Dynamic Bandwidth Scheduling for QoS Enhancement over IEEE 802.11 WLAN

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Abstract : **This paper describes a dynamic Scheduled Bandwidth Reservation/Fairness MAC control scheme for real-time data (rt-data) service and non-real-time data (nrt-data) service of WLAN condition. It uses a schedule table, which is different from the table of IEEE 802.11, maintained in each station to allocate medium accessing time. It specifies a CYCLE period that includes contention free period (CFP) and contention period (CP). CFP is beginning from a Beacon frame that contains the schedule table. The difference from IEEE 802.11 standard is the CFP used to transmit not only rt-data but also nrt-data and CP is only used to transmit management frame for unrecorded stations to apply to record into the schedule table. Each recorded station would not contend the medium during the CP. And the CP can be used as extension period for rt-data service. It means that if bandwidth is fully filled by rt-data service, then no new station would be allowed to join the WLAN. So it reduces collision sensibly and provides enhanced rt-data service and nrt-data service.**

1. Introduction

In WLAN Techniques, there are higher requirements of speed and capacity of data delivery, especially in widespread application of real-time multimedia and quality of service (QOS). The IEEE 802.11 WLAN standard[1] includes a basic distributed coordination function (DCF) scheme and an optional point coordination function (PCF) scheme. The DCF uses carrier sense multiple access with collision avoidance (CSMA/CA) as the basic channel access protocol to transmit asynchronous data in the DCF. An attractive feature of CSMA/CA protocol is that it is simple to implement. However, this contention -based MAC protocol cannot guarantee transfer delay for rt-data traffics. The delay bound services can be provided by employing the PCF. The PCF is divided into CP and CFP. In CP it acts as the same as DCF. And in CFP it uses a polling-based protocol which is not designed for the distributed environment. With PCF, real-time stations will access the channel in a round-robin manner in each CFP. However, the use of centralized scheme in PCF constrains the operation of WLAN. Furthermore, several researchers have pointed out the centralized protocol results in a poor performance and it is not of benefit to the extent of network[2], [3], [5], [14].

A black-burst contention method is one of the MAC mechanisms that were proposed to provide the QoS guarantee and the real-time traffic over carrier sense wireless networks. The considered real-time applications are those like voice and video that require more or less periodic access to the common radio channel during long period of time session. The main performance in these applications requires bounded end-to-end delay, which implies a bounded frame delay at the MAC layer. At the beginning of a session, a station uses conventional CSMA/CA rules, possibly with a more expedited retransmission algorithm to convey its first packet until it is successful.

One approach to improve the throughput and the QoS used a small test package[1]. This approach reduces data loss in collision, however it is not used for real-time data transmission. A BB (black-burst) contention method was proposed to minimize delay for real-time traffic[5]. The main goal of BB is to minimize the delay for real-time traffic. Unlike the other schemes it imposes certain requirements on the high priority stations. The stations jam the medium with pulses of energy, denominated BB's. The length of a BB that transmitted by a station is an increasing function of the contention delay which is experienced and measured by the station from the instant when a attempt is done to access the medium that has been scheduled until the channel becomes idle for a specified time. [12] and [13] also mention the BB contention approach for enhancing rt-data service. And many researchers used the method of dividing different idle area to allocate different priority for different data service in order to reduce collision and delay and to improve the reliability and QoS of rt-data service. It means accessing the medium within a less idle area that would have a higher priority of transmission[7], [9], [10]. This method can keep the distribution, but do not remodel the approach on reducing the collision through. [6] compared the various approaches mentioned in [1], [5] and [10], and it shows that BB mentioned in [5] gets a better performance than the others. A bandwidth allocation method was also proposed for variable bit rate data in [8]. [3] proposed a reservation table approach to allocate the bandwidth for variable bit rate. It improves the bandwidth utilization, but it reschedules the stations by the bandwidth utilizing at the beginning of each cycle that could not guarantee the delay for each station. The approach of using schedule table to allocate the bandwidth can reduce the collision greatly, but it always needs much redundant data to compute the bandwidth and allocate the source. It limits the extensibility of wireless LAN. All of these schemes allocate different priority by different interframe to avoid collision and to improve rt-data service, but they did not resolve the problem of collision ultimately that reduces the contention.

