Opportunistic Scheduling in IEEE 802.11n WLAN

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Abstract: - In wireless local area network (WLAN) environment with independent user fading, at least one user is likely to undergo very good channel state at any time, and this is called *multiuser diversity*. For high system performance, a transmission scheduler at the LLC layer is required to exploit this multi-user diversity by opportunistically selecting a feasible user with a good channel, and it is referred to as *Opportunistic Scheduling (OS)*. In this paper, we proposed an OS scheme which is adaptive to the 802.11n WLAN. Different with existing OS schemes, it takes into account the two distinct characteristics of 802.11n, which are the frame aggregation and the quality of service (QoS) requirements according to the access categories (ACs). Through the simulation results, we prove that the proposed scheme not only improves the total system throughput, but it also preserves fairness and the QoS requirements corresponding to the ACs in the 802.11n WLAN.

Key-Words: - 802.11n WLAN, Opportunistic Scheduling, System Throughput, Fairness, QoS

1 Introduction

As wireless local area networks (WLANs) based on the IEEE 802.11 standard are becoming popular, the interests in high-speed and high quality multimedia communications are also being increased. In order to follow on this tendency, the IEEE 802.11e standard for quality of service (QoS) guarantees and the 802.11n draft for high data rate are released.

According to the 802.11e standard, each access category (AC) has priority, and the contention window (CW) sizes are varied depending on that priority. By not only differentiating the CW sizes, but also providing transmission opportunity (TXOP) time to the real-time (RT) traffic, the 802.11e standard supports multimedia services with different QoS requirements [2]. In the case of 802.11n, the PHY layer extensions provide data rates up to 600Mbps [3], and thus the higher signal-to-noise ratio (SNR) to maintain a certain BER is necessary in order to achieve the high throughput performance. However, on account of the signal attenuation, fading motion of objects, interference and other factors in WLAN environment, each user acquires different channel gains at the same time and receives various SNR. This is referred to as *multiuser diversity*. As a result, no data rate can be proper for such randomized environment. Even though the system adapts the data rate by using the existing rate control scheme, the overall system performance may not necessarily be optimized due to the fact that the channel variations are mitigated. Consequently, in order to enhance the total system performance, more amendable scheme is essential.

Opportunistic scheduling (OS) is a modern approach of communication over varying WLANs whereby multiuser diversity is exploited rather than combated to maximize network capacity [4]. OS algorithms ameliorate the system throughput by choosing a user who is currently experiencing good channel conditions. Since the users with high channel gains are scheduled at every scheduling instance, the channel is efficiently utilized, and thus the whole system performance is improved. However, OS needs not only to maximize the system throughput but also to provide equitable services to every user and guarantee the requirements depending on the users.

Although many OS schemes available for spatiotemporal WLAN environment are published, they do not fully acknowledge the real WLAN environment. For example, they assume the existence of non real-time (NRT) traffic only. Even though several existent OS schemes include the RT traffic, they also face with the limitation when the frame aggregation which is the most critical feature of the 802.11n system, is applied. Also, when the coexistence of RT traffic and NRT traffic is considered, the OS schemes proposed up to now meet the challenges.

In this paper, we propose an optimal OS which can be applicable to the 802.11n WLAN which provides high data rate through the multi-input multi-output (MIMO) antenna system. Here, we involve the coexistence of RT users and NRT users and Ricean fading channel in order to reflect the real WLAN environment. Main contribution in this work is that the proposed OS scheme optimizes the trade-off between system throughput and fairness while guaranteeing QoS requirements of RT users.

The rest of the paper is organized as follows: In section 2, we describe the opportunistic scheduling conceptually and state the related works. In section 3, we introduce our proposed OS scheme and explain the details. Section 4 evaluates the simulation results of our approach, and section 5 includes the conclusions.

2 Background and Related Works

In this section, we explain OS in a general idea and introduce the related works.

