

논문 2007-44TC-8-5

프레임 집합화를 이용한 애드-혹 무선 랜의 성능 향상을 위한 MAC 프로토콜

(Slotted Transmissions using Frame aggregation: A MAC protocol for
Capacity Enhancement in Ad-hoc Wireless LANs)

엠디 무스타피주 라만*, 홍 충 선*

(Md. Mustafizur Rahman and Choong Seon Hong)

요 약

IEEE 802.11 DCF 채널 접근 기능은 충돌을 피하고 hidden-terminal과 exposed-terminal 문제를 회피하기 위하여 두 홉 네트워크 내에서는 단일 전송을 허락한다. 이러한 단일 전송은 전송자의 이웃 노드가 전체 왕복시간 동안 데이터 프레임의 기다리게 하며, 프레임 지연의 증가와 네트워크 처리량을 낮게 하는 결과를 초래한다. 실시간 응용들은 낮은 매체 이용, 특히 높은 네트워크 트래픽에 대해 심하게 영향을 받는다. 본 논문은 IEEE 802.11의 프레임 집합화 기술을 이용하여 기본적인 DCF 기능을 유지한 단일 전송 장애를 극복하는 새로운 방안을 제시한다. 제안한 방안은 비 간섭 동기화 슬롯에서 병렬 전송을 허용한다. 병렬 전송은 몇몇 상황에서 물리적인 전송자 감지와 랜덤 백오프 타임을 회피하며, 프레임 지연을 줄이고 매체 이용과 네트워크 용량을 증가시킨다.

Abstract

The IEEE 802.11 DCF channel access function allows single transmission inside two-hop network in order to avoid collisions and eliminate the hidden and exposed terminal problems. Singular transmission capability causes data frames waiting for the entire roundtrip time in the transmitter neighborhood, and results in increased frame latency and lower network throughput. Real-time and pervasive applications are severely affected for the lower medium utilization; especially with high network traffic. This work proposes a new scheme with the help of Frame Aggregation technique in IEEE802.11n and overcomes the single transmission barrier maintaining the basic DCF functionality. Proposed scheme allows parallel transmissions in non-interfering synchronized slots. Parallel transmissions bypass the conventional physical carrier sense and random Backoff time for several cases and reduce the frame latency and increase the medium utilization and network capacity.

Keywords : DCF, Frame Aggregation, Fragmentation.

I. INTRODUCTION

The CSMA/CA based IEEE 802.11^[1] medium

access control (MAC) standard has been accepted as major wireless shared channel access mechanism for ad-hoc wireless networks including the Sensor and Mesh Networks. It is offering higher data rates gradually maintaining the low cost per bit. The 802.11 Task Group n (TGn) and other researchers are now chasing the limitations in the protocol in order to offer amendments in both MAC and PHY layers for higher throughput, and higher speed enhancements.

* 정희원, ** 정희원-교신저자, 경희대학교
컴퓨터공학과
(Department of Computer Engineering, Kyung Hee University)

※ This research was supported by the MIC, under the ITRC support program supervised by the IITA" (IITA-2006-(C1090-0602-0002))

접수일자: 2007년4월23일, 수정완료일: 2007년5월20일

Two major methods to improve the wireless network performance are offered by the researchers: one is to increase the raw bit rate at the PHY layer and the other is to reduce the overheads in the MAC layer. Repeated contention overhead has been eliminated in 802.11e^[2] by Transmission Opportunity (TXOP) limit and Block Acknowledgement schemes. These schemes offer several data frame transmissions within TXOP limit. Recently, the Frame Aggregation has been offered that reduces overheads for the repeated PHY and MAC headers as well as the channel access overheads. The Frame Aggregation (FA) scheme forms a super frame by aggregating several smaller frames under single MAC header^[3~5]. Both Block-Ack and Frame Aggregation schemes improve the peer-to-peer throughput for sender-receiver pairs. However, larger frame size or prolonged occupancy of the wireless medium obstructs neighboring nodes from transmitting and receiving for longer durations.

