A PRIORITY-BASED EDF SCHEDULING ALGORITHM FOR H.264 VIDEO TRANSMISSION OVER WIMAX NETWORK

Qinli Wang and Guizhong Liu

School of Electronic and Information Engineering, Xi'an JiaoTong University, 710049, China
w.00152651@stu.xjtu.edu.cn, liugz@mail.xjtu.edu.cn

ABSTRACT

With the increasing popularity of broadband wireless networks, video transmission over WiMAX networks has attracted more and more attention in both industrial and academic fields. In this paper, a Priority-based EDF (PEDF) scheduling algorithm, which combines EDF (Earliest Deadline First) with the characteristics of the multimedia, is proposed for H.264 video delivery. To meet the QoS requirements of different video frames, an adaptive deadline is assigned to change the miss rate of video packet dynamically in PEDF. In this way, we can better protect the more important video frames against loss. Simulation results show that the PEDF can achieve higher PSNR than the legacy RR, WFQ and EDF algorithms, and the quality of reconstructed video is improved significantly.

***Index Terms*—** WiMAX, EDF, Video Scheduling

1. INTRODUCTION

With a rapid growth of Broadband Wireless Access solution, video transmission over WiMAX (worldwide Inter-operability for Microwave Access) networks, which are built on the IEEE 802.16 standard [1] [2], has attracted more and more attention in the past few years. At the same time, the strict multimedia application requirements of low latency and high bit-rate, has become challenges for the service providers and network designers. To support the QoS (Quality of Service) requirement, the IEEE 802.16 standard specifies five scheduling classes of services: Unsolicited Grant Service (UGS), extended real-time Polling Service (ertPS), real-time Polling Service (rtPS), non-real time Polling Service (nrtPS), and Best Effort (BE). For example, to support UGS flows, the application packets should be fixed-size and constant bit rate (CBR), such as VoIP or E1/T1. The rtPS is designed to support real-time applications with less stringent delay requirements, which generate variable-size data at periodic intervals, such as MPEG video. As a real-time service extension, ertPS builds on the efficiency of both UGS and rtPS, such as VoIP with silence suppression. In contrast, the nrtPS and BE are used for non-real-time traffics such as http and Email. In the WiMAX operating environment, two transmission modes are defined to share the wireless resources: Point to Multi-Point (PMP) and Mesh. In this paper, we focus on the PMP mode.

Although the WiMAX standard has specified the service framework and the communication mechanisms in the PMP mode, it does not mention any scheduling algorithm to allocate the wireless resources. The scheduling algorithm running on the BS has been reserved for the manufacturers and operators. Accordingly, several scheduling algorithms were proposed to achieve the QoS requirement in [3], some of which are based on the legacy algorithms. In [4], Deficient Round Robin (DRR), based on the ordinary Round Robin (RR) algorithm, was simulated in the WiMAX network. The DRR assigns different quota for all the service flows to avoid the unfairness of the RR scheduling. Nararat et al. [5] analyzed the performance of scheduling schemes over the IEEE 802.16 network in the Time Division Duplex (TDD) mode, and made a comparison between Weighted Fair Queuing (WFQ) and Earliest Deadline First (EDF). In WFQ [6], each service flow has its own FIFO queue and the weight can be dynamically assigned for each queue. Then, the wireless resources are shared according to the proportion of weight. Hence, the selection of weight is the key issue in WFQ. On the other hand, as the most popular scheduling algorithm in real-time systems, EDF [7] assigns a deadline for each packet, and the packet with the minimum or earliest deadline would be served first.

Even though all these scheduling algorithms concern the aspects of the system throughput, end-to-end delay and loss rate, none of them takes into consideration the special properties of multimedia applications. In fact, due to the encoding distortion of video frames, the importance or contribution of the packets is different. Therefore, in this paper, we propose a priority-based EDF (PEDF) scheduling algorithm, which combines EDF with the characteristics of the multimedia applications. In our system, the novel algorithm uses a shadow deadline for each video packet in a multimedia service flow by adding or subtracting a value according to the video distortion and the miss rate of

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multimedia. And the current WiMAX system scheduler uses the traditional EDF algorithm to allocate the wireless resource, as if the shadow deadline was the real deadline. Based on the Real-time Queueing Theory (RTQT), a packet with higher distortion and importance such as that of an I frame, will be assigned a negative bias value relative to the other packets, so as to have a lower miss rate, and vice versa. In this way, the PEDF can better protect the important packets to avoid loss, and improve the performance of the video transmission system.