2.1 Background

Opportunistic scheduling (OS) is a current approach of communications over varying WLANs whereby multiuser diversity is exploited rather than combated to maximize system throughput. The principle is that the OS seeks to pick the one who is currently experiencing the best channel conditions in each scheduling time, among other competing users. As a result, time to transmit the same amount of data can be reduced, and thus the number of users can efficiently utilize the channel [4].

When OS is viewed as a cross-layer protocol approach for WLANs, it can be presented as Fig.1. As shown in Fig.1, traffic QoS related information (TQI) is provided from higher layers such as network or application layer to the MAC layer. The TQI could be traffic timing constraints or user/queue service information. In addition, channel quality indicator (CQI) feedbacks the channel information which can be represented by supportable data rates or bit error rate and so on.

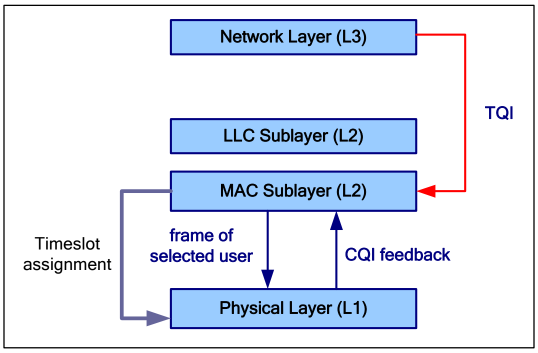

Fig.1. Cross-layer view of opportunistic scheduling for WLANs (TQI=traffic QoS related information, CQI=channel quality indicator).

2.2 Related Works

OS research so far has targeted as conventional cellular network architecture in which the network area is divided into a unit called a *cell*, and the centralized controller schedules users depending on the current channel state of each user. The simplest but well-known methods are round-robin (RR) scheduler and MaxSNR scheduler [4, 5] which are the fairness benchmark and the throughput benchmark, respectively, since RR scheduler polls queues for service in a cyclic order irrespective of the channel conditions of users, and the MaxSNR scheduler picks the user which has the best SNR, or equivalently, the best feasible data rate. [6] explains proportional fair sharing (PFS) scheduler which is the default scheduler for the downlink of CDMA/HDR. The exponential scheduler (EXP) which attempts to equalize the weighted delays of all queues is proposed in [7]. Since it restricts packet delay to a certain level, it could be possible to apply to the RT services. In [8], authors present an OS algorithm to support both RT and NRT services in mobile broadband wireless access systems. This algorithm schedules by adopting existing schedulers such as PFS scheduler and EXP scheduler in terms of delay constraints.

OS for 802.11 WLANs are presented in [9] and [10]. Authors of [9] propose an OS scheme called “Weighted Fair Scheduling based on Adaptive Rate Control (WFS-ARC)”. This scheme chooses the user of which expected throughput is higher than any others. Furthermore, the throughput of the scheduled user is multiplied by a weight factor in order to maintain fairness. While the WFS-ARC is applicable only for the 802.11 WLAN system, OS schemes analyzed in [10] is designed for the frame aggregation mode provided in the 802.11n WLAN. Moreover, authors of [10] take into account the instantaneous channel capacities and queue sizes simultaneously, and their algorithms provide a good compromise between throughput and fairness. However, when different kinds of RT applications are coexisted, it could be difficult to be applied, since different sorts of ACs demand different QoS requirements.

In this paper, we propose an optimal OS which could be applicable to the 802.11n WLAN. It is designed to select the best user at each scheduling time subject to fairness and QoS requirements. Here, we consider various applications of both RT and NRT services in order to be close upon the real WLAN environment. Our approach is going to be introduced in the next section.

3 Proposed Algorithm

[11] analytically shows that uplink utilization rate is gradually augmented while downlink utilization rate decreases, as the number of users increases in WLAN systems. However, in actual system shown in [12]-[15], the total number of downlink traffic frames is more than that of uplink traffic frames owing to the fact that the most common application is web-surfing, downloading from server and so on. From these researches of uplink/downlink traffic patterns under the IEEE 802.11 WLAN system such as campus, conference room or restaurant [12]-[15], we could notice that how crucial the downlink packet scheduling is.

