Performance Evaluation of 802.11e over Multihop WiFi Mesh Networks

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Abstract—**A multihop WiFi mesh network is a wireless network that provides multihop data forwarding services base on 802.11 technologies. However, the original 802.11 MAC and all the recent MAC enhancements (e.g., 11e, 11i, 11k) are designed primarily for one-hop wireless networks and thus, provide no end-to-end consideration or coordination beyond a single hop at all. In this paper, the performance of 802.11e over the multihop WiFi mesh network is investigated.**

Keywords- medium access control, wireless mesh networks

I. INTRODUCTION

In a multi-hop wireless network, communication between two nodes is carried out through a number of intermediate nodes via relaying packets from one node to another. In the past few years, many researchers have focused on issues of 'mobile ad hoc networks (MANETs)', in which relaying nodes are in general mobile, and communication is performed between arbitrary pair of nodes within the same network. Recently, an increasing number of multi-hop wireless deployments and proprietary commercial solutions have focused on a class of networks termed 'wireless mesh networks (WMNs)' [1-4]. One of the potential applications for WMN is to provide high-speed wireless backhaul links that offers low-cost public access services in outdoor environment. To forego costly wired infrastructure, a WMN adopting a tree topology with a single entry point to the wired Internet will be considered herein [1]. Unlike MANET, the WMN serves as an access network that employs multi-hop wireless links provided by non-mobile nodes to relay traffic to and from wired Internet [2]. The non-mobile nodes (also referred as transit access points [1], wireless routers [2], or mesh points and mesh access points [3]) forms a wireless backbone and provides multi-hop connectivity between nomadic users and the entry point(s) (also known as mesh portals [3]) to the wired Internet [2]. In such an environment, power consumption is not a primary concern since relaying nodes are fixed and wire-powered. Due to the lack of a centralized coordinator, each relaying node should be operated in a fully distributed manner which results in inevitable packet collisions and may degrades the network throughput. Hence, one of the main challenges of WMN is the provisioning of a proper medium access control (MAC) protocol that can coordinate the channel access among neighboring nodes base on limited information exchange.

Many researches has been studied the limitation of adopting 802.11 MAC in wireless ad hoc or mesh environment. Currently, IEEE 802.11 MAC uses the virtual carrier sensing with ready-to-send/clear-to-send (RTS/CTS) handshake to alleviate packet collisions due to hidden node problem. However, it may not be applicable in WMN. Jangeun and Sichitiu indicated that RTS/CTS does not correctly solve hidden terminal problem in a mesh network [4]. Xu and Saadawi [5] found that RTS/CTS scheduling along a chain can cause serious TCP fairness problems and backoff inefficiencies. Li *et. al.* [6] found that RTS/CTS does not efficiently schedule transmissions and fails to achieve good schedule in a multi-hop chain. Xu *et. al.* [7] found that 802.11 MAC tends to either sacrifice spatial reuse or allow excessive interference.

Several techniques were proposed to enhance the network utilization. Jain, *et. al.* [8] proposed a multi-channel MAC protocol to mitigate the exposed node problem. Acharya and Misra [9] proposed a MACA-P method which adopts spatial-reuse technique to improve channel utilization. They also proposed a data-driven cut-through medium access (DCMA) method to reserve channel form the next forwarding node and thus, reduce the chance of packet collisions. Raguin, *et. al.* [10] adopted the concept of DCMA and proposed a queue-driven cut-through medium access (QCMA) method for a multiple-queue environment. In QCMA, each node may select the highest priority packet from its queue and thus, a certain degree of quality of service (QoS) can be supported. Benveniste and Tao [13] proposed a MAC protocol to enhance the throughput of wireless mesh networks by utilizing a common control channel. To sum up, existing approaches enhance the network utilization by reducing hidden and expose nodes, adopting spatial-reuse, utilizing cut-through techniques, or common control channel. However, they still adopted a random-access mechanism with exponential backoff and thus, they all suffer from the same backoff inefficiencies and fairness problems as that of 802.11 distributed coordinator function (DCF).

