An Adaptive MAC Scheduling Algorithm for Guaranteed QoS in IEEE 802.11e HCCA[⋆]

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Abstract. The IEEE 802.11e standard guarantees QoS in the MAC layer by using new HCF (Hybrid Coordination Function) protocol. The HCF is composed of two access functions: A distributed contention-based channel access function (EDCA) providing prioritized QoS and a centralized polling-based channel access function (HCCA) providing parameterized QoS. In this paper, we propose a new scheduling algorithm for HCCA to support QoS. The proposed scheduler guarantees QoS by using adaptive service intervals, transmission opportunities, and polling order. The service schedule is based not only on the traffic's TSPEC parameters but also on the instance buffered traffic conditions and transmission delay of other traffic. Simulation results show that the proposed scheduling algorithm is superior to the existing TGe Reference scheduler, SETT-EDD, and ARROW algorithms in terms of throughput, transmission delay and jitter.

1 Introduction

Since multimedia services, such as VoIP (Voice over IP) and moving picture, in wireless networks are sensitive to time delay, we have to consider the problem of managing the QoS (Quality of Service). Modern wireless LAN technologies use the best effort method. Because technology in Modern wireless LAN uses the best effort method, it can not allocate service flexible period and TXOP. Then, it is too difficult to guarantee the traffic QoS of being sensitive to time-delay [1].

In order to guarantee the QoS for IEEE 802.11e, the IEEE 802.11 Task Group has proposed a new protocol, IEEE 802.11e [2]. In IEEE 802.11e, HCF (Hybrid Coordination Function) is defined which corresponds DCF (Distributed Coordination Function) and PCF (Point Coordination Function) in 802.11. HCF is composed of EDCA (Enhanced Distributed Channel Access) which controls the channel access in contention period and HCCA (HCF Controlled Channel Access) which controls the channel access in non-contention period. HCF is backward compatible with the legacy MAC. Stations using the IEEE 802.11e have a chance to transmit the frame through TXOP (Transmission Opportunities).

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In HCCA, the HC (Hybrid Coordinator) located at the AP(Access Point) allocates the TXOPs through polling mechanism, which in turn requires a scheduler. Depending on the HC scheduler,the network throughput may vary. Our research concerns the scheduling in HCCA [2]-[5]. In Appendix of IEEE 802.11e Standard document proposes a basic HCCA scheduling algorithm [2]. However, this scheduler assigns the same SI (Service Interval) to all stations, thus being efficient only for the CBR (Constant Bit Rate) traffic. In case of VBR traffic (Variable Bit Rate), the packet sizes are changed arbitrarily, thus having a same SI for all stations results to bad efficiency [3]-[5].

In this paper, according to the characteristics of traffic in HCCA, we propose a new scheduler to provide the QoS demanded by applications in IEEE 802.11e networks. The proposed scheduler allocates SI adaptively based on characteristics of the traffic. This is accomplished by increasing the size of the next SI by the size of the remaining packets in the current SI, and then rescheduling the adjusted SI to start earlier. This reduces the packet loss and increasing of the time-delay. If the start of the current SI and the expected deadline in the previous SI are not same time, the time-delay is decreased through dynamic SI lengths. After that the QoS can be guaranteed.

This paper is composed as follows. In section 2 we explain our proposed scheduler. In the next section we compare the efficiency between the basic HCCA scheduler and our proposed scheduler using simulation. Finally, we summarize the paper.

2 Proposed Scheduling Algorithm

In this section, we present a new algorithm that makes less delay time than the existing algorithms and services through the characteristic of the traffic stream.

In the Reference Scheduler presented in IEEE 802.11e, as SI and TXOP have fixed values, it has low efficiency due to increased packet loss probability in VBR (Variable Bit Rate) traffic. FHCF (Fair HCF), on the other hand, adaptively allocates TXOPs, but has the same SI for all admission traffic streams. Therefore it also has low efficiency. In SETT-EDD and ARROW algorithms, the different SIs are allocated based on the characteristics of the traffic streams. In these algorithms, the difference between the expected start of a TXOP and the actual start of the TXOP form a delay, which will accumulate to the TXOPs in the consecutive SIs. The proposed algorithm prevents the accumulation of the transmission delay by using the transmission delay information embedded in the status of the traffic stream. Our algorithm changes the start of the next SI according to the size of the remaining packets in the current SI. This reduces loss of the packets, thus increases efficiency.

