A packet scheduling algorithm based on the estimation of packet loss amount for supporting real-time traffic in IEEE 802.22 WRAN systems

Youngdu Lee and Insoo Koo

School of Electrical Engineering, University of Ulsan
680-749 San 29, Muger 2-dong, Ulsan, Republic of Korea
E-mail: leeyd1004@naver.com and iskoo@ulsan.ac.kr

Abstract: In this paper, we propose and evaluate a new packet scheduling algorithm in order to support real-time traffic more effectively in IEEE 802.22 WRAN system where Quiet Period (QP) frame exists per superframe. During QP frame, BS and CPEs stop data transmission, and scan TV channels used by themselves to perform in-band measurements of incumbent users. It will cause packet delay as long as the length of QP, and degrade quality of service of traffic time traffic. The proposed scheme utilizes not only the delay of Head of Line(HOL) packets in buffer of each user but also the amount of expected loss packets in next frame when a service will not be given in current frame. The performances of the proposed scheme are compared with those of PLFS and M-LWDF in terms of average packet loss rate and throughput. The simulation results show that the proposed scheduling algorithm performs much better than the PLFS and M-LWDF algorithms.

1. Introduction

Recently, cognitive radio (CR) which has been a hot issue is a smart wireless communication system that utilizes a part of the spectrum band which is allocated to the licensed "primary" users but it is not being used by them at a particular time and a specific geographic location [1]. The first attempt to make a standard based on CR technology is IEEE 802.22 wireless regional area network (WRAN) operating on a license-exempt and non-interference basis in the spectrum allocated to TV broadcast services (between 47–910 MHz). It aims to provide alternative broadband wireless Internet access in rural areas without creating harmful interference to licensed TV broadcasting[2][3]. On the condition that the services of IncUmbent (IU) users are not interrupted by CR users, WRAN system can provide service to CR users where IU users are denoted as "primary" users and CR users are denoted as "secondary" users in WRAN respectively. It means that CR users should vacate the spectrum band when the IU users are activated since the CR users borrow spectrum from IU users. To find the spectrum available in real-time, WRAN system uses the Quiet period (QP) frame during which WRAN do not access to the spectrum and focus on detecting the appearance of IU users. Even though the QP frame is essential to detect IU users, it will cause the QoS degradation for the CR users especially when real-time traffic is serviced. It is mainly due to the facts that whole packets are delayed as long as a length of QP frame and the packet of real-time traffic can be dropped when a packet delay exceeds the maximum delay bound.

In the aspect of Quality of Services (QoSs) of real-time traffic, it is more important to ensure time delay bound than to maximize data transmission rate or to provide fairness among users. Hence, a packet scheduling algorithm that can fulfill the required delay bound is necessary. Up to now, various scheduling algorithms for supporting real-time traffic have been proposed [4] [5] [6] [7]. Among them, EXPonential rule (EXP) and Modified Largest Weighted Delay First (M-LWDF) are the scheduling algorithms that utilize a channel state of user and a delay of packet in Head of Line (HOL) of buffer at the same time. More specially, the EXP scheduling algorithm gives a more weighting to the delay of packet in HOL of buffer, while the M-LWDF scheduling algorithm considers both the channel status of user and the delay of packet in HOL of buffer. In the case of Packet Loss Fair Scheduling (PLFS) algorithm, the average packet loss rates of users was additionally taken into account along with the channel status of user as well as the delay of packet in HOL of buffer. In the mentioned scheduling algorithms, however, only the delay of packet in HOL of buffer was considered. As just that, It is insufficient to provide resource allocation sensitive to "delay", because the number of packets dropped in next frame is different according to buffer state. In order to support real time traffic more effectively in WRAN systems, we propose a scheduling algorithm based on the estimation of packet loss amount. The proposed scheduling algorithm utilizes the amount of expected loss packets in next frame when a service will not be given in current frame. In more details, the proposed scheduling algorithm assigns radio resource through two steps: In the first step, we assign radio resource to users having packets that are expected to be dropped in next frame if radio resource will not be assigned in current frame. In the second step, we assign the remaining resources to the other users according to the conventional scheduling algorithms. The performances of the proposed scheduling algorithm are compared with those of previous proposed scheme algorithm such as PLFS and M-LWDF in terms of the average packet loss rate and the throughput. The simulation results show that the proposed scheduling algorithm provides much better performance than the conventional PLFS and M-LWDF algorithms.

2. System model

IEEE 802.22 WRAN employes the superframe structure as like Figure 1 which is comprised of three main parts: a PHY preamble, a Superframe Control Header (SCH) and a number of frames[2],[3]. At the beginning of every superframe, the BS shall transmit a special preamble and SCH (with a known modulation/coding) through each and every TV channel it is currently using for communication with its associated CPEs. Any device tuned to any of these TV channels and who synchronizes and receives the SCH, is able to obtain the information it needs in order to establish communication with the transmitter (in this case, the Base Station (BS)). Excluding the superframe preamble and SCH, the superframe shall have a fixed and pre-determined size of 16 frames. Here note that a Quiet period (QP) frame exists per superframe in order for both the BS and CPEs to perform in-band measurements for detecting incumbent users.