Currently, IEEE 802.11 task group s (TGs) is drafting an amendment of 802.11 MAC that specify a protocol for auto-configuring paths between APs over self-configuring multi-hop topologies in a Wireless Distribution System (WDS) and to support both broadcast/multicast and unicast traffic in such a WiFi mesh network. The network architecture of 802.11s is shown in Fig. 1 [12], where 'mesh point (MP)' is a node responsible for relaying traffic for the other nodes; 'mesh access point (MAP)' is both an MP and an access point (AP) that can aggregate traffic to and from nomadic WLAN users; and, 'mesh portal' is the anchor point of the WiFi mesh network to the wired Internet. 802.11s aims to support five usage models, including *Residential*, *Office*, *Campus/Community/Public Access Network*, *Public Safety*, and *Military*.

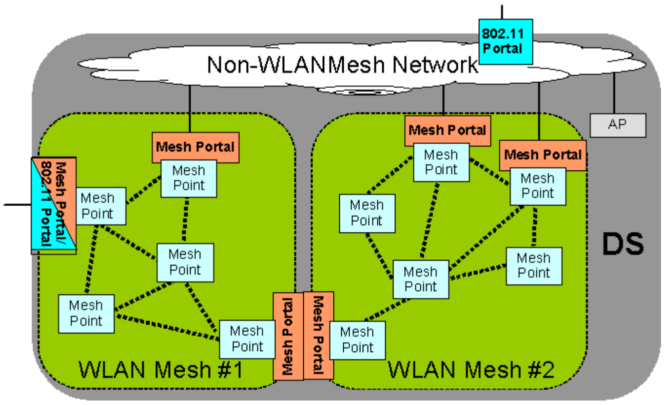

Figure 1. 802.11s network architecture.

However, most of the studies are focus on the throughput enhancement and little attention is paid on the way to support quality-of-service (QoS) in the multihop WiFi mesh network. The basic assumption of IEEE 802.11s, the standard body that draft the specification for WiFi mesh network, is to adopt 802.11e enhanced distributed channel access (EDCA) mode as a baseline to provide QoS. Hence, the purpose of this paper is to evaluate the performance of 802.11e in multihop WiFi mesh networks through simulation. In Section II, the background of 802.11e is briefly reviewed. The key parameters of 802.11e and their effect on the system performance are discussed. Section III presents the simulation results. Conclusions are finally drawn in Section IV.

II. Background of IEEE 802.11e

One challenge for supporting multimedia services in WLAN is the ability to provide differentiated QoSs for stations (STAs) with different priorities. IEEE 802.11 WLAN provides two channel access modes, a contention-based DCF and a polling-based point coordinator function (PCF). IEEE 802.11e [13] further defines an EDCA mode to support prioritized services. The major difference between DCF and EDCA is that the values of the contention window (CW) and the inter-frame space (IFS) are the same for all STAs in DCF but could be different in EDCA.

The EDCA mode of 802.11e supports four different channel access priorities, known as access categories (ACs). Each AC has associated CW and AIFS values. An STA with a new packet can transmit data only if the channel is sensed idle for AIFS. Otherwise, the transmission is deferred and an exponential backoff procedure is invoked. In 802.11, the backoff procedure is implemented using a backoff counter. During each backoff, the backoff counter is decreased whenever the channel is sensed idle for a constant duration, frozen when any packet transmission is detected, and reactivated when the medium is sensed as idle for AIFS again. The STA transmits data as soon as the backoff counter reaches zero. The AIFS for the *k*-th AC, denoted by $AIFS_k$, is defined by

$$AIFS_k = SIFS + L_k \cdot \sigma, \text{ for } 1 \le k \le 4, \qquad (1)$$

where L_k is an integer in the range 1-255 and σ is a constant duration defined. Specifically, $AIFS_k$ corresponds to the PIFS and DIFS utilized in PCF and DCF modes for $L_k = 1$ and $L_k = 2$, respectively.

