무선랜에서의 적극적 공간 재활용 기법

김 진 경˙, 안 재 민°

Aggressive Spatial Reuse Scheme for the 802.11 Wireless LAN

Jinkyeong Kim˙, Jae-Min Ahn°

요 약

본 논문에서는 무지향성 안테나를 장착한 IEEE 802.11 기반 무선랜이 서로 이웃하는 환경에서 채널의 혼잡 여부를 판별하여 적극적으로 공간 재활용을 함으로써 전체 네트워크의 성능 향상을 높이는 기법을 제안한다. 파괴적 RTS(Disruptive RTS), 혼잡 랜덤 백오프(Busy Random Backoff), 제로 패딩(Zero Padding)과 불가용 단말쌍 관리로 이루어진 적극적 공간 재활용 전략은 기존의 IEEE 802.11 기반 무선랜과의 역호환성을 유지하며 최대 50%부터 최소 14%의 성능 향상을 가져옴을 확인하였다.

Key Words : Aggressive Spatial Reuse, Wireless LAN, IEEE 802.11, Disrupted RTS

ABSTRACT

We provide an aggressive spatial reuse scheme exploiting the space sensed busy when neighboring 802.11 stations radiate radio wave in omni-directions. For this purpose, we develop four strategies, i.e., disruptive RTS, busy random backoff, zero padding, and unavailable pair management. The simulation results show that the proposed scheme can improve the aggregate network throughput from 14% to 50% while the station adopting the proposed scheme coexists with the legacy stations.

Ⅰ. Introduction

Almost everywhere, we can recognize that it is possible to find the 802.11 Access Points (APs), thus enjoying Internet services thanks to fast and widely spreading 802.11 Wireless Local Area Networks (WLANs)[1]. Besides, WLANs are expected to deliver almost fifty percent of world-wide Internet traffic in the year of 2017[2]. Accordingly, we face an urgent demand to improve the network throughput so that extensive studies on the issues have been carried out in academic areas as well as standard areas in IEEE 802.11ac/ad/ah.

Along with the efforts for the recent research, spatial reuse schemes are employed to exploit idle spaces for aggregate network throughput improvement when directional transmissions and receptions are utilized for the WLANs in 60 GHz bands due to strong directivity of the wave propagation[3-5]. In contrast to the 60 GHz band, 2.4

GHz bands are harsh environments in which WLAN stations apply spatial reuse. It is because it is not easy to make sharp directional beams for frame transmissions and receptions[6]. Generally, the WLANs in 2.4 GHz bands accomplished network throughput improvement with frame aggregation method because network throughput degradation caused by mainly ACK frame which is always transmitted on lowest rate and also waiting SIFS time before sending ACK frame[7,8].

In this paper, we propose to aggressively utilize the spaces near by the stations transmitting frames even when those spaces are sensed busy for aggregation network throughput enhancement rather than network throughput improvement that can be achieved through frame aggregation. Surprisingly, it is possible since a station detecting busy channel can send a frame to another station sensing its channel idle. For this purpose, we design an aggressive spatial reuse scheme consisting of disruptive RTS (dRTS), busy random backoff, zero padding and unavailable pair management as detailed later. The rest of this letter is organized as four sections. In Section II, we explain the background for our aggressive spatial reuse. In Section III, we propose the spatial reuse scheme in the 2.4 GHz bands. In Section IV, we show the evaluation results and Section V concludes this paper.

Ⅱ. Background

In the 802.11 WLAN, stations check if the channel is sensed idle or not prior to transmitting a frame by performing Clear Channel Assessment (CCA) or referring to Network Allocation Vector (NAV). If a station detects idle channel, it transmits data frame. Otherwise, it defers the frame transmission until idle channel is detected[9].

Figure 1 shows the case when station B and C attempt to send their frames to station A and D, respectively. We can assume that station C wins against station B to access channel by conducting random backoff. In order to prevent hidden station, station C first transmits Ready-To-Send (RTS) frame. Then, the NAV conveying in the RTS
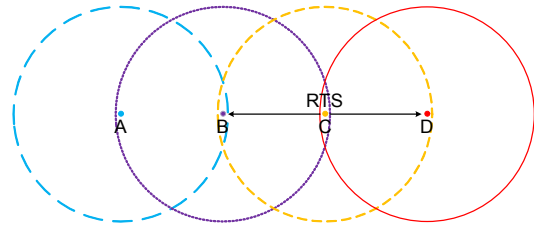

Fig. 1. RTS frame for preventing from transmission by station B and D

prohibits the station B from transmitting a frame in the air while station C transmits a frame to station D.