2.1 Operation Method of the Proposed Scheduler

The proposed algorithm uses the EDD algorithm, (Earliest Due Date; polls the station of which deadline is the earliest) [6][7] which has transmission priority in sensitivity of delay as in SETT-EDD and ARROW [4][5]. When the channel is idle in PIFS, the scheduler polls the QSTA to provide service for the delay-sensitivity station if equation (1) holds.

$$t_{pre_i} + mSI_i <= t' \tag{1}$$

Here, t_{pre_i} means the start time of previous SI of the QSTA i, and t' means the present time. If there are many QSTAs that satisfy the condition, QAP polls the QSTA which has the minimum deadline. In this polling operation, the deadline value is $t_{pre_i} + MSI_i$. The reason is to service QSTAs sensitive to delay first. If there is no QSTA that satisfies the equation (1), the scheduler waits until a SlotTime, and after that tries again. SI is fixed in SETT-EDD and ARROW, so QSTA can be serviced after mSI(Minimum Service Interval) from the start of the previous SI. But, in some cases, it makes low efficiency; the reason is due to non necessary transmission delay. The proposed algorithm changes mSI and MSI(Maximum Service Interval) adaptively according to the state of the traffic to keep the transmission delay and allocates TXOP adaptively. Therefore, it decreases the transmission delay and reduces packet loss.

2.2 Method of allocating TXOP

In IEEE 802.11e, QoS Control field was added. QoS Control field is used to get the information of QoS request. In the proposed algorithm, TXOP is allocated adaptively by using requested TXOP duration value of the QoS Control field. If the 4th bit of the QoS Control field is 0 when a Non-AP QSTA transmits the QoS data frame, the bits from 8th bit to 15th bit mean the necessary time to transmit the rest of the packet. So, on transmitting final QoS data frame in the present SI, the additional TXOP is allocated to the next SI by transmitting the requested TXOP duration value. During the next SI, QSTA will transmit the packet which is not transmitted during the current SI.

The average TXOP which is calculated at the end of every SI is calculated by (2) because it must guarantee transmission of at least a packet which has Maximum MSDU size.

$$TXOP_{avg_i} = \max\left[\frac{(\frac{mSI_i \cdot \rho_i}{L_i}) \cdot L_i}{R_i} + O, \frac{M_i}{R_i} + O\right] \tag{2}$$

where O is the total MAC/PHY overhead time. It is summation of the time to transmit QoS CF-Poll frames and the ACKs of data frames and IFS time. mSI means Minimum Service Interval. ρ means the average transmission rate. L means Nominal MSDU Size. M_i means the Maximum MSDU Size of traffic stream i and R_i means the minimum transmission rate. So, if QSTA obtains chance to access to the channel, at least it guarantees the minimum transmission time of the packet which is the Maximum MSDU Size. Hence, total TXOP size is the addition of additive TXOP size which is the value of the requested TXOP duration (TDr) and the average TXOP derived from (3).

$$TXOP_i = TXOP_{avg_i} + TDr_i \tag{3}$$

Figure 1 shows the method of TXOP allocation in the proposed algorithm.

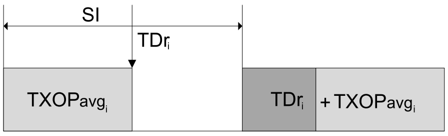


Fig. 1. TXOP assignment with proposed algorithm

2.3 Method of allocating SI

In this section, we explain how to decide SI in the proposed algorithm. QSTA extracts mSI and MSI from the TSPEC information. The mSI value is used as the minimum time to successive TXOPs. SI has to be more than this interval. However, as seen in figure 1, if there are packets that were not serviced during the previous SI, these packets appear as additional delay. Consequently, the packets arriving first during the present SI will have unnecessary delay. If there are packets that were not serviced during the previous SI, mSI is increased by the value of *TDr*. Since this information is submitted by the QSTA to the QAP when the final QoS data frame of allocated TXOP is exchanged, we can avoid the unnecessary delay, as shown in figure 2. The calculation is presented in (4).

$$mSI_{new_i} = mSI_i + TDr_{pre_i} - TDr_{cur_i} \tag{4}$$

where TDr_{pre_i} means the value of TXOP Duration request to QAP and TDr_{cur_i} means the value of current TXOP duration request. If the mSI and the start of the previous SI are known, the starting time of the next mSI can be calculated.