The 'backoff stage' is defined as the number of retransmissions. For a priority *k* STA at backoff stage *i*, the backoff counter $C_{k,i}$ is defined as

$$C_{k,i} = Rand(0, W_{k,i} - 1) + X, \text{ for } 1 \le k \le 4,\ 0 \le i \le M_k, \qquad (2)$$

where *Rand* is a random function with uniform distribution; $W_{k,i}$ represents its CW; X is set to 1 if $L_k = 1$, and 0 otherwise, and M_k denotes the maximum backoff stage of the priority *k* STA. Normally, $W_{k,0}$ represents the minimum CW, and $W_{k,i} = 2^i \times W_{k,0}$. As defined in 802.11, the backoff procedure is terminated and the $W_{k,i}$ is reset while the number of failed retransmission exceeds M_k.

To summarize, in EDCA, one can prioritize users by assigning different AIFSs and/or CW size (i.e., minimum CW and maximum CW). A larger value of AIFS may result in a longer carrier sensing delay and thus, lead to a lower throughput. A larger CW size may result in a longer backoff delay but may reduce the packet collision probability under heavy loading.

This work considers a WiFi mesh network with one to four classes of STA operated under the EDCA mode. An ideal channel condition with error-free transmission is assumed. Simulation is utilized to investigate the effectiveness of 802.11e EDCA in supporting QoS for WiFi mesh networks. A chain with four or eight nodes is chosen as an example. Each node is injected by packets belonging to one or four ACs.

III. Simulation Results

The simulations in this work were performed using *Network Simulator version 2 (NS2)* [14] and each sample was obtained by averaging outcomes collected within 600 seconds. The link capacity was 1 Mbps [6] and. Each access node, *Ni*, was injected by a Poisson arrival process with rate λ_i. Two scenarios were considered. Both scenarios studied a chain of homogeneous nodes that separated by equal distance. Both the transmission range and interference range were assumed to be one-hop radius. The network topologies of the two scenarios are shown in Figs. 2 and 3, respectively. There are eight nodes in scenario 1 and four nodes in scenario 2, respectively, that provide wireless access services for nomadic users. The nodes are interconnected through wireless links and route user data to and from the wired Internet via the mesh portal. The offered load is defined as the sum of the arrival rate for all access nodes. The end-to-end effective throughput of each access node, which is defined as 'goodput' herein, was chosen as the key performance index herein.

In a chain-based multihop WiFi mesh network, the goodput of each access node is highly depended on the location of the node. In order to illustrate this location-dependent problem, the first simulation studied the case that each node injected by a single access category traffic source. In the first simulation, the network topology of scenario 1 with $\lambda_0 = \lambda_1 = \ldots = \lambda_7$ was used. The cannel access parameters of AC_VO were adopted by each node and the parameters are listed in Table 1. The performance of the first simulation is shown in Fig. 4. It can be found that at light offered load, each node is able to transmit it packets to the mesh portal. However, node *N0* attains the least goodput since its packets should be relayed by seven nodes. As the increasing of the offered load, the probability of packet collision among nodes is increased and thus, only packets from *N5*, *N6*, and *N7* can reach the mesh portal.

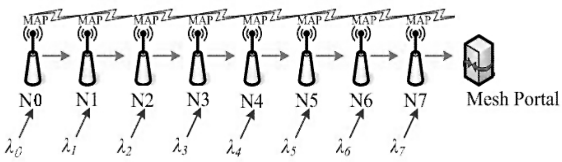

Figure 2. Topology of Scenario 1

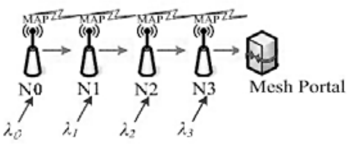

Figure 3. Topology of Scenario 2

Parameters	AC_VO	AC_VI	AC_BE	AC_BG
CWmin	7	15	31	31
CWmax	15	31	1023	1023
AIFS	2	2	3	7
Packet size(byte)	1000	1000	1000	1000

Table 1. Type-I channel access parameters

The second simulation tries to investigate that whether 802.11e EDCA can be utilized to overcome the location-dependent problem of the chain-based WiFi mesh network or not. In the second simulation, the network topology of scenario 1 with $\lambda_0 = \lambda_1 = \lambda_2 = \lambda_3$, and $\lambda_4 = \lambda_5 = \lambda_6 = \lambda_7 = 0$ was used. *N0* is assigned by the top access priority, AC_VO; *N1* is assigned by the second access priority, AC_VI; *N2* is assigned by the third access priority, AC_BE, and *N3* is assigned by the lowest access priority, AC_BG. The cannel access parameters of AC_VO, AC_VI, AC_BE, and AC_BG are listed in Table 1, respectively. The performance of the second simulation is shown in Fig. 5. It can be found in Fig. 5 that *N3* always achieved the highest goodput even though it has the lowest access priority.