Correspondingly, we here focus primarily on the downlink packet scheduling in 802.11n WLAN infrastructure system. The packets from the LLC layer are buffered at the access point (AP) until it is scheduled by a centralized controller, an AP. AP obtains the queue information from the higher layer and the channel state information of the user through the receiving packets from that user. The scheduling decision is conducted at the beginning of each contention period (CP) with the proper decision algorithm.

Now, the proposed algorithm is explained specifically. The brief concept is as follows; it categorizes the ACs in terms of delay requirement, since AC[3] and AC[2] are belong to the RT services and have different delay bound. Then, users belonging to the categorized AC are scheduled with respect to the expected throughput. The signal flow chart of the proposed scheduling scheme is shown in Fig.2.

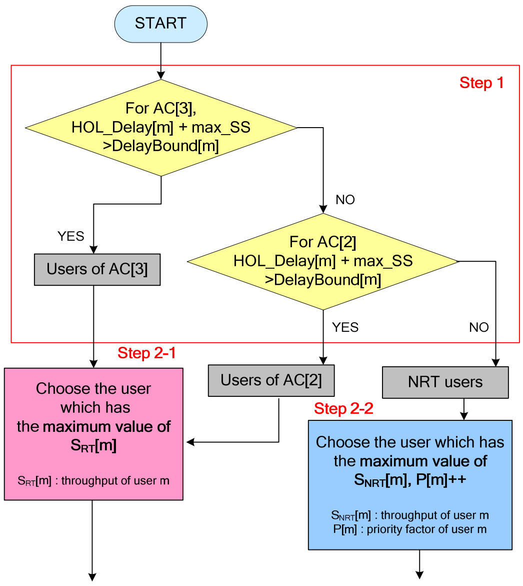

Fig.2. Signal Flow Chart of the proposed scheduling algorithm.

In Step 1 (Fig.2), ACs are categorized corresponding to the delay requirements of RT services. Here, HOL_Delay[m] and max_SS indicate the head-of-line packet delay of user m and the maximum estimated scheduling slot, respectively, and both could be determined by the following equations.

$$\begin{aligned} &HOL\_Delay[m] = N_{que}[m] \times T_{arrival}[m] \\ &\max\_SS[m] = AIFS[m] + ave\_bkoff[m] + \max\_TXOP \end{aligned} \quad (1)$$

In equations (1), $N_{que}[m]$ and $T_{arrival}[m]$ denote the number of packets in the queue of user m and the packet arrival time of user m, for each. *Ave_bkoff[m]* is average backoff time and calculated as follows.

$$\begin{aligned} &ave\_bkoff[m] = SLOT \times (1 + P_{coll}) \times CW_{\min} \\ &P_{coll} = 1 - \left(1 - \frac{1}{CW_{\min}}\right)^{M-1} \end{aligned} \quad (2)$$

P_{coll} expresses the probability of collision simply by neglecting the multiple successive collisions [16]. Here, *M* indicates the total number of users.

By comparing the sum of *HOL_delay[m]* and the *max_SS* with the delay bound of each user, the proposed OS chooses the group of users belonging to the same AC first.

In Step 2-1 and Step 2-2 (Fig.2), RT users or NRT users are scheduled if the expected throughput is higher than any others. The expected throughput for RT users and NRT users, $S_{RT}[m]$ and $S_{NRT}[m]$ are calculated as follows.

$$S_{RT}[m] = \frac{N_{agg}[m] \times L_{MSDU}[m]}{\left(\begin{array}{l} AIFS[m] + ave\_bkoff[m] + T_{PHY} + \\ T_{agg\_MPDU}[m] + T_{Block\,Req} + SIFS + T_{BlockACK} \end{array} \right)} \quad (3)$$

$$S_{NRT}[m] = \frac{L_{MSDU}[m]}{\left(\begin{array}{l} AIFS[m] + ave\_bkoff[m] + T_{PHY} + \\ T_{MPDU}[m] + T_{Block\,Req} + SIFS + T_{BlockACK} \end{array} \right)}$$