Long frame transmissions reserve the wireless medium for prolonged period. The prolonged reservation defers other transmissions, and these frames experience increased latency. Eventually the network performance degrades, and Multimedia and other QoS services are dropped out due to timeouts.

This work concentrates on frame latency reduction at the neighboring nodes of an active transmitter-receiver pair. Proposed Slotted

Transmission scheme uses mutually non-interfering parallel transmissions during the carrier sense stages and reduces the frame latency. Parallel transmissions are synchronized with each other and avoid interference between them.

We begin by presenting the motivation of the work with some of the related works, in the next section. Section III describes our proposed MAC protocol and the performance analysis is presented in the section IV. Section V concludes the paper.

II. MOTIVATION AND RELATED WORK

The 802.11 family of MAC protocols uses distributed channel access functions (DCF) or its enhancements (EDCA or AEDCF) for ad-hoc networks^[1~2]. These methods avoid collisions by both physical and virtual carrier sensing. For convenience, we use the term DCF and the 802.11 channel access function interchangeably. Detailed of DCF functionality is available in [1] and [2].

1. Frame Latency in 802.11 DCF

The term 'frame latency' is defined as the duration that a (data) frame waits after its arrival to the MAC layer and before being transmitted. Figure 1 shows the timing diagram of the DCF channel access mechanism for 802.11 MAC and how a frame experience latency in the MAC layer. A node

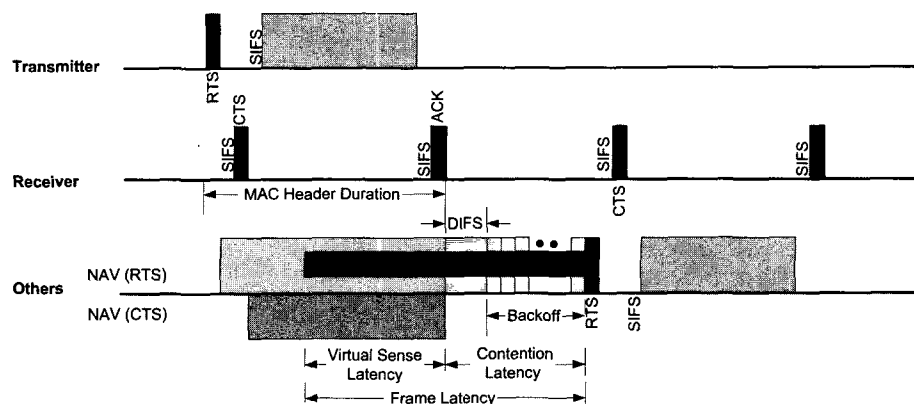


그림 1. IEEE 802.11 DCF 채널 접근 메커니즘에서의 프레임 지연

Fig. 1. Frame Latency in IEEE 802.11 DCF channel access mechanism.

switches to the virtual carrier sensing mechanism and updates its network allocation vector (NAV) when it overhears an RTS, CTS or a DATA frame. Overhearing nodes update the NAV duration from the duration field in the MAC header. The NAV is decremented in each time-slot and the node refrains from transmitting until this value reaches to zero. When the NAV expires in the nodes that were waiting for transmit data, it switches to the physical carrier sense and contend for medium access. There are many interesting delay analysis and performance evaluation of IEEE 802.11 DCF and similar protocols [6~8]. Most of the analyses, however, consider single flow within one-hop network from transmitter and receiver and describe the peer-to-peer delays and factors.

An awaiting frame experiences latency during the virtual and physical carrier sense procedures. Details of the latency can be observed in the NAV(RTS) timeline in figure 1. The length of the delay is the remaining part of the NAV plus the time required to send an RTS frame for the frame after winning the medium access contention. In mathematical form:

$$\text{Frame latency, } \delta = (v - t) + (T_{DIFS} + T_{Backoff}) \quad (1)$$

where, v is the initial NAV value (time) and t is the arrival time of the data frame.