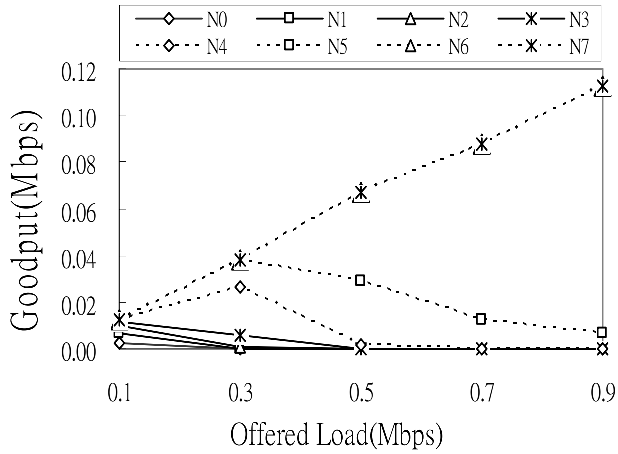

Figure 4. Performance of nodes with single access category

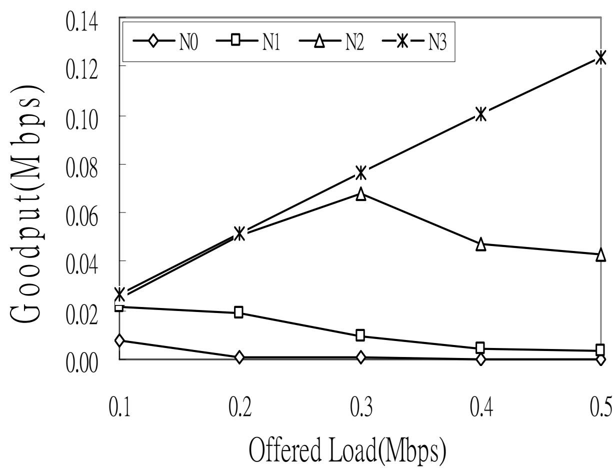

Figure 5. Scenario 1 with Type-I channel access parameter

The second simulation demonstrated that 802.11e EDCA may not be able to solve the location-dependent problem. However, it could be due to the improper setting of the channel access parameters. To further investigate the effectiveness of EDCA, the new channel access parameters were assigned to the four access categories. In the third and the fourth simulations, the effect of AIFS and CW size were investigated.

The environment of the third simulation was the same as the second simulation except for the channel access parameters. The channel access parameters adopted by the third simulation is listed in Table 2. In this simulation, the CW size was fixed for the four access categories. However, each access category was assigned by three AIFSs, denoted as Case (a), Case (b), and Case (c), respectively. Figure 6 illustrated the effect of adjusting AIFS. From Case (a) to Case (c), the difference of AIFS among access categories were increased. It can be found in Fig. 6 that that *N3* always achieved the highest goodput even though it has the lowest access priority. It can also be found that a larger AIFS differentiation among access categories also contributed a higher goodput.

The environment of the forth simulation was the same as the second simulation except for the channel access parameters. The channel access parameters adopted by the third simulation is listed in Table 3. In this simulation, the AIFS was fixed and the priority was assigned via adjusting CW size. Figure 7 illustrated the effect of adjusting CW size. From Case (a) to Case (c), the CW size was gradually increased. It can be found in Fig. 7 that that *N3* still achieved the highest goodput even though it has the lowest access priority. Moreover, it was found that the goodput of each node in Fig. 7 was slightly lower than that in Fig. 6. It implies that, from the goodput point of view, adjusting AIFS is more effectiveness than adjusting CW size.

