number of hosts ht_{ij} using link l_{ij} for the Internet access, and the link priority p_{ij} are calculated by the following procedure:

1) Initialize ht_{ij} by 0.
2) Add the number of hosts associated with AP_k to ht_{ij} if the route between GW and AP_k includes l_{ij} for $k = 1, \cdots, N$.
3) Sort every link in descending order of ht_{ij} where the tiebreak is resolved by the number of links relaying packets of the link.
4) Assign p_{ij} for l_{ij} by the sorted order.

Then, the two fixed backoff-times for each link are given by using the link priority. The active backoff-time ta_{ij} and the passive one tp_{ij} for link l_{ij} are given by:

$$\begin{aligned} ta_{ij} &= p_{ij} \times \delta \\ tp_{ij} &= (P + p_{ij}) \times \delta \end{aligned} \tag{9}$$

where δ represents the unit backoff-time, and P does the largest priority among the links.

IV. Implementation of CSMA-FBS Protocol

In this section, we present our implementation of the CSMA-FBS protocol on the QualNet simulator.

A. Target Link Activation Rate

1) Initial Parameter Values: The initial values of the parameters rb_{ij}, fb_{ij}, fe_{ij}, and ft_{ij} for the target link activation rate must be given before communications.

First, the number of bits to be transmitted per second rb_{ij} for link l_{ij} is given by the summation of the bit rates of all the communication requests of the hosts using l_{ij} by the following equation:

$$rb_{ij} = \sum_{k \in H_{ij}} hr_k \tag{10}$$

where H_{ij} represents the set of the host indices using link l_{ij} for the routing path to the GW, hr_k does the communication request (bps) of host k.

Unfortunately, each link in WIMNET has the capacity in packet transmissions. When rb_{ij} exceeds this capacity LC_{ij}, it should be saturated there to avoid the serious degradation of the performance of WIMNET. LC_{ij} can be calculated by:

$$LC_{ij} = \frac{NC \times 0.6}{\sum\limits_{pq \in I_{ij}} rb_{pq}} \tag{11}$$

where NC represents the total network capacity that should be specified beforehand in the QualNet simulation, 0.6 does the coefficient to calculate the effective network capacity by considering the guard time and the acknowledgement response in a wireless link, and I_{ij} does the set of the interfered links to link l_{ij}.

In our simulations, $NC = 5.5Mbps$ is used, and the initial values for the number of bits per frame $fb_{ij} = 2272$, the frame transmission error rate $fe_{ij} = 0.1$, and the frame duration time $ft_{ij} = 0.02$ are assigned.

During communications, these parameter values are automatically updated by using the obtained values of $sb_{ij}(t)$, $sf_{ij}(t)$, $ff_{ij}(t)$, and $of_{ij}(t)$. For this purpose, we modified the *MacDot11StationProcessAck* function in QualNet to obtain $sb_{ij}(t)$ and $sf_{ij}(t)$ when the AP received ACK message. Besides, we increased $ff_{ij}(t)$, when the AP retransmitted a failed frame by the function *MacDot11StationRetransmit*. To obtain $of_{ij}(t)$, we use the NAV counter in the function *MacDot11StationProcessNotMyFrame*. In the function *MacDot11StationSetBackoffIfZero*, we updated the target link activation rate rt_{ij} by using the updated parameters.

B. Actual Link Activation Rate

In our implementation, ac_{ij} is counted every time AP_i detects the clearance of the channel where no node is using the same channel. Then, pn_{ij} is counted every time link l_{ij} starts transmitting a packet. In QualNet, we added a necessary variable *dot11− >chance* in the function:
MacDot11AttempToGoIntoWaitForDifsOrEifsState
for pn_{ij}, and increase the value every time this function is called. Then, for ac_{ij}, we get the value from the variable *dot11->pktsToSend*. By using two variables *node->nodeId* and *dot11->currentNextHopAddress*, we obtain the link index ij of link l_{ij}.

C. Backoff-time Modification

For very crowded links that can often happen around GW in WIMNET, even different backoff-times among the links in the CSMA-FBS protocol cannot avoid collisions of interfered links due to propagation delays in wireless links. In such situations, the difference of backoff-times among links should be enlarged to further stagger their transmission timing. Besides, the waiting time before starting the transmission should be long enough to detect activations of other conflicting links as in [11]. Therefore, any backoff-time is randomly selected between the minimum and the maximum that satisfy the constraints for the backoff-time in the CSMA-FBS protocol:

- Any active backoff-time must be smaller than any passive backoff-time.
- The backoff-time for a link with the higher priority must be smaller than that for a link with the lower priority.