The first component in (1) depends on the size of current data frame. On the other hand, we find that second part is for the physical carrier sensing. The second part maintains the collision avoidance mechanism. So we can conclude that, frame aggregation mechanism or multi-frame TXOP scheme increases the frame latency. The prolonged NAV does not only increase the latency but also increase the frame arrival probability in 1-hop network within current transmission and results in increased collision probability.

From (1), we find that the frame latency can be reduced in two ways only. First, allowing parallel transmission during the virtual sense mechanism; and, the second is to avoid medium contention

whenever possible. The first method requires distributed and precise synchronization between the parallel flows and should avoid the hidden and exposed terminal problems. The second method requires a collision avoidance procedure as well as efficient handling of the hidden and exposed terminals.

2. Related Works

Several solutions for parallel transmissions in wireless medium that reduce frame latency have been proposed in recent years. Most of them use multi-channel wireless medium or centrally-coordinated channel access mechanism. HomeRF^[9], Bluetooth^[10] and IEEE 802.16 (WMAN protocol)^[11] are the standardized forms of such proposals. HomeRF uses cordless telephone channel frequency, Bluetooth uses master-slave architecture, and the IEEE 802.16 uses centrally coordinated channel access scheme. Researchers are working on parallel transmission in single channel wireless medium over a long period. The conservative nature of IEEE 802.11 DCF for avoiding collisions creates challenge for parallel transmission. Parallel transmissions using transmission power control is proposed by Singh et al.^[12]. However, the power control from MAC requires enhancements in the physical layer. The MACA-P^[13] and its extension^[14] use a delay between the first RTS signal and data transmission in order to schedule non-interfering parallel transmission. The control delay creates and computation for scheduling adds large overheads. Some solutions are also available that uses directional antennas in order to avoid interference between concurrent transmissions^[15~16], but the solutions causes huge increase in cost. In all solutions, enhancements in the basic DCF architecture or in the physical layer are required.

In contrast, our proposed scheme uses the basic 802.11 DCF architecture without any enhancement in the physical layer. We synchronize the parallel transfers using available control frames and the synchronization itself avoids interference and collisions.

III. PROPOSED SLOTTED TRANSMISSION

Parallel transmissions and avoiding the physical carrier sensing mechanism are the two key methods for reducing latency. Parallel transmission within neighborhood of both sender and receiver is prohibited by DCF in order to avoid interference at receivers (or at transmitters while they receive acknowledgements). The protective measures like physical carrier sense and RTS/CTS exchanges are used for collision avoidance and to handle the hidden and exposed terminal problems. Allowing parallel transmissions within these conservative approaches in the DCF is the main challenge in reducing frame latency.

1. Fixed Length Transmission Slots

Parallel transmissions require precise synchronization to keep them away from interference with each other. Figure 2 shows how data and acknowledgement frame transmissions can be synchronized. Transmitters T1, interfere at the corresponding receivers. Again, if the T2 and T3 transmit data in parallel, so, they do not interfere at the corresponding receivers. Again, if the receivers R1, R2 and R3 send their acknowledgements simultaneously, the signals do not interfere at corresponding transmitters. Although the idea is simple, it is very difficult to implement when data frame sizes are different or they start transmissions at different time instants; and such situations are quite natural. In such case, the receiver of the smallest data frame (for example R₁) would acknowledge immediately after an SIFS interval and that would interfere at the transmitter (T₁) with

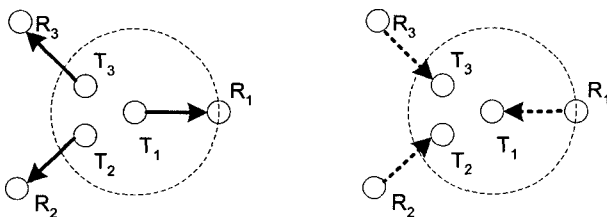


그림 2. 병렬 전송을 위해 요구되는 동기화
Fig. 2. Required Synchronization for Parallel Transmission.

other data frame signals (coming from T₂ and T₃).