And [4] presented a fully distributed fair scheduling (DFS) algorithm, which is derived from the DCF in the IEEE 802.11. In DFS, a flow with a larger weight will obtain a higher throughput. However, how to assign appropriate weights for real-time and non-real-time flows is still an open issue. Furthermore, the DFS did not consider the delay bound of real-time frame. In this paper, we propose a new algorithm using small redundant data to provide perfect services and to reduce contention providing enhanced rt-data service. It does a dynamic bandwidth scheduling with reservation for rt-data transmission and also keeps the fairness for nrt-data service. Section 2 presents simple background knowledge about interframe spaces of the IEEE 802.11 standard for WLANs. Section 3 describes the suggested protocol. The analysis of this protocol is given in Section 4. The results are presented and discussed in Section 5.

2. Interframe spaces of IEEE 802.11 MAC

The DCF is the basic access mechanism of IEEE 802.11. It uses a CSMA/CA algorithm to mediate access to the shared medium. The IEEE 802.11 defines four type of IFS(interframe space) which is the time interval between frames. A station shall determine that the medium is idle through the use of the carrier-sense function for the interval specified. IFSs are defined to provide priority levels for access to the wireless media medium; they are ordered from the shortest to the longest as follows,

SIFS(short IFS), PIFS(PCF IFS), DIFS(DCF IFS), EIFS(extended IFS)

SIFS shall be used when stations have seized the medium and need to keep it for the duration of the frame exchange sequence to be performed. PIFS shall be used only by stations operating under the PCF to gain priority access to the medium at the start of the CFP. And the DIFS shall be used by stations operation under the DCF to transmit data frames and management frames. The EIFS shall be used by the DCF whenever a station did not result in the correct reception. So the EIFS is terminated and normal medium access continues following reception of that frame. PCF is a centralized, polling-based access mechanism which requires the presence of a base station that acts as Point Coordinator. During the CFP, the central station polls each station in its polling. At the nominal beginning of each CFP, the PC shall sense the medium. When the medium is determined to be idle for one PIFS period, the PC will transmit a Beacon frame containing the CF parameter.

3. Dynamic Bandwidth Scheduling MAC (DBSM) Protocol

Many researchers have pointed out that polling is a poor performance approach for rt-data transmission. We try to find an enhancement for rt-data transmission. The proposed DBSM protocol not only improves the bandwidth availability, but also it is robust and scalable. The DBSM reduces collision sensibly and it provides QoS enhancement for rt-data service and fairness for nrt-data service in distributed environments. The DBSM uses the several frames as follows.

3.1. Format of Schedule Table, Beacon and EF Frame

Whether a station supports rt-data transmission or not, all stations maintain a schedule table which records the state of each active station that is transmitting data. And stations decide the time when data will be transmitted according to the schedule table. Figure 1 shows the format of schedule table, and figure 2 is beacon frame's format that is broadcasted at the beginning of each CYCLE. EF (Extension Flag) frame's format is shown in figure 3 and it is used for rt-data transmission. If the idle counter reaches 3, it means that the station is move out of the BSA(basic service area) or failed.

Bits:					
8	1	7	1	2	3
STA ID	Link Type	Last Success Time	Extension Flag	Idle Counter	Reserved

STA ID:	Station Identifier
Link Type:	0 for real-time data and 1 for non-real-time data
Last Success Time:	the time record in millisecond when received ACK last time
Extension Flag:	has more data to transfer
Idle Counter :	if this station has no data to transmit then increase one, and if it reaches 3 this note would be deleted from Schedule table

Figure 1 Schedule table format

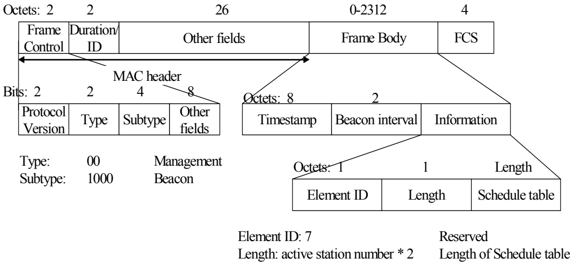


Figure 2 Beacon frame format

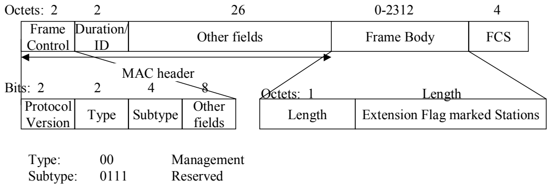


Figure 3 EF (Extension Flag) frame format

3.2. Establishment of Schedule Table

When an unrecorded station (i.e., a station did not hear the beacon frame) wants to transmit data, whether rt-data or not, it must sense the medium. Also, if it is not idle while waiting for a specified idle time(DIFS for nrt-data and PIFS for real-time data), it contends the medium by BB contention algorithm. And then, it sends a management frame in order to register itself into the schedule table of established WLAN. If it never senses any message from the beginning of listening while waiting for a DIFS, it performs a BB contention to generate a schedule table that has only one note for itself and it broadcasts to others through a beacon frame.