However, from this figure, we can recognize that station A and D are far from station C and B, respectively. Therefore, we can consider a scenario that station A senses negligible power emitted from station C so that the signal transmitted by station B is strong enough to overcome the signal from station C. If this scenario may exist, the station B can send a frame to station A as long as this frame transmission does not influence the frame transmission of the station C destined for station D.

We focus on this scenario. If a station can recognize it is under this scenario, it can employ spatial reuse in even busy channel. For this reason, we design a method how to recognize this scenario for better use of spatial reuse. After that, we modify the 802.11 random backoff for the scenario. This modified 802.11 random backoff is called busy random backoff. Then, we show zero padding on DATA frame with aggressive spatial reuse scheme for timely acknowledgement. At last, we suggest a way how to manage transmission and reception pairs unsuitable for aggressive spatial reuse scheme.

Ⅲ. Aggressive Spatial Reuse Scheme

In this chapter, we describe four strategies constituting aggressive spatial reuse scheme.

3.1 Disruptive RTS

It is obvious that neighboring stations should not disturb the station transmitting frames during neighboring station's frame transmission period, it may incur collision in the air, thus resulting in frame

transmission failure. This failure certainly deteriorates the overall network throughput. However, even in this case, there is a room for improvement. Accordingly, we propose to disturb frame transmissions of neighboring stations. Ultimately, we target at improving aggregate network throughput in spite of the throughput degradation incurred by intended disturbances. We explain the reason why the intended disturbances are needed and what we propose for this purpose in detail as follows.

In Fig. 1, we assume that station B and C transmit to station A and D without acknowledgements, respectively under the situation that station B and C does not interfere with station D and A, respectively. In this case, station A and D can receive each frame successfully. However, the major problem is that it is no way to recognize this situation. For this reason, we design disruptive RTS for the recognition without a priori information.

Fig. 2 shows an exemplary snapshot of the intended disturbances called disruptive RTS. In this figure, station B intentionally transmits an RTS frame while station C sends a frame to station D.

This operation is certainly prohibited in legacy stations. However, the operation can be used to find it out that station C may fail to transmit a frame to station D due to the disruptive RTS frame transmission by observing the frame retransmission of the station C. In other words, disruptive RTS from B interferes with station D so that the station D cannot receive station C's frame successfully. Actually, the frame transmission failure can happen due to channel error either. In either case, we consider that the disruptive RTS disturbs station C's
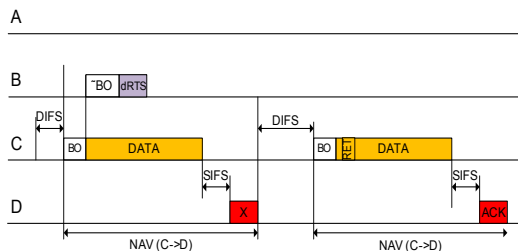
frame transmission so that we conservatively determine that station B's frame transmission generates interference against station D's reception.

In contrast, we can consider the case when the disruptive RTS does not influence station C's frame transmission. It implies that it is possible that the station B can transmit a frame to station A without interference with the station C. Consequently, we employ spatial reuse that a station can transmit frames while it senses its channel busy. However, we need more elaborate strategy in order to fulfill the spatial reuse scheme in an omni-environment as detailed in the next subsection.

3.2 Busy Random Backoff

Fig. 3 illustrates the case when station B and station E send data frame (srDATA) simultaneously to station A with aggressive spatial reuse scheme while station C transmits data frame to station D. In this case, station B and station E collide with each other since they attempt to transmit data frame simultaneously.

In order to avoid the collision, we adopt a new binary exponential random backoff. Logically, this backoff scheme is identical to the 802.11's binary exponential random backoff except the case when the backoff is conducted in busy channel. A station can transmit data frame only when it wins against the other stations in this busy random backoff procedure.