Parameters	AC_VO	AC_VI	AC_BE	AC_BG
CWmin	31	31	31	31
CWmax	1023	1023	1023	1023
Case(a)_AIFS	2	4	6	8
Case(b)_ AIFS	2	6	10	14
Case(c)_ AIFS	2	8	14	20
Packet size(byte)	1000	1000	1000	1000

Table 2. Type-II channel access parameters

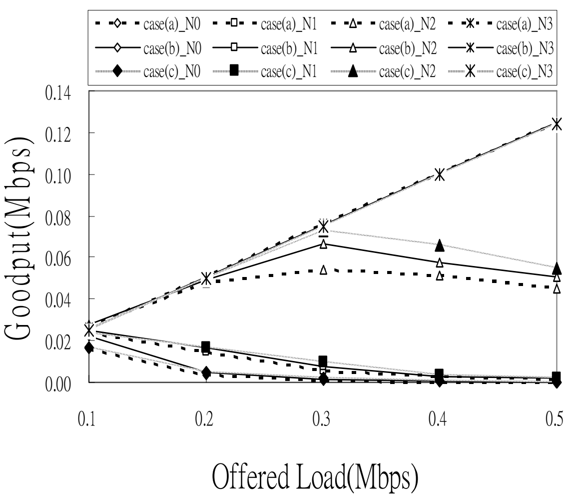

Figure 6. Scenario 1 with Type-II channel access parameter

Parameters	AC_VO	AC_VI	AC_BE	AC_BG
Case(a)_CWmin	3	7	31	31
Case(a)_CWmax	7	15	63	127
Case(b)_CWmin	7	15	127	127
Case(b)_CWmax	15	31	255	511
Case(c)_CWmin	15	31	255	255
Case(c)_CWmax	31	63	512	1023
AIFS	2	2	2	2
Packet size(byte)	1000	1000	1000	1000

Table 3. Type-III channel access parameters

The fifth simulation was designed to observe the effectiveness of EDCA without considering the location-dependent problem. The topology shown in Fig. 3 was adopted and four access categories with channel access parameters defined in Table 1 were all injected into node *N0*. Figure 8 demonstrated the performance of EDCA in such an environment. It was found that all the four access categories attained the same goodput if the offered load is relatively low. As the offered load increases, the goodput of the four access categories may suddenly decrease due to excess collision. However, in this environment, EDCA can preserve the priorities of the four access categories (i.e., AC_VO was assigned by the highest priority and AC_BG was assigned by the lowest priority).

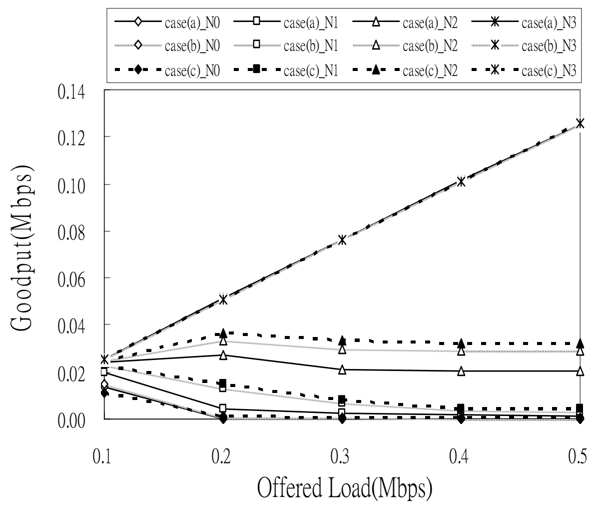

Figure 7. Scenario 1 with Type-III channel access parameter

In the following, the performance of EDCA in multihop WiFi mesh network was studied. In order to minimize the location-dependent problem, the topology shown in Fig. 3 was adopted in the following simulations and all four access categories were injected into *N0* only.

The sixth simulation studied the effect of AIFS. The simulation was the same as the fifth simulation except for that channel access parameters defined in Table 2 was utilized here. Figure 9 demonstrated the performance of EDCA with three

AIFSs in such an environment. Similarly, the priority of each access category is preserved. It was found that Case (a) attained the best performance when the offered load is relatively low. It is because that a smaller AIFS may contribute a higher goodput. However, the Case (c) has the best performance if the offered load exceeds 0.2 Mbps. It is because that a higher AIFS helps to resolve the excess collisions occurred at high offered load.