3.3. Update Procedure

Every station in the basic service area (BSA) can receive all of the frames including management frames and data frames that might be transmitted between them and update the corresponding value in schedule table. At the beginning of each repetition period, named CYCLE, the first named station in schedule table will broadcast a beacon frame that contains "*Timestamp*" element, duration field and the others. The other active stations in the BSA would receive it, keep the status synchronized by the "*Timestamp*" element and set their NAV by duration field and store the schedule table. CYCLEs will repeat at a prespecified repetition rate to provide rt-data service. After the first beacon frame, all active stations receive all of the frames in the BSA so that they will have the same schedule table. In fact, the following beacon frames at the beginning of each CYCLE contains the schedule table with intent to keep completely consistency and to avoid collision occurred by the reason of any difference in schedule table. Each active station listens to the medium and updates the "*last success time*" of correlative station at every time when it received ACK frame. The first named station in the schedule table will be deleted after receiving a frame marked with "*Link terminated*". When a station does not have data to transmit at continued 3 times, it implies the station may move out of the BSA. If the first named station in the schedule table failed, then the first name in the schedule table will be deleted and the second named station recorded in the schedule table would act as the first named station to send the beacon frame. Figure 4 depicts an example of schedule table updating of nrt-data service. At first, station B contends the channel and generates the schedule table that contains only one note of itself. Then station B broadcasts a beacon frame to begin a CFP period for data transmission. After receiving the first ACK frame, the station update the "*last success time*".

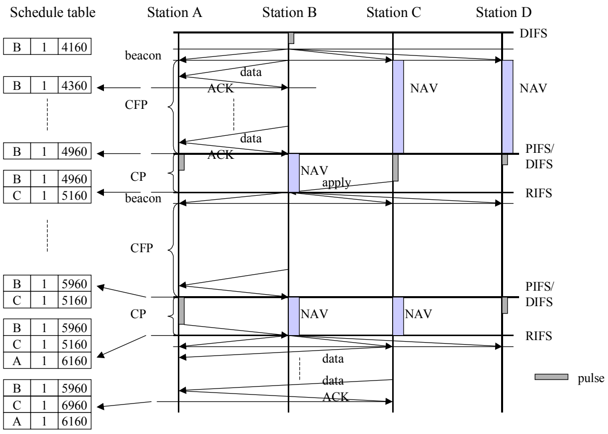
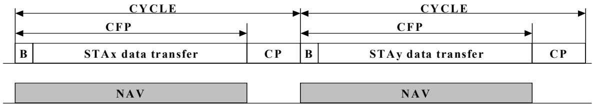


Figure 4 Establishing and updating of schedule table

At the end of the first CFP period, the "*last success time*" is updated by the time of receiving the last ACK frame. In following CP period, station B stops contending the channel and the other stations A, C and D contend the channel. If station C gets the right of transmission from a management frame applied to the recorded information in the schedule table, the C's "*last success time*" is the time recorded into the schedule table. After a RIFS(Resend IFS), next CYCLE begins by a beacon frame broadcasted by station B. And next step proceeds according to same procedure.

3.4. nrt-Data Transmission Procedure

In DBSM protocol, a time frame, CYCLE repeats. CYCLE consists of CFP and CP of IEEE 802.11. But CFP and CP are different from does of IEEE 802.11. When CYCLE is used for only nrt-data transmission during its period, it permits only one station to transmit data. Each station is stored in the order of "*last success time*" in the schedule table. The station having the smaller value of the "*last success time*" is earlier transmitted. The nrt-data transmission function is shown in figure 5.