2. Frame Aggregation and Transmission Slots

For perfect synchronization, we propose to convert variable length data frames into a fixed length frame (or fixed length fragments) using the Frame Aggregation Scheme for IEEE 802.11n^[3-4]. We use the maximum allowable frame (or fragment) size of the MAC as the common fixed length (Fig. 3). Lacking number of bytes is padded by a dummy frame at the end which is discarded at the receiver during dispersal.

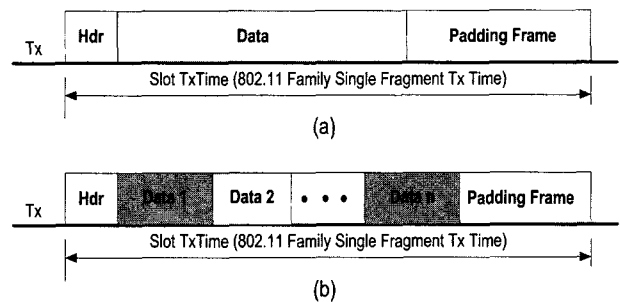


그림 3. 프레임 집합화를 이용한 고정된 길이의 전송 슬롯
슬롯

Fig. 3. Fixed Length Transmission Slot using Frame Aggregation

3. The SlotThreshold

The Aggregation process that makes frame size to the size of a maximum fragment (2304 bytes) adds large overheads for small sized frames. Further, we already discussed that small sized frames causes little latency of frames at the neighboring nodes. Depending on these facts we introduce a new threshold value to determine when the node would go for slotted transmission. From experimentation, we set the value of *SlotThreshold* to the half of the maximum fragment size (i., e., 1152 bytes). So, any frame (single or aggregated) of size less than 1152 bytes would follow the existing DCF procedure. Otherwise, the aggregation sub-layer^[4] would make the frame size equal to a multiple of fragment size and the slotted transmission would be initiated.

4. Slot Initiation

Any frame larger than *SoltThreshold* in a node is

converted to a super-frame of fixed length from the aggregation sub-layer. When the node gets the transmission opportunity (TXOP) after winning the contention procedure, it sends the RTS signal to the receiver. The duration field in the RTS frame contains the value :

$$D = T_{CTS} + (3 \times T_{SIFS}) + \tau + T_{ACK}$$

where, and are the required transmission time to transmit the CTS and ACK frames by the receiver at the lowest rate (6Mbps), is the SIFS interval, and, is the slot duration equal to the required transmission time for the frame of maximum fragment size. After sending the RTS, the first transmission slot starts at:

$$\phi_{start} = D - (T_{CTS} + (2 \times T_{SIFS}))$$

Nodes overhearing the RTS signal in the transmitter neighborhood can easily extract the same slot-start time from the duration field. So, using the existing RTS frame the first transmitter (hereinafter referred as Initiator) informs it neighbors about the slotted transmission.

5. Parallel Transmissions

Any node within the neighborhood of the initiator can initiate a new transmission within the same transmission slot(s) subject to the following conditions:

- The node has data frame(s) to send
- The node received the RTS signal from the Slotted Transmission Initiator (NAV is set due to RTS of the Initiator), and,
- The node did not receive any CTS frame from any of its neighbors

Condition (a) is straight-forward, condition (b) confirms that it has transmitter(s) in its neighborhood that is (are) transmitting in the slotted mode, so it should not go through the EDCA contention mechanism, and, finally, condition (c) confirms absence of any receiving station within its neighborhood where its signal can interfere.