Actually, the active backoff-time ta_{ij} for link l_{ij} with the priority p_{ij} are given by:

$$\begin{aligned} amin_{ij} &= CW_{\min} \cdot \left(2^{m-1} + 2^{m-2} \cdot \tfrac{p_{ij}-1}{P}\right), \\ amax_{ij} &= CW_{\min} \cdot \left(2^{m-1} + 2^{m-2} \cdot \tfrac{p_{ij}}{P}\right), \\ ta_{ij} &= rand\left[amin_{ij}, amax_{ij}\right], \end{aligned} \tag{12}$$

and the passive backoff-time tp_{ij} is given by:

$$\begin{aligned} pmin_{ij} &= CW_{\min} \cdot \left(2^{m-1} + 2^{m-2} \cdot \tfrac{P+p_{ij}-1}{P}\right), \\ pmax_{ij} &= CW_{\min} \cdot \left(2^{m-1} + 2^{m-2} \cdot \tfrac{P+p_{ij}}{P}\right), \\ tp_{ij} &= rand\left[pmin_{ij}, pmax_{ij}\right]. \end{aligned} \tag{13}$$

The number of consecutive transmission failures m is saturated by 6. Once these backoff-times are generated, they are fixed subsequently in our implementation.

For the implementation in QualNet, we added the above-mentioned procedures in the function
MacDot11StationSetBackoffIfZero.

V. Evaluation by Simulations

In this section, we show simulations results on the QualNet simulator to evaluate the CSMA-FBS protocol in this paper.

A. Simulation Environment

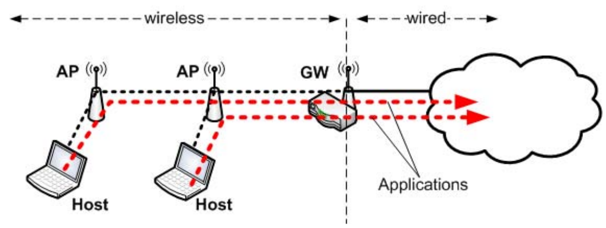
Two network topologies with static routing in Figure 2 are examined, namely, a) Line and b) Grid. The IEEE802.11b protocol is adopted for any node where the nominal bit-rate is $5.5Mbps$ and the nominal wireless range is $250m$.

Each host performs CBR as a real-time UDP application and FTP as a TCP application. For CBR, 20 packets are transmitted from the source node to the GW at every second, where the packet size is changed from 160 bytes to 2560 bytes. For FTP, one file of different sizes from 160 bytes to 2560 bytes is transmitted from the source host to the GW at every 0.05 sec. The network simulation is executed for 30 minutes, and the average result throughout the simulation is used in evaluations. The simulation environment is summarized in Table I.

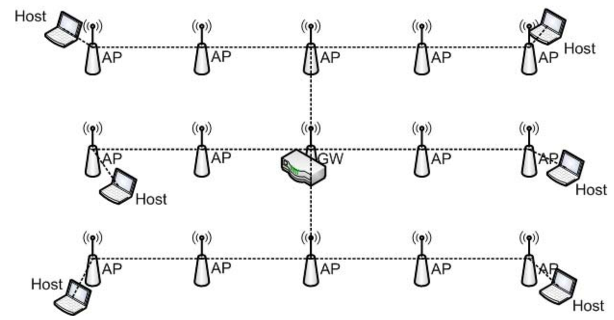
B. Performance Evaluation for Real-time Application

First, we evaluate the performance improvement of the CSMA-FBS protocol from the conventional CSMA/CA protocol in a real-time application using CBR.

1) Throughput: We compare the throughput between two protocols when only CBR is used. Figure 3 shows the throughput for different packet sizes. This result indicates that as the traffic load is low at 160 bytes or 320 bytes, their throughputs are similar, and when the traffic load is high at 1280 bytes or 2560 bytes, the CSMA-FBS protocol improves the throughput by about 27% from the conventional one.



(a) Line



(b) Grid

Figure 2: Simulated network topology.

Table I: Simulation environment.