B: Beacon packet
Stax data transfer: used for only one station to transfer data continuously
CP: contention period, used for those stations which haven't noted in schedule table

Figure 5 nrt-data transmission procedure

After receiving the beacon frame, each station updates the NAV, stops sending any frame and listens the medium. And only the station having the smallest value can send messages during CFP period. The interval between each data frame and ACK frame is a short interframe SIFS. When the CFP is completed, the station would stop to transmit any message immediately whether it has more data or not. And the "*last success time*" is the time of the last received ACK frame during the CFP period. If a station finished its transmission in the CFP period, the station would be deleted from the schedule table and the next station would start its data transmission in remained period after SIFS when received an ACK frame marked with "*Link terminated*" or it would start its transmission after PIFS. During the following CP period, unregistered stations in the table will not contend the medium. This scheme can reduce the collision greatly. And in order to support rt-data transmission even more, we adopt BB contention scheme during CP period. Using equivalent transmission time to provide the fairness between each nrt-data station is better than the scheme of equivalent number of frames or equivalent data quantity. Each nrt-data station has the same transmission time. There has not the problem of "*monopolization*" and "*starvation*". If the precondition is not impacting other stations and stations with high throughput can transmit more data as it can do. Note that the fairness is only provided in nrt-data service.

3.5. Rt-data Transmission Procedure

Each station transmits rt-data in the order sorted by the "*link type/last success time*" field stored in the schedule table. We put the two field into one byte in order to compute easier and faster. If a data frame is successfully transmitted, then an ACK would be received after the SIFS and the "*last success time*" would be updated. If the station did not receive an ACK, they do not update the record. The station must retransmit the frame immediately and the "*Idle counter*" increases by one. If it reaches three, this station would be deleted from the schedule table. As shown in figure 6, when the sum of current station's value of "*last success time*" and *duration of current frame* is greater than the sum of the smallest "*last success time*" in the schedule table and *a CYCLE time* it sets "*Extension Flag*", current station stops transmitting and next station starts its data transmission.

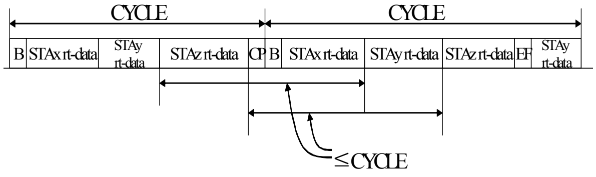
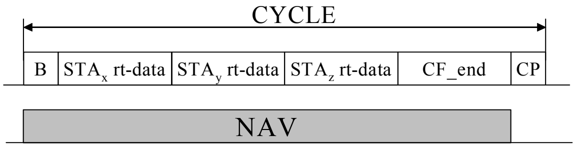


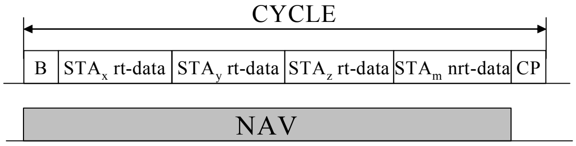
Figure 6 rt-data transmission procedure between contiguity CYCLE

Each station must transmit data before "*last success time*" + *one CYCLE time* for the real-time service. When a station terminates transmitting data before scheduled time, it would announce "*current transmission finished*" or "*Link terminated*". And the next station can transmit data ahead of schedule. In the CYCLE, when all of the rt-data stations have transmitted once, one CYCLE is finished. After that, the first named station in the schedule table would broadcast the EF frame when "*Extension Flag*" is marked to announce that stations have more data to transmit. And the mapped station sorted by "*last success time*" begins again to transmit their buffered data. If a station has more data to transmit but it has not received the EF frame, the station marks the EF frame and then it must wait for next CYCLE to transmit its buffered data. As depicted in figure 7, if any station has rt-data to transmit but the CFP has finished, the station will transmit rt-data during the CP period remaining in current CYCLE. That is, no new stations will be permitted to be recorded into the schedule table because there is no CP period for them to apply to be recorded into the schedule table. By this way, it provides more data transmission time and extends bandwidth and QoS for action station.

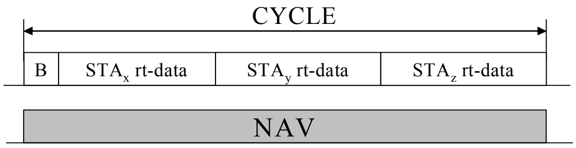
If all of the rt-data stations finish their transmitting and the CFP is not finished, it allows a nrt-data station to transmit data during remaining period of CFP. And if rt-data stations finish their transmitting and there are nrt-data stations, the current CFP finishes by broadcasting "*CF_end*" frame using the first named station in the schedule stable. Also, the CYCLE length can be shortened than prespecified length which gives higher throughput when there are not enough rt-data and nrt-data service to fully fill the CYCLE.