Here, $N_{agg}[m]$ and $L_{MSDU}[m]$ indecates the number of aggregated MSDUs in a frame and the MSDU length, respectively. $T_{agg\_MPDU}[m]$ and $T_{MPDU}[m]$ denote the transmission time of an aggregated frame and the transmission time of a frame, for each. Here, we notify that the expected throughput should be calculated in a differeng way, since the frame aggregation mode is provided to the RT users in 802.11n system, and thus RT users send back the block acknowledgment frame (BlockACK) instead of the normal ACK.

In Step 2-1 (Fig.2), the proposed OS only takes into account the expected throughput, but not fairness. This is because the fairness is already considered in Step 1. In other words, RT users always can have a chance to transmit packet whenever the HOL packet delay is close to its delay bound regardless to the channel conditions. Therefore, the difference among the number of buffered packets in the queues of RT users becomes equalized.

However, as shown in Step 2-2 (Fig.2), an additional priority factor is necessary when scheduling NRT users. Since NRT users do not have any delay constraint, TXOP and frame aggregation mode, an priority factor is inevitable so as to preserve the fairness among NRT users. Step 2-2 in detail is as follows.

$$\begin{array}{l} \mathit{if} \left(P[m] >= \dfrac{\max\_Load}{Load[m]} \right) \\ \quad \textit{choose user } m. \\ \quad P[m] = 1; \\ \mathit{else\ if} \ \textit{user } m \textit{ which is not serviced}, \\ \quad P[m]++; \end{array} \quad (4)$$

Here, *max_Load* indicates the maximum offered load among the NRT users. By taking into account the offered load, the OS preserves the fairness not equally but in proportion to the offered load.

4 Performance Analysis

In this section, we introduce our simulation environment in detail and then analyze the simulation results.

4.1 Simulation Environment

Under the IEEE 802.11n contention-based system, we assume following statements.

- AP has perfect knowledge of the updated wireless channel states of users.
- The wireless channel condition for a user does not change during packet transmission.
- Each user has a link adaptation algorithm (Here, we use the ARF algorithm [17]), and so they can determine the appropriate data rate depending on the channel conditions.
- Only downlink packets are buffered during the simulation.

In order to reflect the real WLAN environment, we adopt four different types of traffic: VoIP(AC3), video(AC2), HTTP(AC1) and email(AC0). Table 1 lists the system parameters of traffic.

Table 1. System Parameters.

Traffic	AC	MSDU Size (Bytes)	Offered Load (Mbps)	Delay Bound (msec)	TXOP (msec)
VoIP	3	120	0.096	30	1.504
Video	2	512	4	200	3.008
HTTP	1	1500	30	.	.
Email	0	300	1	.	.

Data rate is adaptively selected from the set {13, 39, 52, 78, 104, 117, 130} which is provided in 802.11n draft [3]. Since we assume that each user has a link adaptation algorithm, data rate is flexibly changed according to the instantaneous channel states.

Each user experiences independent channel condition which is varied every 1000us. The channel model is Ricean fading channel which have Doppler spread 20Hz corresponding to 2.5m/s velocity.

Total simulation time is 50 seconds.

4.2 Simulation Results

In order to observe the system throughput corresponding to the increment of users, we change the number of users M and M[i] belonging to the AC i. The ratio among VoIP, video, HTTP and email are 1:2:4:3.