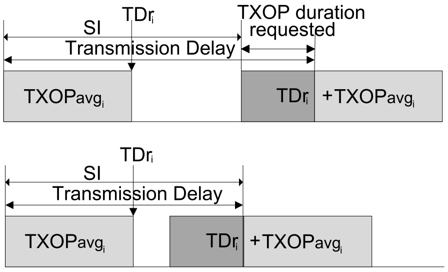


Fig. 2. Modification of mSI with TXOP duration requested value

Since QSTA can transmit only in TXOP in IEEE 802.11e HCCA, QSTA can get the channel access right no longer even though data frames to have to transmit is remaining. In this case, as in accordance with the control method explained above, QAP will find other QSTA satisfying the equation (1). It makes unnecessary delay of QSTA which loses the tranmission opportunity. In order to prevent this, the proposed algorithm adaptively changes mSI and MSI by considering the difference between the actual starting time of a SI and expected SI starting time in previous SI at QSTA. Hence, QAP flexibly changes mSI and MSI of QSTA after the retransmission of QoS data frame of TXOP. The altered values of mSI and MSI are as follows and the MSI value will be altered by the difference.

$$
\begin{aligned}
&\text{if}(t_{curr-SI-sst_i} - t_{curr-SI-due_i}) > 0,\\
&\qquad mSI_{new_i} = mSI_{new_i} - (t_{curr-SI-sst_i} - t_{curr-SI-due_i})\\
&\qquad MSI_{new_i} = MSI_{new_i} - (t_{curr-SI-sst_i} - t_{curr-SI-due_i})\\
&\text{otherwise},\\
&\qquad mSI_{new_i} = mSI_{new_i}, MSI_{new_i} = MSI_{new_i}
\end{aligned}
\tag{5}
$$

where t_{cur_i} means the actual starting time of present SI of QSTA i, and $t_{cur\text{-}due_i}$ means the expected starting time of the present SI of QSTA i.

3 Performance Evaluation of the Proposed Algorithm

In this section, in order to confirm the operation of the proposed scheduling algorithm, we evaluate the results of simulation using NS-2 [8]. For this purpose, we compared our algorithm with the Reference scheduler and SETT-EDD. The compared aspects were delay-time, transmission rate and loss probability of packets during total simulation hours.

3.1 Simulation scenario

IEEE 802.11e scenario was constructed using a star type Topology to analyze the performance of the proposed algorithm. QAP supporting HCCA and QSTA transmitting QoS data were the components of the network. Each QSTA had an up-link traffic stream to transmit data to QAP.

We compared the delayed time by traffic types, transmission rate during total simulation hours and packet loss probability by increasing the number of QSTA from 1 to 12. Physical layer used in this simulation is IEEE 802.11b. Parameters of the simulation are presented in Table 1. For MAC level, IEEE 802.11e HCCA module which was developed by Pisa University in Italy [9] was used. In this simulation RTS/CTS frame was not used.

VoIP was used for CBR Traffic, and MPEG4 video (Jurassic Park) was used for VBR Traffic [10] to analyze the function of the proposed algorithm. The simulation length was 1000 seconds. The channel status was assumed to be healthy. Summarized traffic characteristics are shown in Table 2.

Table 1. Parameters of the simulation

Parameters	**Value**
Slot Time	20s
SIFS	10s
PIFS	30s
Basic Tx Rate	1 Mbps
Data Rate	11 Mbps

Table 2. Parameters of the simulation

TSPEC	**CBR traffic**	**VBR traffic**
Mean Data Rate	83Kbps	128Kbps
Peak Data Rate	83Kbps	1.7Mbps
Nominal MSDU SIze	208Bytes	1,300Bytes
Maximum MSDU Size	208Bytes	5,211Bytes
Maximum Burst Size	576Bytes	5,211Bytes
Minimum PHY Rate	11Mbps	11Mbps
Maximum Service Interval	30ms	40ms
Delay Bound	60ms	80ms

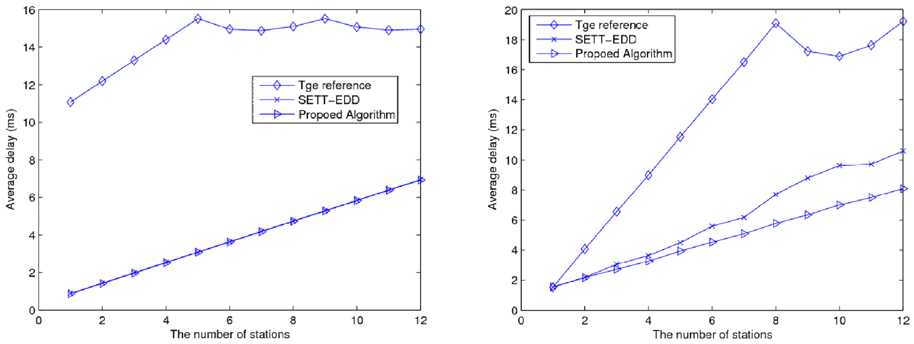
3.2 Analysis of the Simulation Results

In the simulation we measured the average delay time in accordance with the traffic characteristics, transmission rate, and packet loss probability for the Reference Scheduler, SETT-EDD and the proposed algorithm.