Have not nrt-data station



Have at least one nrt-data station : Not fully filled



Have at least one nrt-data station : Fully filled

Figure 7 The rt-data transmission procedure in a CYCLE

3.6. Error Processing

Based on the characteristic of the digital signal propagation, the errors are always occurred to as several bit errors, but they do not lose the signal. Our error processing will be based on this premise. We will define a RIFS to replace the EIFS and the order is SIFS < RIFS < PIFS < DIFS. If a source station does not receive the acknowledgement after SIFS, it would resend the frame after RIFS and it is used also before beacon frame so that the first station has higher priority than new real-time stations. SIFS is used as interframe between continued frame and ACK from one station. Also, PIFS is used to switch stations and DIFS is used between CFP and CP.

4. Analysis

We assume that there are n stations, the weight of station i is w_i and L_i is the packet length of station i. The throughput of station i is σ_i, the length of collision window is 0~1023. T is the total time for all of the stations that finish their transmission.

In CSMA/CA,

$$T_{CSMA/CA} = \sum_{i=1}^{n} [\frac{w_i}{\sigma_i} + \left\lceil {w_i}/{L_i} \right\rceil * (T_{CW} + T_{RTS} + T_{CTS})] \quad (4\text{-}1)$$

In DBSM,

$$T_{DBSM} = \sum_{i=1}^{n} [\frac{w_i}{\sigma_i} + \left\lceil {w_i}/{(T_{CYCLE} - T_{CW} - T_{beacon}) * \sigma_i} \right\rceil * (T_{CW} + T_{beacon})]$$

(4-2)

If $T_{CSMA/CA} > T_{DBSM}$, it means that the DBSM is better than CSMA/CA.

$$\sum_{i=1}^{n} [\frac{w_i}{\sigma_i} + \left\lceil {w_i}/{L_i} \right\rceil \times (T_{CW} + T_{RTS} + T_{CTS})]$$
$$> \sum_{i=1}^{n} [\frac{w_i}{\sigma_i} + \left\lceil {w_i}/{(T_{CYCLE} - T_{CW} - T_{beacon}) \times \sigma_i} \right\rceil \times (T_{CW} + T_{beacon})]$$

$$\sum_{i=1}^{n} [\left\lceil {w_i}/{L_i} \right\rceil \times (T_{CW} + T_{RTS} + T_{CTS})]$$
$$> \sum_{i=1}^{n} [\left\lceil {w_i}/{(T_{CYCLE} - T_{CW} - T_{beacon}) \times \sigma_i} \right\rceil \times (T_{CW} + T_{beacon})]$$

For each station,

$$\left\lceil \frac{w}{L} \right\rceil \times (T_{CW} + T_{RTS} + T_{CTS})$$
$$> \left\lceil {w}/{(T_{CYCLE} - T_{CW} - T_{beacon}) \times \sigma} \right\rceil \times (T_{CW} + T_{beacon})$$

Let $ML = (T_{CYCLE} - T_{CW} - T_{beacon}) \times \sigma$ and $M \geq 1$ which means that there are M packets could be transmitted during a CYCLE period. Then we have

$$\left\lceil \frac{w}{L} \right\rceil \times (T_{CW} + T_{RTS} + T_{CTS}) > \left\lceil {w}/{ML} \right\rceil \times (T_{CW} + T_{beacon})$$

$$M(T_{CW} + T_{RTS} + T_{CTS}) > T_{CW} + T_{beacon}$$

$$M > {T_{CW} + T_{beacon}}/{T_{CW} + T_{RTS} + T_{CTS}} \quad (4\text{-}3)$$

By the nominal values for the parameters of the system [3] [5], we can know the eq.(4-3) is right. So we can conclude that DBSM can get higher throughput than general CSMA/CA.

4.1. Backoff Time of CSMA/CA and Scheduled BB

Let assume there are n nodes and each node has $m_i (i=1 \ldots n)$ packet.