Parameter	Value
Interface	IEEE802.11b
Nominal bit-rate	5.5 Mbps
Channel Frequency	Backbone: 2.484 GHz Host: 2.412, 2.437, 2.482 GHz
Network simulation time	30 min.
Application	CBR for UDP FTP Generic for TCP
packet rate for CBR	20 packets/sec
packet size for CBR	160, 320, 640, 1280, 2560 bytes
File size for FTP	160, 320, 640, 1280, 2560 bytes

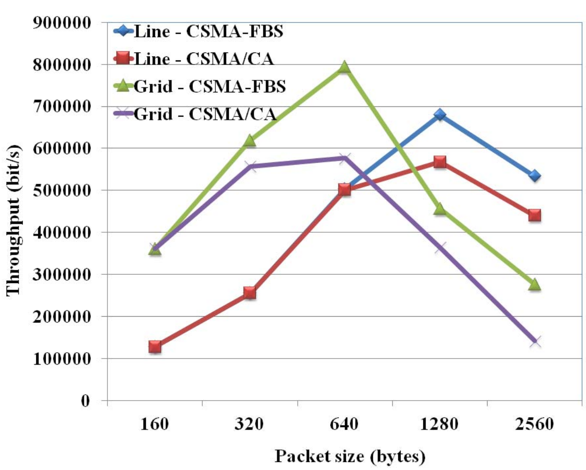


Figure 3: Throughput.

2) *End-to-End Delay:* We compare the end-to-end delay from the source (host) to the destination (GW) between them. Figure 4 shows the average delay from one host to the GW among all the hosts and packets for the different packet size. The result indicates that as the traffic increases, the delay increases in both methods, where the CSMA-FBS protocol can reduce it by about 24%.

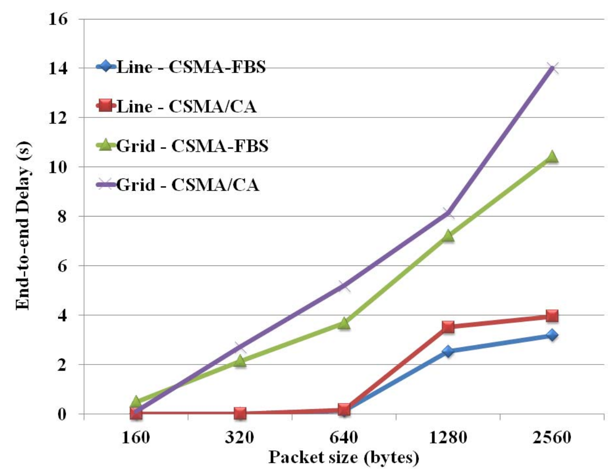
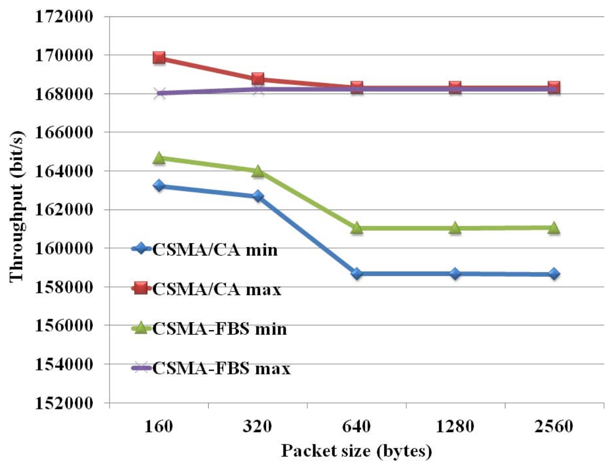


Figure 4: End-to-end delay.

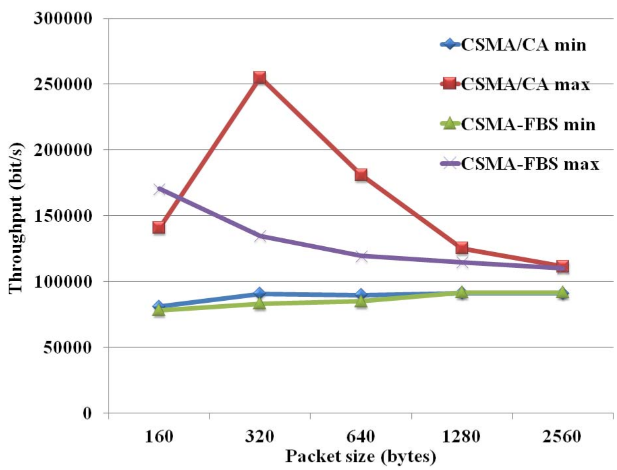
C. *Fairness Evaluation for TCP Application*

In WIMNET using the conventional CSMA/CA protocol, it has been observed that hosts close to GW in terms of hop counts dominate more bandwidth than hosts far from GW. Thus, a host may receive unfair services in TCP applications depending on the location in WIMNET in terms of the hop count from GW. This unfairness is another serious problem in WIMNET.