The rest of this paper is organized as follows: In Section 2, the proposed scheduling algorithm is described in detail. The simulation environment is introduced and the experimental results are analyzed in Section 3. Finally, a conclusion is drawn in Section 4.

2. PRIORITY-BASED EDF SCHEDULING ALGORITHM

2.1. Framework of the PEDF Scheduling Algorithm

As is well known, EDF is one of the most popular algorithms in real-time systems, and it has been proved to be an optimal scheduling algorithm under many different conditions in [8]. In spite of these obvious advantages, it has some shortcomings. One major problem of EDF is that, the miss rates of all the packets are the same, regardless of their traffic characteristics and QoS requirements. Especially in the H.264 video transmission, every packet has its own importance for the quality of video application in the decoding process. This makes the standard EDF scheduling algorithm unsuitable for the situation where each packet has different QoS requirement in WiMAX network. In order to overcome this shortcoming, we propose a priority-based EDF scheduling algorithm, as shown in Figure 1.

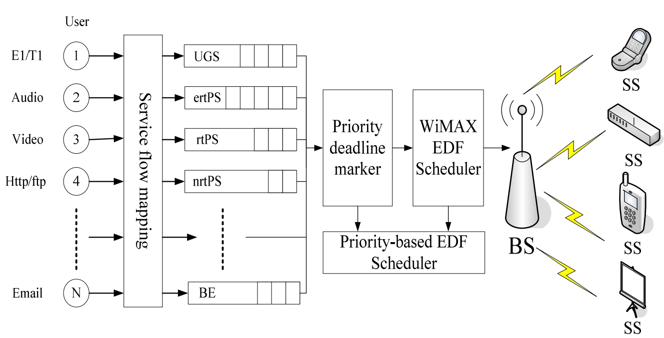

Fig. 1. The Framework of the PEDF Scheduling Algorithm

When the multimedia application packets reach the WiMAX BS, the scheduler operates as follows:

Step1 Each packet is mapped into a corresponding service flow queue according to its QoS requirement. Among the service flows, the UGS, ertPS and rtPS are mainly used for real-time traffics such as audio and video, while the nrtPS and BE are used for non-real-time traffics such as http and Email. Moreover, the priorities of the service flows are inherent (UGS > ertPS > rtPS > nrtPS > BE). In addition, VBR video applications such as H.264 and MPEG, are usually mapped into the rtPS service flows.

Step2 After the packet is assigned to a specific service flow queue, the scheduler records the packet's arrival time T_A, and calculates the basic deadline D_B, as defined by

$$D_B = D_S + T_A \quad D_S \in \{D_{UGS}, D_{ertPS}, D_{rtPS}, D_{nrtPS}, D_{BE}\} \qquad (1)$$

where the service deadline interval D_S is defined according to the service type, and $D_{UGS} < D_{ertPS} < D_{rtPS} < D_{nrtPS} < D_{BE}$.

Step3 If the packet is not video application data, set the adaptive deadline D_A to 0 directly. Else, The Priority Deadline Marker calculates the D_A according to the distortion of video for each packet, which will be detailed in Section 2.4. Then, the final deadline D_F is deduced:

$$D_F = D_B + D_A = D_S + T_A + D_A \qquad (2)$$

Step 4 In the last step, the WiMAX EDF Scheduler serves packets in the order of their final deadline D_F. The packet with the minimum or earliest final deadline D_F will be scheduled first.

2.2. Real-time Queueing Theory

To explain our algorithm more clearly, we refer to the Real-Time Queueing Theory (RTQT), which was proposed in [9] [10]. Because of the limitation of space, we only cite two conclusions.

First of all, a scheduling model should be built in RTQT. Assume that we have K service flows such as UGS, ertPS, rtPS, nrtPS and BE. Each service flow has different QoS requirement and transmission characteristic. Flow j can be characterized as follows:

- A service flow packet's inter-arrival follows the exponential distribution with a mean of $1/\lambda_j$. Let $\Lambda = \sum_{j=1}^{k} \lambda_j$, the total system arrival rate.
- A service flow packet's service requirement follows the exponential distribution with a mean of $1/\mu_j$
- Each service flow has it's own deadline $D_j > 0$. And let $\overline{D} = \sum_{i=1}^{k} \lambda_j D_j / \Lambda$ be the mean packet deadline of all the flows.
- Define $\rho_j = \lambda_j / \mu_j$, the traffic intensity of flow j, and $\rho = \sum_{i=1}^{k} \rho_j$,the total traffic intensity.