- CSMA/CA

The node would contend for sending packet.

$$Total \;\; backoff \;\; time = \sum_{i=1}^{n} (m_i * T_{backoff}) - T_{overlap}$$

Here, $T_{overlap} = \sum n * \min(T^i_{backoff})$,

$T^i_{backoff} = CW * T_{slot}$ is the backoff time of node i that is not overlapped. And a collision window is
$CW = random\ [0, min(2^n\text{-}1, CW_{max})]$

- BlackBurst

The nodes only contend at first packet sending, and then they schedule the following packets.

$$Total \;\; blackburst \;\; time = \sum_{i=1}^{n} T_{blackburst}$$

Here, $T_{blackburst} = \max(T^i_{blackburst})$,

$T^i_{blackburst} = CW * T_{slot}$ is the black burst time of node i.

T_{slot} is the time of slot.
$CW = random\ [\, max(0, 2^{n-1}\text{-}1), min(2^n\text{-}1, CW_{max})\,]$

4.2. Simulation

We have simulated both 802.11 standard MAC protocol and the proposed DBSM protocol to compare each other. We used a Network Simulator 2.26 [15] in this evaluation and the parameters are shown in Table 1. Also, We assumed that the stations do not move in wireless evaluation and the channel condition is assumed to be error-free and have not hidden station.

Parameter	Value
Channel rate	2 M bits/s
CYCLE time	50 ms
Slot time	20 μs
Data stations	10
Transmission time of RTS	144 μs
Transmission time of CTS	120 μs
Transmission time of a data packet	4.292 ms
MAC header	272 bits
PHY header	128 bits
Beacon frame length	800 bits
EF frame length	368 bits
ACK frame length	240 bits
Short interframe space(SIFS)	10 μs
Priority interframe space(PIFS)	30 μs
DCF interframe space(DIFS)	110 μs

Table 1 Nominal Values for the parameters of the system

Figure 8 depicts the number of collisions in the stations when packet is sent during 500 seconds as the node number is increasing. And Figure 9 shows the total delay time during the backoff period in 802.11 standard and the blackburst period in DBSM protocol. Figure 10 plots the throughput of 802.11 standard and DBSM protocol.

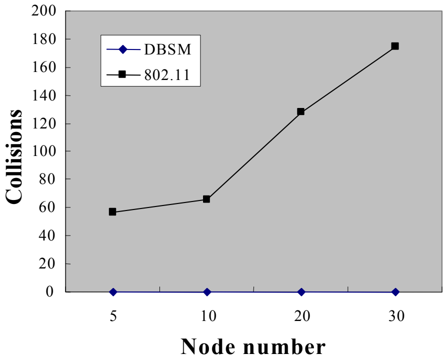


Figure 8 Number of collision

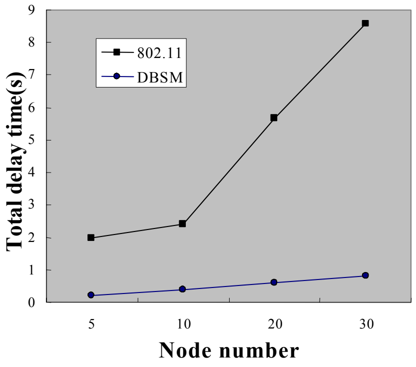


Figure 9 Delay time

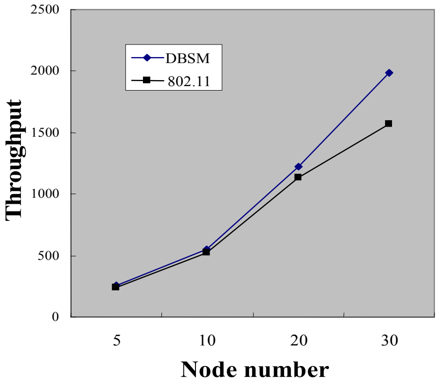


Figure 10 Throughput

5. Conclusion and Future Work

In this paper, we have proposed a scheme to enhance the capability of rt-data services and nrt-data services at WLAN MAC layer. It has several advancements as follows:

- It reduces the collision greatly and improves the throughput of data transmission.
- It's robust. The whole network would be maintained even though any station had failed.
- It's more scalable.
- It provides the fairness for nrt-data services.
- It provides effective bandwidth reservation for rt-data services.

In this paper, we did not consider the overlapping space and the wireless routing algorithm for ad hoc network. [11] proposed a scheme of routing algorithm over ad hoc network. However, it is based on TDM technology and it seems difficult to avoid the bandwidth waste in idle time and remaining slots. In future work, we will work on routing algorithm for providing handoff service, end-to-end delay and real-time service based on DBSM.

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