Fig.3 shows the system throughput as the number of users increases

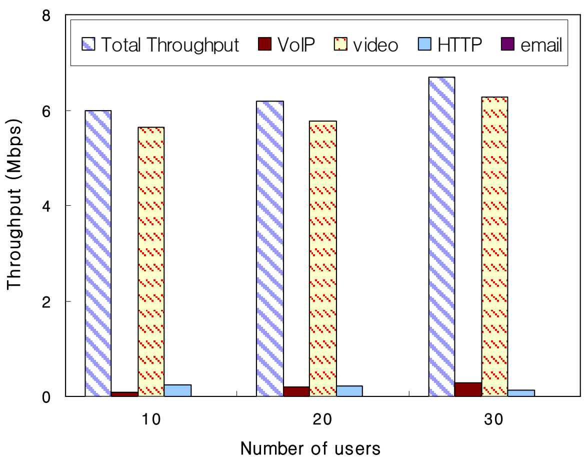

Fig.3. System throughput vs. the number of users.

As we can see that the total throughput ameliorates as the number of users increases. In addition, the RT traffic such as VoIP and video not only satisfy the throughput requirements but also improve system throughput according to the varying number of users. This result could be explained by the following fact; as the number of users in the network increases, the probability that one user has a very good channel also increases.

However, the throughputs of HTTP and email decrease as the number of users increases. This is owing to the fact that the proposed OS gives a chance to occupy the channel to the RT users first whenever its HOL packet delay is close to the delay bound. Here, we could notice that the throughput of NRT users decreases as the number of RT users increases, in spite of the OS.

Now, in order to evaluate the fairness performance of the proposed scheduling algorithm, we define the unfairness factor presented in [10] in a different way, in terms of ACs. Since the users in different AC need to satisfy different QoS requirement, fairness among whole users does not make sense. The equation is as follows.

$$UF[i] = \frac{\sigma[i]}{S_{av}[i]} \tag{5}$$

$$\sigma[i] = \frac{1}{M[i]} \sum_{m=1}^{M} S_m^2[i] - \left(S_{av}[i]\right)^2$$

Here, $UF[i]$, $\sigma[i]$ and $S_{av}[i]$ indecate the unfairness factor of AC i, the standard deviation of the set of throughput of each user of AC i and the average user throughput of AC i, for each. From the equations (4), we could observe the fairness performance as shown in Fig.4. Here, it is obvious that the larger UF obtains, the distribution of throughputs among users becomes more unfair.

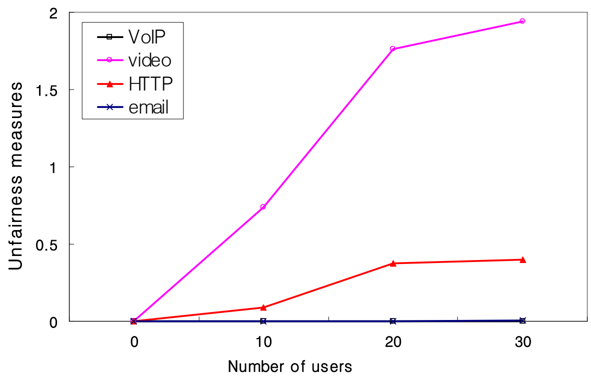

Fig.4. Fairness performance vs. the number of users.

From result in Fig.4, we can notice that fairness performance of VoIP is perfectly preserved, and the fairness performance of NRT users is also relatively well-maintained. However, in the case of video, it can be seen that there is a lack of fairness. This is because the gap between the number of MSDUs in an aggregated frame with a good channel and the number of MSDUs in an aggregated frame with a bad channel is too high compared with that of VoIP.

5 Conclusions

In this paper, we have presented an optimal OS for IEEE 802.11n WLAN system, which not only optimizes the trade-off between system throughput and fairness but also supports QoS guarantees.

Primarily, the proposed OS categorizes AC i according to the delay constraints. Then, it schedules a user whose expected throughput is higher than any others. In the case of NRT users, additional priority factor is adopted so as to maintain the fairness performance.

The simulation results prove that the total system throughput is enhanced as the number of users increases. Besides, fairness is also well-preserved in terms of AC i.

As future work, we intend to dedicate to the fairness performance and then apply the OS algorithm to more extensive environment which is close to the real WLANs.

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