6. Parallel Transmission Synchronization

When these three basic pre-requisites come together, the node(s) go for parallel transmission bypassing the 802.11 DCF/EDCA/AEDCF channel access contention mechanism. Depending on the size compared to the $RTS_{Threshold}$, it determines the start of transmission time and the padding frame size for aggregation.

$$t_{start} = \begin{cases} \phi_i + (\tau - \lambda - T_{data}) & , L < Th_{RTS} \text{ and } (T_{data} + \lambda) < \tau \\ \phi_{i+1} = (\phi_i + \tau) & , L < Th_{RTS} \text{ and } (T_{data} + \lambda) \geq \tau \\ \phi_i + (\tau - T_{RTS} - T_{SIFS} - T_{CTS}) & , L \geq Th_{RTS} \end{cases}$$

where, L , and represents the frame size, $RTS_{Threshold}$, and the arrival time of the data frame within current slot respectively, is the start time of current transmission slot, and, represents the round trip time for the frame ($T_{data} + T_{SIFS} + T_{Ack}$).

The first case in the equation is used for frames that do not require RTS/CTS exchange and the transmission can be completed within remaining slot time. The second case is for frames that do not require RTS/CTS but cannot complete the transmission within the remaining time of current slot. So, it transmits the data in the next slot without going for the physical carrier sense and random Backoff procedure. And the third case is for frames that require RTS/CTS exchange. In the second and third case, data frame is transferred in the next slot whether initiator uses it or not. The slotted transmission timing with parallel transmission is shown in figure 4.

By selecting appropriate transmission start time within a slot we avoid collisions and interference between the parallel flows. The starting time and fixed length of data frames ensure proper synchronization of acknowledgements and CTS frames from the receivers.

IV. PERFORMANCE ANALYSIS

The performance of the proposed slotted transmission scheme has been analyzed and compared

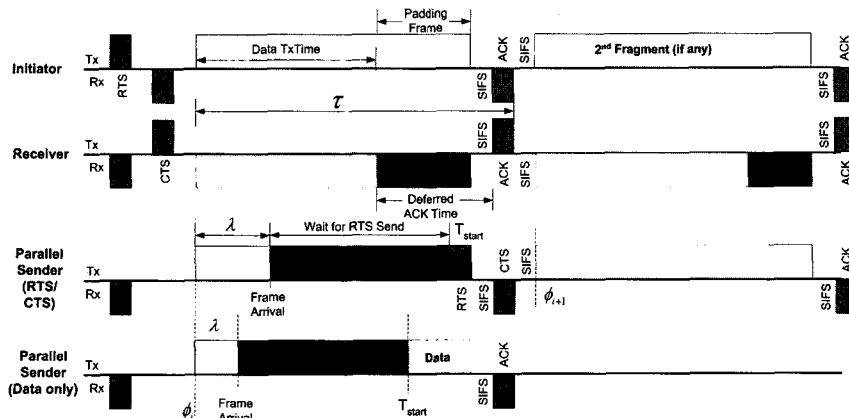


그림 4. 슬롯 기반 전송 타이밍
Fig. 4. Slotted Transmission Timing.

with existing 802.11 DCF (and its descendents). Two-hop network topology from the transmitter has been considered. Frame arrival follows Poisson distribution. In all cases, we used 216 Mbps (802.11n) and 6 Mbps rates for data and control frame respectively. Single rate transmissions are considered for the difficulties in multi-rate support in NS2.

A two-stage performance evaluation procedure has been performed. In the first stage, impact on flow throughput without any parallel transfer has been considered to identify performance degradation when there is no frame waiting at the neighboring nodes of the transmitter. In the second stage we analyze the parallel transmission cases and the frame latency and overall network throughput is observed.

1. Single Flow Performance

The proposed scheme adds some overheads in data frames that are larger or equal to the *SlotThreshold* in order to offer parallel transmission and resulting in sacrificing some throughput. Figure 5 describes the impact for the overheads on throughput when there is no parallel transmission and figure 6(a) shows the average throughput for both schemes. Throughput of both legacy 802.11 DCF and Slotted Transmission is identical when the payload size smaller than the *SlotThreshold*.

Shaded components in figure 5 identify the regions where the slotted-transmission performance degrades

compared to the legacy MAC protocols. Both schemes offer same flow-throughput when the payload size is multiples of the Fragmentation Threshold and the performance in slotted-transmission degrades as payload size is away from the next multiple of Fragmentation Threshold. It behaves like that because as the payload size approaches to the multiple of Fragmentation Threshold, the overhead size (padding bytes in frame) reduces. The padding overhead could be minimized by careful aggregation in the aggregation sub-layer.