With the above assumptions, the following two conclusions on RTQT can be drawn:

Theorem 1**:** A prediction to the deadline-miss rate for the EDF scheduler is calculated by

$$\phi_j = e^{-\theta \overline{D}}, \quad \theta = \frac{2(1-\rho)}{\sum_{i=1}^{k} \lambda_j (\lambda_j^2 + \mu_j^2) / \mu_j^2} \qquad (3)$$

Theorem 2**:** If we add an additional constant B_j (be either positive or negative) to the service flow's deadline, the resulted RTQT approximation to this flow's deadline miss rate is

$$\phi_j = e^{-\theta(\overline{D'} - B_j)} \tag{4}$$

Where: $\overline{D'} = \sum_{i=1}^{k} \alpha_j (D_j + B_j)$ and $\alpha_j = \rho_j / \rho$.

2.3. Analysis of D_A Deadline Miss Rate

In this part, we focus on the deadline D_A's influence on the our PEDF scheduler. As described before in Section 2.2, if we treat the video service flow as flow j, the effect of the parameter B_j is entirely equivalent to D_A. Hence, we can study the D_A through the Real Time Queueing Theory.

Suppose that we add an adaptive deadline D_A to video service flow j, and the deadlines of the other service flows stay the same. According to Theorem 2, the average deadline $\overline{D}$ will change to $\overline{D'} = \overline{D} + \alpha_j D_A$. The deadline miss rate of the video service flow j will be $e^{-\theta(\overline{D} + \alpha_j B_A - B_A)}$, and those of the others will be $e^{-\theta \overline{D'}}$.

Assume that the adaptive deadline D_A be a positive value (D_A>0). Due to the fact that $0 < \alpha_j < 1$, we can get $\overline{D'} < \overline{D}$. Then, according to Theorem 1, it is easy to deduce that the deadline miss rate of all the other service flows except flow j will be smaller than their previous values ($e^{-\theta \overline{D}} < e^{-\theta \overline{D'}}$). For the video service flow j, if D_A >0, according to Theorem 2, its deadline miss rate will be $e^{-\theta(\overline{D} + \alpha_j D_A - D_A)}$, which means that the video deadline miss rate is bigger than its former value by a factor $e^{-\theta(\alpha_j - 1)D_A}$.

In general, if we set a positive value for D_A. The deadline miss rate of video service flow will increase, and the other service flows will decrease accordingly, and vice versa. The deadline miss rate has strong correlation with the adaptive deadline D_A, and more specially, the deadline miss rate strictly decreases monotonically with the adaptive deadline D_A. Therefore, the selection of D_A is the key issue for the PEDF scheduler.

2.4. Selection of D_A Based on Video Distortion

To support the different QoS requirements of multimedia applications, the value of D_A is determined dynamically to change the video packet's loss rate. For example, the important video packets with higher distortion can be assigned a negative D_A's value to more protect them against loss, and vice versa. Moreover, the selection of D_A 's value for video packets should satisfy the following constraints:

- As mentioned in Section 2.1, the packets of video applications are mapped into the rtPS service flow, and the priorities of the service flows are inherent (UGS > ertPS > rtPS > nrtPS > BE). Therefore, for each packet's D_A, the final deadline for video packet should:

$$D_{ertPS} \le (D_{video} + D_A) \le D_{nrtPS} \tag{5}$$

- To keep the fairness among the rtPS service flows, in a video GOP (Group of Pictures), the average value of D_A should be 0.
- To protect the more important video packet which leads to higher distortion, we should give a negative and smaller D_A's value, so that it has a lower miss rate.For the less important video packet, we can give a positive and larger D_A. In general, there is a need to ensure that the D_A should decrease monotonically with increase in the distortion of video packet.

For the sake of convenient implementation, we do not calculate the distortion of each video packet. A novel priority-classification scheme [11] is employed to measure the importance and distortion of video packets. In a single GOP, we define Q priority grades for the video packets. 1's are assigned to the packets of the I frames, and Q's are assigned to those of the B frames. Since the packets of different P frames have different impacts on the quality of their sequel frames, we assign the remaining priority grades (from 2 to Q-1) to the packets of P frames in accordance with the encoding order. Let p_k be the k^{th} packet in the GOP and $prio(p_k)$ be the priority of p_k, defined by:

$$prio(p_k) = \begin{cases} 1, & \text{if } p_k \in I \text{ frame} \\ \left\lceil \frac{Q-2}{N_p} * i \right\rceil + 1 & \text{if } p_k \in i^{th} P \text{ frame} \\ Q, & \text{if } p_k \in B \text{ frame} \end{cases} \tag{6}$$

Here $\lceil \bullet \rceil$ is the ceil operator, k = 1,2,...K, and i = 1,2,.. N_p.