Procedure 1 shows the procedure that stations should follow prior to the frame transmission.
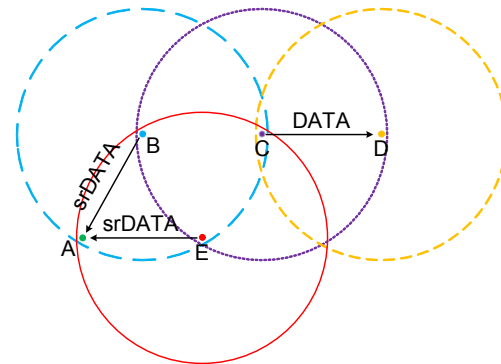

Fig. 2. Disruptive RTS usage

Fig. 3. Collision of srDATA frames transmitted by multiple stations employing aggressive spatial reuse scheme

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Procedure 1 Busy random backoff

1: Choose random number (N) in SR-Window
2: Store a currently noise power (Pn)
3: **while** N > 0 **do**
4: Regardless of channel condition, N decrease in every slot and update Pn
5: **if** Pn exceeds a certain threshold (Pth) **then**
6:   fail to transmit
7: **end if**
8: **if** N equals to Zero without exceeding Pth **Then**
9:   win to transmit
10: **end if**
11: **end while**

Busy random backoff is employed for the frame transmissions including data frames and RTS frames in aggressive spatial reuse scheme.

3.3 Zero Padding

In fact, the proposed scheme allows a station detecting busy channel to transmit data frames. Therefore, it would be more likely that ACK frame corresponding to a transmitted data frame may be replied in the busy channel. Then, the station transmitting data frame cannot receive the ACK frame. In order to resolve this collision, we propose to fill zeros extending the data frame size up to potential idle channel region.

Fig. 4 depicts the case when station B transmits a data frame (srDATA) to station A while station C sends a data frame to station D. In this figure, station B's transmission time duration plus station
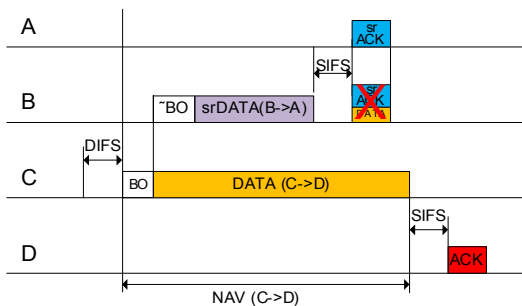
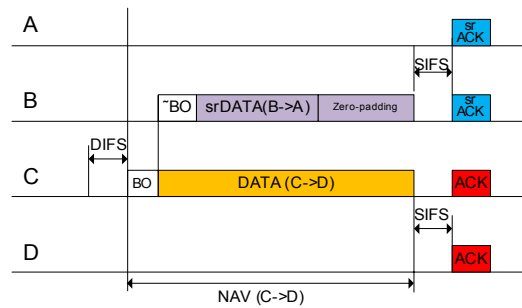Fig. 4. Collision of srACK frame and DATA frame

A's ACK transmission time is not sufficiently long to cover the station C's transmission time duration. For this reason, station B fails to receive station A's ACK frame (srACK) due to the collision with station C's a data frame.

Meanwhile, Fig. 5 illustrates the data frame (srDATA) transmissions with zero padding in aggressive spatial reuse scheme. The data frame with zero padding is long enough to ensure that srACK frame dose not collide with DATA frame transmitted by station C. In this figure, we can also notice that srACK frame can collide with ACK frame transmitted by station D. However, station D is far from station B so that it does not interfere with station B's reception. Note that the frame transmissions in busy channel are conducted only after it is confirmed that interferences of the neighboring stations are ignorable.

3.4 Unavailable Pair Management

Fig. 6 illustrates the case when station B, G, E, and I have a pending packet destined for station A, F, H, and J, in turn, during station C's transmission time for station D. In this case, we assume that station C is in the position where station C can employ the proposed aggressive spatial reuse scheme. If the one among station E, G, or I wins busy random backoff to a data frame, the ACK frame sent by station F, H or J may collide with the ACK frame sent by station D. Therefore, station C may fail to receive the ACK frame from station D.

In order to prevent this situation, we propose to stop the aggressive spatial reuse when a station fails to receive ACK frame pre-defined number of times.