Figure 6(b) depicts the throughput sacrifice by the initial flow within transmitter neighborhood. We shall see in the next stage of the analysis that the gain in overall network throughput for parallel transmission

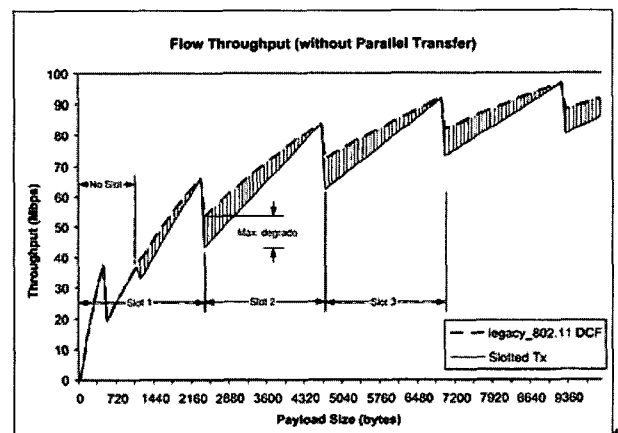
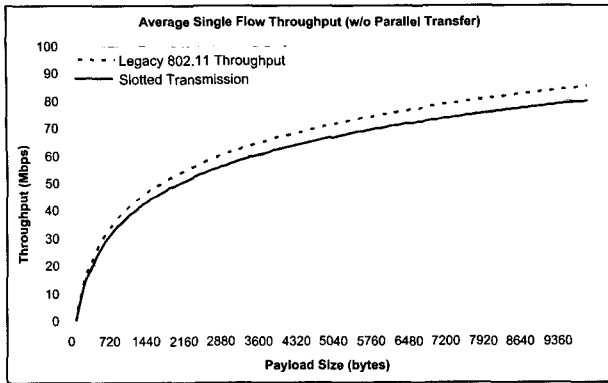
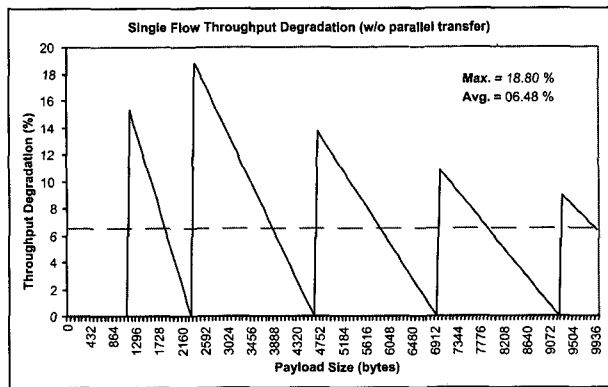


그림 5. 단일 흐름 처리량 분석
Fig. 5. Single Flow Throughput Analysis.



(a)



(b)

그림 6. (a) 평균 단일 흐름 처리량 비교
(b) 슬롯 기반 전송에서 페이로드 길이에 대한 처리량 감소

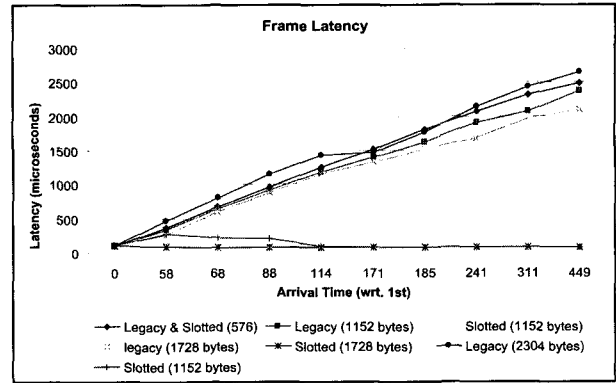
Fig. 6. (a) Average Single Flow Throughput Comparison, and (b) Throughput degradation with respect to payload size in slotted Transmission.

is high enough than the single throughput degradation.