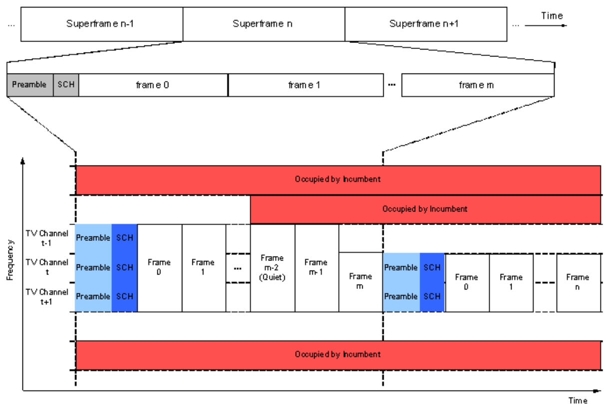

Figure 1. The superframe structure of WRAN [2],[3]

IEEE 802.22 WRAN uses OFDMA as a multiple access . In the frequency domain, an OFDMA symbol is defined in terms of its sub-carriers. The subcarriers are divided into M subbands. The minimum allocation resource unit is one subband per slot, where one slot consists of a fixed number of OFDM symbols. Adaptive modulation and coding (AMC) is employed in the system to supply variable transmission rate. Each user feeds back the channel quality information, namely the indexes of Q strongest subbands with highest downlink SNR and the corresponding indexes of their modulation and coding modes (MCS), where Q is not larger than M and can be adjusted by the system in order to reduce the amount of feed-back information but can also exploit multi-user diversity effectively [6]. After receiving the users' feed- back information, BS allocates appropriate subbands to users and broadcasts the scheduling results to all users before packets are transmitted. The table 1 shows an example of AMC option.

Table 1. AMC options

index	$SNR_{req}(dB)$	The number of packets / BU(Basic Unit)	Modulation method	coding rate
1	1.5	1	QPSK	1/6
2	4.0	2	QPSK	1/3
3	7.0	4	QPSK	2/3
4	10.5	6	16QAM	1/2
5	13.5	8	16QAM	2/3
6	18.5	12	64QAM	2/3

3. The proposed scheduling algorithm

BS establishes an individual queue for each user which is assumed to have infinite length. Arriving packets for each user are stored in its own individual first-in first-out (FIFO) queue. If a packet is for a real-time traffic, the scheduler records its arrival time which is useful for scheduling and discarding. In frame, the scheduler utilizes the users' feed-back information to allocate subbands according to the scheduling algorithm.

In the case of real-time traffic, it is very important to satisfy maximum allowable delay bound. If a packet exceeds maximum allowable delay bound, then the packet will be dropped. Therefore in order to effectively provide real-time service in WRAN system, queue state of each user should be taken into account effectively. In order to reflect the queue state of each user in BS on the scheduling algorithm, we adopt a new factor, called the expected packet loss amount (EPLA). The EPLA can be simply calculated as follows: we quantitatively estimate the amount of packet loss that will be expected to occur at next frame, if service is not given to users, by comparing the maximum allowable delay bound with the time difference between the packet generated time and the time of next frame. That is, if the calculated time difference exceeds the maximum allowable delay bound, the EPLA will be counted. And then the EPLA is utilized when the scheduler calculates the priority value of each subchannel of each user for radio resource allocation. More specially, the priority value of the n-th subchannel of the k-th the user due to EPLA, $\Phi_{k,n}(t)$ is calculated as follows:

$$\Phi_{k,n}(t) = \begin{cases} \min(A_{k,n}(t), N_{drop,k}(t+FP)) \cdot \beta, \\ \text{if the next frame is a normal one} \\ \min(A_{k,n}(t), N_{drop,k}(t+FP+QP)) \cdot \beta, \\ \text{if the next frame is a QP} \end{cases} \quad \text{Eqn. (1)}$$

where t is the current time, FP denotes Frame Period, QP denotes Quiet frame Period, $A_{k,n}(t)$ is amount of packets that can be carried with the n-th channel of the k-th user, $N_{drop,k}(t+FP)$ is EPLA of the k-th user when next fame is a normal one, $N_{drop,k}(t+FP+QP)$ is EPLA of the k-th user when next fame is a Quiet frame, and β is a weighting factor which can be used to give different weighting values for different service classes.

It is a noteworthy that $\Phi_{k,n}$ selects the smallest value between an instant data transmission capacity, $A_{k,n}$ and the EPLA of the k-th user, $N_{drop,k}$. The operation of Φ selecting the smaller value will lead the scheduling algorithm to the direction that total EPLA is minimized at system level.