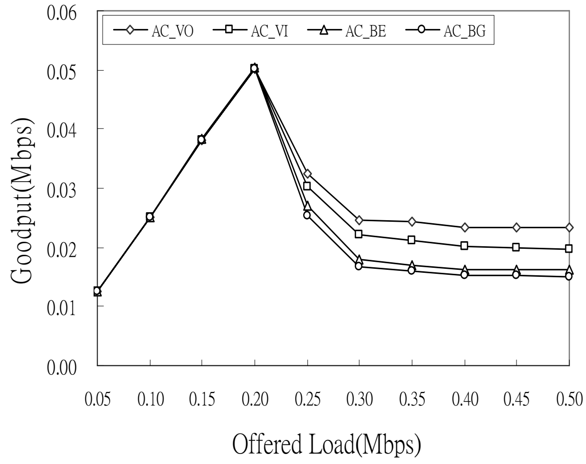

Figure 8. Scenario 2 with Type-I channel access parameter

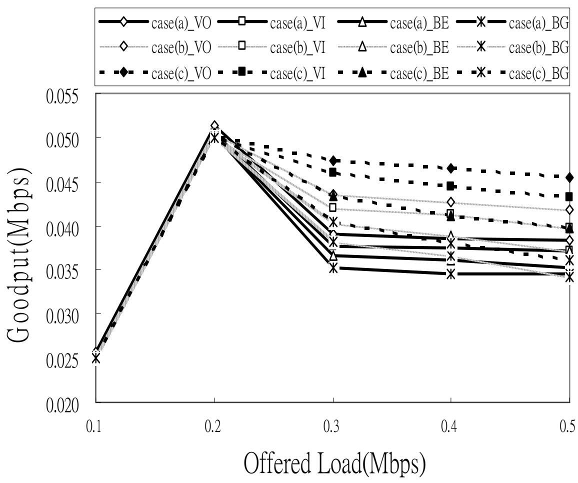

Figure 9. Scenario 2 with Type-II channel access parameter

The seventh simulation studied the effect of CW size. The simulation was the same as the fifth simulation except for that channel access parameters defined in Table 3 was utilized here. Figure 10 demonstrated the performance of EDCA with three CW sizes. Similarly, the priority of each access category is preserved. It was found that Case (c) always attained the best performance because a higher CW size helps to resolve the excess collisions. From Figs. 9 and 10, it was found that adjusting AIFS is more effectiveness than changing CW size since the former may achieve a higher goodput.

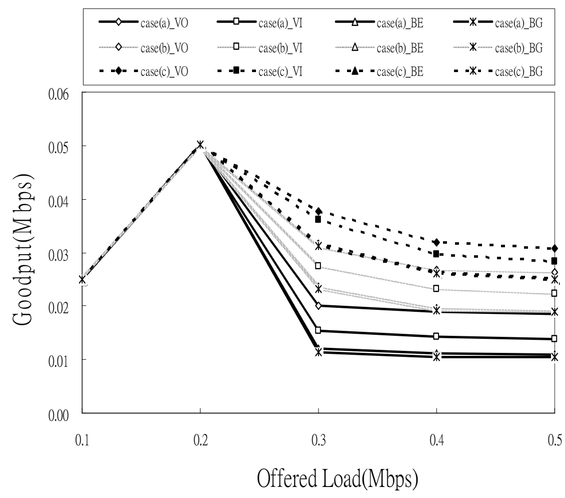

Figure 10. Scenario 2 with Type-III channel access parameter

IV. CONCLUSIONS

In this paper, we extensively studied the performance of 802.11e EDCA over multihop WiFi mesh networks by using *NS2*. The goodput of nodes with different setting of AIFS and CW size were investigated. The results show that, even in a chain topology, the location-dependent problem of WiFi mesh network cannot be resolved by adopting EDCA. Hence, a new priority access mechanism or even a new MAC protocol may be needed to support QoS in multihop environment.

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