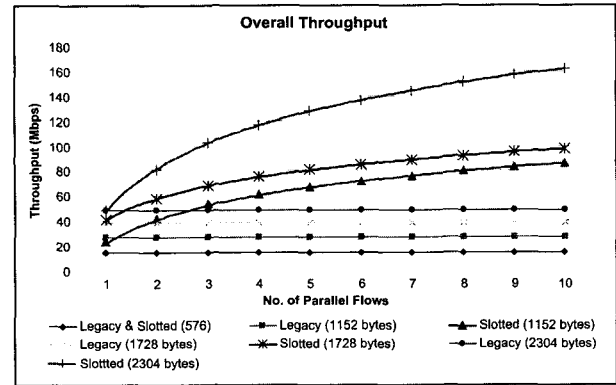
2. Parallel-Flow Performance

In the parallel flow model, the simulation was run for a number of frame arrivals within the originator neighborhood. Fixed-length frames arrive following the Poisson distribution. The corresponding frame latency and overall network throughput have been calculated. We observe distinguished reduction in frame latency and large gain in overall throughput when several data flows exist.

Figure 7(a) shows observed frame latencies for both legacy DCF and proposed slotted transmission for several payload sizes and random arrival time.



(a)



(b)

그림 7. 병렬 흐름 성능: (a) 다른 페이로드 길이에 대한 지연 시간과 (b) 전체 네트워크 처리량 분석

Fig. 7. Parallel flow performance: (a) Latency for different Payload sizes, and (b) Observed Overall Network Throughput for.

The arrival time in the table is relative to the first frame arrival time. All frames experience high latency in the legacy DCF, whereas, in the slotted transmission the latency remains very low.

The first frame in both scheme experience the same latency for the contention for medium. However, next frames having the size greater than (or equal to) the *SlotThreshold* waits for a shorter time in the slotted transmission than that in legacy 802.11 DCF. Frames that are smaller than the *SlotThreshold* experience same latency in both schemes. The slotted transmission scheme avoids the slotted transmission for small-sized frames. Both schemes give the same result for small sized frames.

Figure 7(b) shows corresponding overall network throughput for the parallel flows. The legacy 802.11 DCF provides constant throughput for same size

payloads as because it transmits frames one after another. Each frame contends for medium access with a random Backoff time after getting the free medium for DIFS period. In contrast to this, in the slotted transmission, frames are transmitted within the current or next transmission slot avoiding the physical carrier sensing mechanism. The slotted transmission performs better than DCF because it allows parallel transmissions from the transmitter neighborhood.

V. CONCLUSION

This work introduces parallel transfer within the existing legacy MAC framework defined in IEEE 802.11 standard in order to reduce frame latency and enhance overall network throughput. The frame aggregation mechanism is used to control the transmission duration of a frame and to synchronize the acknowledgements with other parallel receivers. Distinct advantage of the proposed slotted transmission is observed when parallel flows are opened within the transmitter neighborhood. Frames experience little latency and the overall network throughput increases compared to the legacy 802.11 MAC protocols. To find out the maximum number of parallel flows, network limit and probabilistic analysis of the proposed mechanism are the open issues for future work.