Figure 3-(a) presents the mean delay times of CBR Traffic of the three algorithms. In this simulation, one packet (exact size: 208bytes) was We can see that the average delay for the Reference Scheduler is the longest and the delays for SETT-EDD and the proposed algorithm are the same. In case of the Reference Scheduler, more than the required amount of TXOP is allocated by the maximum TXOP size of IEEE 802.11e MAC, thus wasting about 40.33% of the allocated TXOP. Transmission delay of the Reference Scheduler is increased because servicing every 30 seconds is in accordance with the Maximum service interval. The Reference Scheduler does not show better performance than SETT-EDD and the proposed algorithm in case of CBR Traffic. The reason is that the characteristics of the traffic stream are not considered in the Reference Scheduler. SETT-EDD and the proposed algorithm allocate required quantity of TXOP of CBR Traffic based on the characteristics of the traffic stream, and transmit the CBR Traffic every 20 seconds.

Figure 3-(b) shows the average delay seconds of MSDU upon successful transmission when transmitting the VBR Traffic. The delay seconds for the proposed algorithm is the shortest. The reason is because the proposed algorithm, as explained above, increases the probability of admitted channel access by adjusting mSI and MSI of QSTA as according to the time difference when transmitting is not possible as scheduled. In case the packet was not transmitted during the

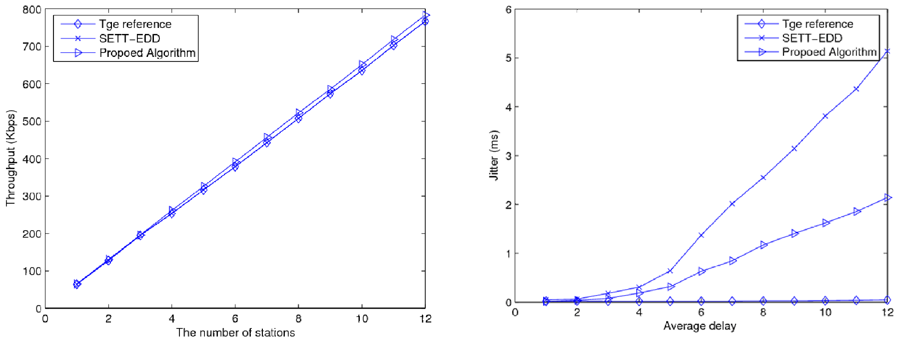
previous SI, it is possible to prevent the delay accumulation by adjusting MSI. As mSI and MSI of QSTAs are adjusted in accordance with the QSTA status, transmission delay time occurred due to another QSTA will be compensated.



(a) Average delay of CBR traffic (b) Average Delay of VBR traffic

Fig. 3. Comparison of delay in CBR and VBR traffic.

Figure 4-(a) shows the transmission rate of VBR data during the whole simulation. SETT-EDD and the proposed algorithm are very similar. In case of the Reference Scheduler, the transmission rate is a little low because severe packet loss occurred. In case of VBR Traffic used in the simulation, the maximum size of the produced packets is about 5,211 bytes. However, in case of the Reference Scheduler, the required TXOP is insufficient due to the allocation of required TXOP for transmitting 2,304 byte-packets. However, there was no packet loss in all twelve nodes, because of the small number of burst traffics. Jitters of reference, SETT-EDD and the proposed algorithm are compared in figure 4-(b). As we can see in this figure, the proposed scheduling algorithm shows better per-



(a) Throughput of VBR traffic (b) Jitter of VBR traffic

Fig. 4. Throughput and Jitter in VBR traffic.

formance in jitter than SETT-EDD using EDD algorithm. This is because the proposed algorithm changes more flexibly the MSI and mSI values. The reference scheduler has a low jitter because of fixed SI.

4 Conclusion

The existing scheduling algorithms for IEEE 802.11e do not reflect well the characteristics of the traffic, thus QoS cannot be guaranteed. This gives serious effects to restoration of the traffic. In case of video traffic, packet loss may occur due to accumulated delay.

In order to solve the problems of the existing scheduling algorithms, we utilized the transmission delay information of the QSTA upon acquiring a channel access. In case the packets are not transmitted which should be transmitted due to the lack of allocated TXOP, the occurrence of unnecessary delay was prevented through adaptively adjusting mSI and MSI of the QSTAs. Occurrence of the packet loss was prevented by compensating the insufficient TXOP to the following SI. In our algorithm, the transmission priority was given to the traffic stream which was the most sensitive to delay. Simulation results show that this algorithm has a superior performance compared with existing algorithms.

In this paper, we proposed a new scheduling algorithm under assumption of a stable channel. However, The future circumstance of wireless network coexists with various wireless technologies. More efficient scheduling study should be done under the circumstance of an unstable wireless channel.

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