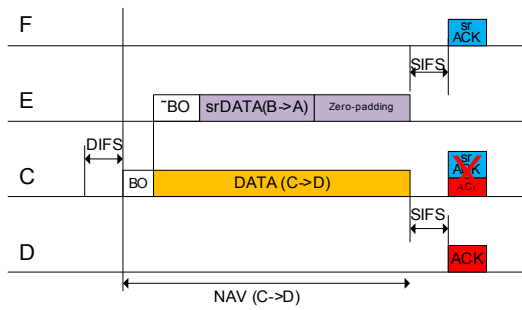Fig. 5. Zero padding to srDATA frame

Fig. 6. Collision of srACK and ACK frame

The rule to stop the aggressive spatial reuse is summarized as follows with Fig. 7:

1. Station C employing aggressive spatial reuse scheme first sends disruptive RTS frame. Then, station D replies with CTS.

2. Station H, J, and F receiving disruptive RTS and/or CTS do not reply with srACK although they receive srDATA frame from station E, G, and I, respectively.

3. Station E, G, and I increase their contention window because they fail to receive srACK and then station H, J, and F retransmit srDATA frame continuously.

4. Station E, G, and I delete stations F, H, and J, respectively on its aggressive spatial reuse list because those station are not suitable for aggressive spatial reuse scheme when retransmissions of srDATA exceed pre-defined number.

So far, we explain how stations exploit aggressive spatial reuse in omni-environments by utilizing disruptive RTS, busy random backoff, zero padding,
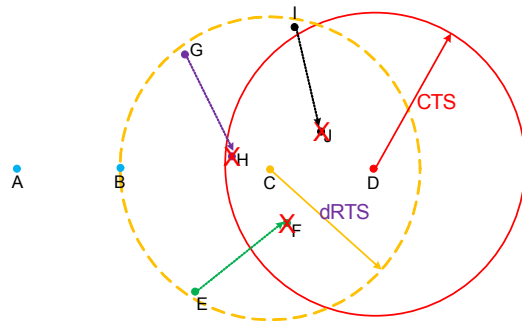

Fig. 7. Deletions of unavailable stations in aggressive spatial reuse list

and unavailable pair managment. Subsequently, we will show how much the performance improves compared with the existing policies.

Ⅳ. Performance Evaluation

The performances are evaluated with NS2 simulator[10,11]. For the simulations, we assume that UDP packets are transmitted from a source station to a destination station at a constant rate. The parameters, we adopt for our simulations, are summarized in Table 1.

Fig. 8 shows the aggregate network throughput when 20 stations are deployed every 250 meters in a line. In this case, ten stations among those 20 stations participate in transmissions and the rest keep receiving. We vary the offered load from 1 Mbps to 13 Mbps, and thereafter, observe the performances.

Table 1. The parameters for our simulation.

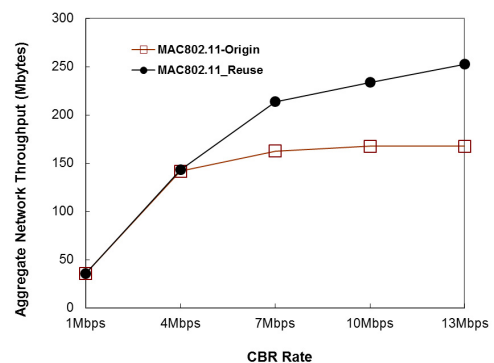| Attributor	Parameter
Propagation	TwoRayGround path loss model
Antenna	OmniAntenna
CS Threshold	3.162e-12 (-85dBm)
Noise Floor	2.512e-13 (-96dBm)
TX Power	0.01 (10dBm)
PreambleCapture	2.5118 (4dB)
Busy Random Backoff Threshold	3.162e-12 (-85dBm)
Total Simulation Time	100 sec
Data Rate	6 Mbps

Fig. 8. Grid topology with fixed distance

In this figure, we can find the aggregate network throughput improves up to 50 % compared with the legacy 802.11 stations.

Fig. 9 show the performances when stations are situated regularly in a grid topology. In this scenario, the distances between two stations are constant. We conduct the simulations by varying the distances from 100 meters to 450 meters. Also, we set the offered traffic load to 7 Mbps. In this scenario, we can observe that the aggregate network throughput is maximized when the distance is 250 meters. There are two reasons for this as follows: (1) when the distance is short, stations are not likely to employ the spatial reuse since more densely deployed stations may collide with each other for the spatial reuse more frequently. (2) When the distance is long, transmission rates should be degraded to reach long-distanced stations. It results in poor performances in spite of more opportunities for the spatial reuse.