In order to evaluate the improvement in this unfairness by the CSMA-FBS protocol, we observed the difference between the highest throughput and the lowest throughput among the hosts when all of them are executing FTP. Figure 5 shows the highest and lowest throughputs among the hosts for each topology for the different packet size. The results indicate that for Line, the CSMA-FBS protocol reduces the difference between them by about 25% by heightening the lowest throughput, and for Grid, the CSMA-FBS reduces it by about 45% by lowering the highest throughput. Thus, the CSMA-FBS protocol can contribute to the improvement of the unfairness problem in TCP



(a) Line



(b) Grid

Figure 5: Fairness for TCP application.

applications in WIMNET, although the further improvement is necessary there.

VI. Conclusion

This paper presented a protocol for the CSMA-based Fixed Backoff-time Switching (CSMA-FBS) method implementable on access points for a wireless Internet-access mesh network (WIMNET) and its implementation on the QualNet simulator. The simulation results in two network topologies confirmed the effectiveness of our proposal in terms of the throughput, the delay, and the fairness. Our future works include the further improvement of the CSMA-FBS protocol for the unfairness problem in TCP applications, the combination with our previous proposal of the traffic control method for real-time applications [12], and the implementation on hardware for evaluations in real networks.

Acknowledgment

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References

[1] I. F. Akyildiz, X. Wang, and W. Wang, “Wireless mesh networks: a survey,” *Computer Networks*, vol. 47, no. 4, pp. 445–487, Mar. 2005.

[2] Y. Zhang, J. Luo, and H. Hu, *Wireless mesh networking: architectures, protocols and standards*, H. Hu, Ed. New York: Auerbach Publications, 2007.

[3] N. Funabiki, *Wireless mesh networks*, N. Funabiki, Ed. InTech-Open Access Publisher, 2011. [Online]. Available: http://www.intechopen.com/books/show/title/wireless-mesh-networks

[4] S. Tajima, N. Funabiki, and T. Higashino, “A proposal of fixed backoff-time switching method by link activation rate for wireless mesh networks,” in *International Conference on Complex, Intelligent, and Software Intensive Systems, 2011*, 2011, pp. 647–652.

[5] C. Society, *IEEE standards for IEEE 802.11 - part 11: wireless LAN medium access control and physical layer specifications*, Jun. 2007.

[6] S. N. Technologies, “QualNet developer - scalable network technologies.” [Online]. Available: http://www.scalable-networks.com/products/qualnet/

[7] G. A. D. Caro, “Analysis of simulation environments for mobile ad hoc networks,” *Artificial Intelligence*, Dec. 2003.

[8] S. Xu and T. Saadawi, “Does the IEEE 802.11 MAC protocol work well in multihop wireless ad hoc networks?” *IEEE Communications Magazine*, vol. 39, no. 6, pp. 130–137, Jun. 2001.

[9] K. Nakamura, S. Satake, and H. Inai, “An access method using fixed backoff for wireless LANs,” *Electrical Engineering in Japan*, vol. 173, no. 3, pp. 30–39, Jul. 2010.

[10] H. Minooei and H. Nojumi, “Performance evaluation of a new backoff method for IEEE 802.11,” *Computer Communications*, vol. 30, no. 18, pp. 3698–3704, 2007.

[11] C.-M. Wu, H.-K. Su, and W.-H. Yang, “Efficient backoff algorithm in wireless multihop ad hoc networks,” *International Journal*, vol. 3, no. 1, pp. 87–96, 2011.

[12] S. Sukaridhoto, N. Funabiki, and T. Nakanishi, “A proposal of traffic control method with bandwidth usage estimation for real-time applications in wireless mesh networks,” in *IEICE Technical Report, NS2010-109*, 2010, pp. 25–30.