After calculating priority value for each sub-channel and each user, the proposed scheduling algorithm assigns radio resource to users with following two steps: In the first step, we assign radio resource units to users who have expected loss packets in next frame if radio resource will not be assigned in current frame, which corresponds to the case of $\Phi_{k,n}(t) > 0$. In the second step, we assign the remaining resources to other users who have $\Phi_{k,n}(t) = 0$ according to the conventional scheduling algorithms.

In order to demonstrate how the proposed method can be combined with conventional scheduling algorithms, let us consider M-LWDF, and PLFS. In the case that M-LWDF and the proposed scheduling algorithm are combined, the n-th subchannel will be assigned to the $\hat{k}_n$ user who satisfies the following equation.

$$\hat{k}_n = \arg\max \begin{cases} \Phi_{k,n}(t), & \Phi_{k,n}(t) > 0 \\ \gamma_k \cdot W_k(t) \cdot r_k(t), & \Phi_{k,n}(t) = 0 \end{cases} \quad \text{Eqn. (2)}$$

Where note that the priority value of the n-th channel of the k-th user is determined by Eqn.(1) when $\Phi_{k,n}(t) > 0$, while the priority value of the n-th channel of the k-th user is determined by the M-LWDF when $\Phi_{k,n}(t) = 0$. In here, $\gamma_k = \alpha_k / \overline{r_k}$, $\alpha_k = -(\log \delta_k)/T_k$. $\overline{r_k}$ is the average channel value of user k, T_k is the maximum delay time of packet required by user k, δ_k is the maximum probability of $\Pr\{W_k > T_k\} \le \delta_k$. γ_k performs a role of channel scheduler coefficient, it normalizes α_k with $\overline{r_k}$ of each user and it adjusts packet delay distribution about users. $W_k(t)$ is the packet delay time of queue head of user k in current time t. $r_k(t)$ represents a channel state.

4. Simulation results

This simulation is performed with the consideration of the requirements of IEEE 802.22 WRAN[2]: The superframe consists of 16 frames. In each superframe, a QP frame exists. The length of frame and the length of QP frame are set to 10ms, respectively. We consider voice and video traffic. The required packet loss rate of voice and video traffic are given as 10^{-6} and 10^{-4}, respectively. The maximum allowable delay bounds of voice and video traffic are 20 ms and 40ms, respectively. The other system parameters are summarized in Table.1. The performances of the proposed scheduling algorithm are compared with those of the conventional M-LWDF and PLFS scheduling algorithms in terms of the packet loss rate (PLR) and the overall throughput.

Table 2. The system parameters

Parameter	Value
Multiple access / Duplexing method	OFDMA / TDD
Downlink channel bandwidth	20 MHz
The number of slots per frame	10
The number of subchannels	12
The number of subcarrier per subchannel	128
Frame duration	10 ms
Slot duration	1 ms

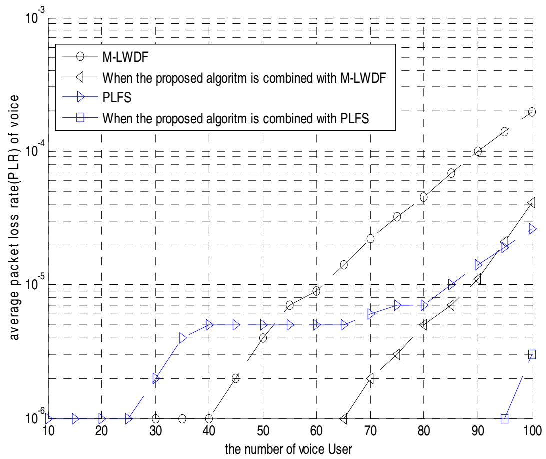

Figure 2. Packet loss rate of voice traffic

Figure 2 shows the PLR of voice traffic according to the number of voice users when the number of video users is given as 7. As shown in the figure, we can easily find that each combined scheduling algorithm case has better PLR performance than each conventional that. In case of voice traffic, the required PLR of WRAN system is 10^{-6}. Thus when the proposed scheduling algorithm is combined with

PLFS, the number of acceptable voice users is increased from 25 to 95. And in the case of M-LWDF, it is increased from 40 to 65.