Fig. 10 represents the aggregate network throughput when stations are randomly scattered in a 1000 meters by 1000 meters region. In this case, the distance between a pair of transmitter and receiver keeps constant as 100 meters. The offered load varies from 1 Mbps to 13 Mbps. The simulation results are averaged after performing the simulations 100 times. From this figure, we can observe the aggregate network throughput improves up to 20 %.

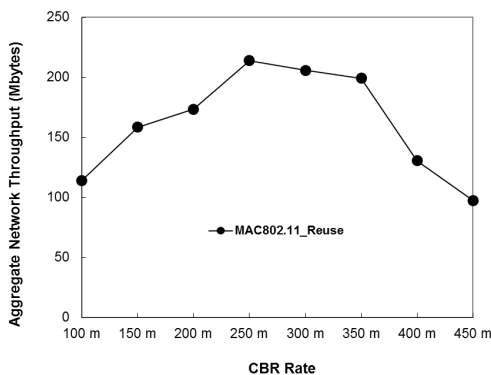For the performance evaluation shown in Fig. 11,

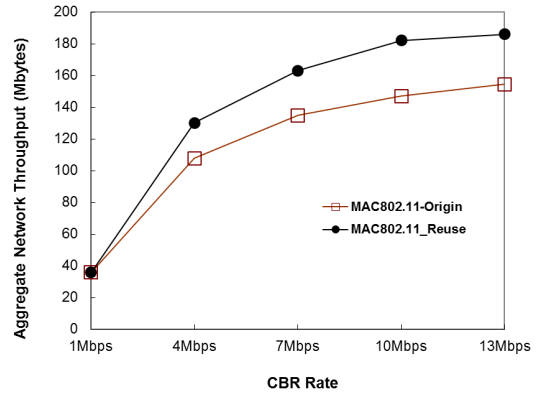Fig. 9. Grid topology with variable distance

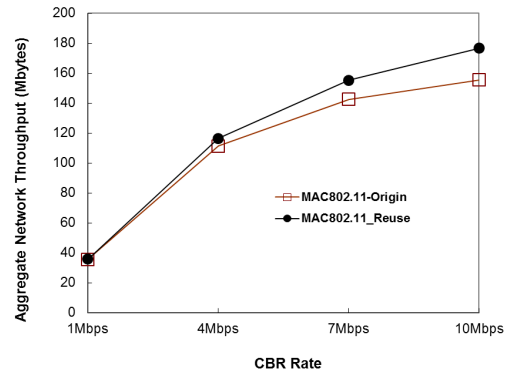
Fig. 10. Random topology with fixed distance

Fig. 11. Random topology with variable distance

we conduct our simulations by randomly varying the distance between two stations in a transmission-and-reception-pair. The offered load varies from 1 Mbps to 13 Mbps and we obtain the simulation results averaged over 100 simulation results. From this figure, we can observe the aggregate network throughput improves 14 % at maximum.

V. Conclusion

We have developed a scheme to aggressively improve the aggregate network throughput in omni-transmission/reception environments. For this purpose, we provide four strategies such as disruptive RTS, busy random backoff, zero padding, and unavailable station deletion. The simulation results show that aggregate network throughput improves up to 50 percent and at least 14 percent in

grid and random network topologies, respectively. Our research is expected to contribute to the research regarding spatial reuse significantly since we prove that spatial reuse can be employed in even omni-transmission/ reception environments. For the further study, we will also evaluate random topology with higher data rate including dense environment and provide mathematical analysis on our scheme.

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김 진 경 (Jinkyeong Kim)

1992년 2월 : 인하대학교 전자공학과 졸업
1994년 2월 : 인하대학교 전자공학과 석사
1994년 3월~현재 : 한국전자통신연구원 책임연구원

<관심분야> 차세대 이동통신 셀 관리, 무선랜 매체제어접속, 밀리미터파 대역 무선통신, 초장거리 무선통신

안 재 민 (Jae-Min Ahn)

1987년 2월 : 서울대학교 전자공학과 학사
1989년 2월 : 한국과학기술원 전기 및 전자공학과 석사
1994년 8월 : 한국과학기술원 전기 및 전자공학과 박사
1994년~1999년 : 삼성전자 선임연구원
2007년~2008년 : 정보통신연구진흥원 차세대이동통신사업단장, 정보통신부 차세대 이동통신 PM
1999년~현재 : 충남대학교 전기정보통신공학부 교수
<관심분야> 차세대 이동통신 물리계층 및 Radio Resource management

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