Reference

- [1] Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specification (Part 11). IEEE Std. 802.11. June 1997.
- [2] Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications (Part 11); Amendment 8: Medium Access Control (MAC) Quality of Service Enhancements. IEEE Std. 802.11e. Nov. 2005.
- [3] Yang Xiao. IEEE 802.11n: Enhancement for Higher Throughput in Wireless LANs. IEEE Wireless Communications, pp. 82 - 91. December 2005.
- [4] Youngsoo Kim, Sunghyun Choi, Kyunghun Jang, and Hyosun Hwang. Throughput Enhancement of IEEE 802.11 WLAN via Frame Aggregation. In proceedings of the IEEE Vehicular Technology Conference, 2004. VTC2004-Fall. Vol. 4. pp. 3030 - 3034. 2004.
- [5] Changwen Liu and Adrian P. Stephens. An Analytic Model for Infrastructure WLAN Capacity with Bi-directional Frame Aggregation. In proceedings of the IEEE Wireless Communications and Networking Conference, Vol. 1, pp 113 - 119. 2005.
- [6] Liang Zhang, Yantai Shu, Oliver Yang, and Guanghong Wang. Study of Medium Access Delay in IEEE 802.11 Wireless Networks. IEICE Transaction on Communication, Vol.E89-B, No. 4. April 2006.
- [7] Teerawat Issariyakul, Dusit Niyato, Ekram Hossain, and Attahiru Sule Alfa. Exact Distribution of Access Delay in IEEE 802.11 DCF MAC. In proceedings of the IEEE Global Communication, IEEE GlobeComm, 2005.
- [8] G. Bianchi. Performance Analysis of the IEEE 802.11 Distributed Coordinate Function. IEEE Journal on Selected Areas in Communications. Vol. 18, no 3, pp. 535 - 547. 2000.
- [9] The HomeRF Technical Committee. HomeRF Specification. HomeRF. Revision 2.1. 1 July 2002. url:<http://www.palowireless.com/homerf/homerfस्प ec.asp>
- [10] Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPANS) (Part 15.1). IEEE Std 802.15.1. 2002.
- [11] IEEE Recommended Practice for Local and metropolitan area networks: Coexistence of Fixed Broadband Wireless Access Systems, IEEE Std. 802.16. Sep. 2001.
- [12] K. P. Sigh, C. M. Chou, M. Y. Lu, and, S. M. Chen. A distributed Spatial Reuse (DSR) MAC protocol for IEEE 802.11 Ad-hoc Wireless LANs. In the proceedings of the 10th IEEE symposium on Computers and Communications, ISCC. pp. 658 - 663, 2005.
- [13] A. Acharya, A. Misra, and S. Bansal. MACA-P: A MAC for concurrent transmissions in multi-hop wireless network. In proceedings of the IEEE International Conference on Pervasive Computing and Communications. pp. 505 - 508, 2003.
- [14] A. Archya, A. Misra, and S. Bansal. Design and Analysis of Co-operative Medium Access Scheme for Wireless Mesh Networks. In proceedings of the First International Conference on Broadband Networks (BROADNETS'04). pp. 321 - 631, 2004.

- [15] R. R. Chowdhury, X. Yang, N. H. Vaidya, and, R. R. Ramanathan. Using Directional Antennas for Medium Access Control in ad-hoc Networks. In proceedings of the ACM International Conference on Mobile Computing and Networking, pp. 59 - 70, 2002.
- [16] Y. Wang, and J. J. Garcia-Luna-Aceves. Spatial Reuse and Collision Avoidance in ad-hoc Networks with Directional-Antennas. In proceedings of the IEEE Global Telecommunications Conference, vol. 1. pp. 112 - 116, 2002.

----- 저 자 소 개 -----



Md. Mustafizur Rahman(정회원)
 1992년 Department of Computer Science and Engineering, University of Dhaka, Bangladesh, 학사졸업.
 1993년 Department of Computer Science and Engineering, University of Dhaka, Bangladesh, 석사졸업.

2005년~현재 Department of Computer Engineering, Kyung Hee University, 박사과정.
 <주관심분야 : Wireless Ad-hoc and Mesh network>



홍 충 선(정회원)
 1983년 경희대학교 전자공학과 학사졸업.
 1985년 경희대학교 전자공학과 석사졸업.
 1997년 Keio University, Department of Information & Computer Science 박사졸업.

1988년~1999년 한국통신망 연구소 수석연구원/네트워킹 연구실장
 1999년~현재 경희대학교 전자정보학부 부교수
 <주관심분야 : 네트워크 보안, 인터넷 서비스 및 망 관리 구조, 분산 컴포넌트 관리, IP 프로토콜, 센서 네트워크>