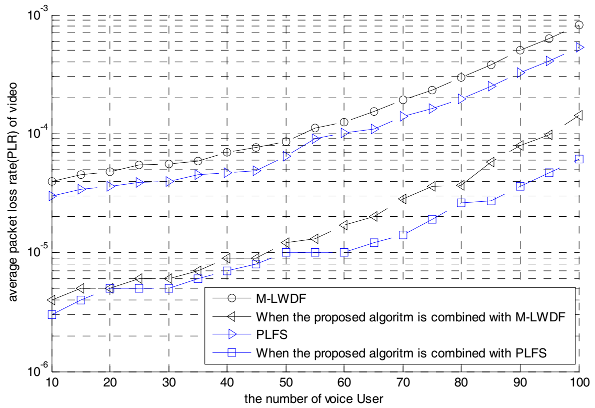

Figure 3. Packet loss rate of video traffic

Figure 3 shows the PLR of video traffic according to the number of voice users when the number of video users is given as 7. In case of video traffic, the required PLR of WRAN system is 10^{-4}. We can find that when the proposed scheduling algorithm is combined with PLFS, the number of acceptable voice users is increased from 60 to more than 100, and in the case of M-LWDF, it is increased from about 54 to 95. Although PLFS takes more acceptable voice users than M-LWDF in case of both voice and video when combining with the proposed scheduling algorithm, the complexity is higher. When considering both the required PLR of voice and video, the acceptable voice user of PLFS and MLWDF are 25 and 40 respectively. And in the case of combing with the proposed scheduling algorithm, respectively 65 and 95.

Figure 4 shows overall throughput of WRAN according to the number of voice users when the number of video users is given as 7. The overall throughput is defined as the ratio between the number of successfully transmitted packets and the number of the generated packets. As shown in the figure, the cases combining with the proposed scheduling algorithm have better the overall throughput. Although the overall throughput of PLFS in both the conventional and the combined scheduling algorithm is bigger than M-LWDF, in the increased throughput gap M-LWDF is much bigger.

5. Conclusions

In IEEE 802.22 WRAN, CR users will inevitably experience a considerable delay by the QP frame during which service will not be given in order to sense the IU users. This situation may result in a lot of packet drop where a packet drop occurs when the delay of packet exceed the maximum allowable delay bound. Therefore, the WRAN system will need a more delay-sensitive packet scheduling algorithm. In this paper, we have proposed a packet scheduling algorithm based on the estimation of packet loss amount for supporting real-time traffic in IEEE 802.22 WRAN systems. The simulation results showed that the performances of the conventional packet scheduling algorithms such as M-LWDF and the PLFS can be improved by the proposed algorithm.

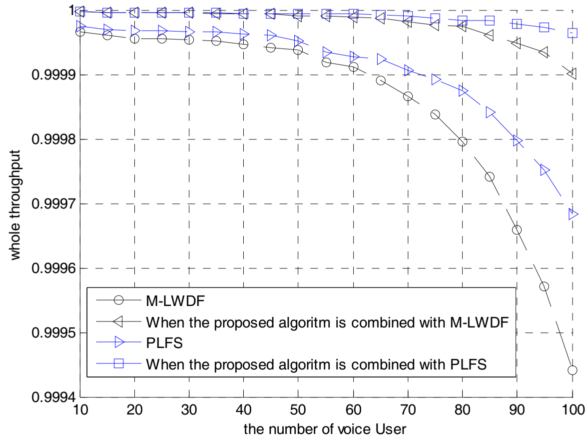

Figure 4. Overall throughput of WRAN

References

[1] Mitola, J.: Cognitive Radio for flexible mobile multimedia communications. Proc. of IEEE Workshop on Mobile Multimedia Comm., pp. 3—10, 1999

[2] IEEE 802.22,"IEEE 802.22 / D0.2 Draft Standard for Wireless Regional Area Networks Part22 : Cognitive Wireless RAN Medium Access Control and Physical specifications : Policies and procedures for operation in the TV Bands", November 2006

[3] IEEE 802.22,"IEEE 802.22 / D0.3.7 Draft Standard for Wireless Regional Area Networks Part22: Cognitive Wireless RAN Medium Access Control and Physical specifications: Policies and procedures for operation in the TV Bands", July 2007

[4] Shakkottai, S., Stoylar, A.L.: Scheduling for multiple flows sharing a time-varying channel : the exponential rule. Bell Laboratories Technical Report., December 2000

[5] Shakkottai, S., Stoylar, A.L.: Scheduling algorithms for a mixture of real and non-real-time data in HDR. Bell Laboratories Technical Report. December 2000

[6] Shin, S.J., Ryu, B.H.: Packet loss fair scheduling scheme for real-time traffic in OFDMA system. ETRI Journal, vol. 26, 5, 391-396, October 2004

[7] Park, T.W., Shin, O.S., Lee, K.B.: Proportional Fair Scheduling for Wireless Communication with Multiple Transmit and Receive Antenas. Vehicular Technology Conference. vol. 3, pp. 1573-1577, 2003

Acknowledgement

This work was supported by the second stage of the Brain Korea 21 project in 2008. This work was also supported in part by the Ministry of Commerce, Industry, and Energy and in part by Ulsan Metropolitan City through the Network-based Automation Research Center at the University of Ulsan.