Through the above analysis and constraints, we can determine an appropriate value for D_A given by:

$$D_A(p_k) = \frac{(D_{nrtPS} - D_{ertPS})}{Q} * (prio(p_k) - Q/2) \tag{7}$$

3. SIMULATION ENVIRONMENT AND EXPERIMENTAL RESULTS

To evaluate the performance of our algorithm, we use the Network Simulator 2 (NS-2) module for WiMAX PMP mode for simulation in [12]. In the video application layer, we adopt the Forman CIF format video sequence with 3000 frames. The sequence is encoded into the standard H.264 bit-streams with the mean bit of 500 Kbps, and each frame is fragmented into packets of 1000 bytes. A GOP contains one I frame, 5 P frames and 10 B frames.

3.1. WiMAX Simulation Environment

In our experiment, we consider a WiMAX network comprising of one BS and several SSs in PMP mode. And Fig.2 shows the simulation topology of the wireless network.

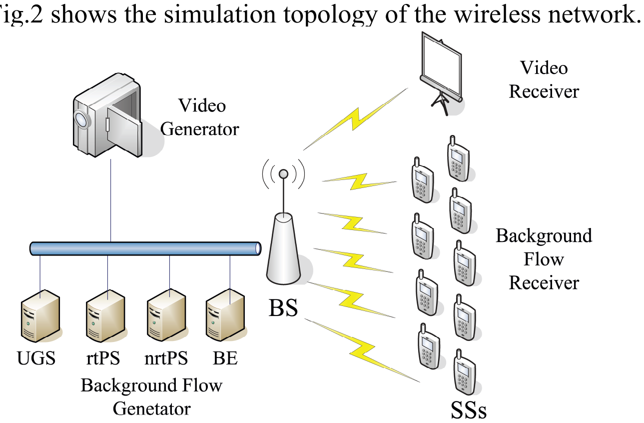

Fig. 2. WiMAX Simulation topology

Table 1 summarizes the simulation parameters used in the experiments. With 10M system bandwidth, we use the TDD mode to divide the transmission time frame, where the ratio of Uplink/Downlink is 1:1. The total frame size is 5ms and fixed during 80s simulation time. The mobile nodes are placed in random over a simulation grid of 500*500. The number of SS increases from 8 to 18, and each SS can have one type connection of traffic source.

Table 1. Simulation Parameters

WiMAX Parameter	Value
PHY	OFDMA
Mac Frame Length	5 ms
Number of Symbols per Frame	48
UL : DL	1:1
Bandwidth	10 M
DL Usage Mode	PUSC
Number of SSs	8-18
Simulation Grid Size	500m*500m
Simualtion time	80s

3.2. Traffic Parameters

To enhance the validity of the simulation, we implement four different traffic flows, one for each WiMAX traffic class. And the values of all the traffic service parameters are based on one connection per Mobile Station, which is shown in Table 2. Then, Table 3 presents the service flows configuration in simulation experiments.

The UGS service flow is modeled by a constant bit rate (CBR) real-time traffic, which consists of a constant packet size of 200 bytes. As another real-time service flow in our experiment, we use a variable bit rate traffic stream to simulate the rtPS service, and its rate is 1.5 Mbps. For the non-real-time service flows, Ftp and HTTP traffic sources are used to imitate the nrtPS and BE service flows separately. In our system, any packet which is not transmitted before its deadline will be dropped.

Table 2. Traffic Parameters

Class	Model	Rate	MaxLatency
UGS	CBR	64Kbps	50ms
rtPS	VBR	1.4Mbps-1.6Mbps	100ms
nrtPS	FTP	400Kbps-1Mbps	500ms
BE	HTTP	600Kbps-1.2Mbps	1000ms
Video	H.264	400Kbps-600Kbps	100ms

Table 3. Service Flows Configuration

Number of SS Nodes	Number of Service Flows				
	UGS	rtPS	nrtPS	BE	Video
8	1	4	1	1	1
10	1	5	2	1	1
12	2	6	2	1	1
14	2	7	2	2	1
16	2	8	3	2	1
18	2	9	3	3	1

3.3. Results on Video Quality

In our experiment, we compare the video quality of the proposed algorithm against 3 legacy WiMAX scheduling schemes: RR[4], WFQ[6] and EDF[7]. Fig.3 shows the average PSNR (Peak Signal-to-Noise Ratio) comparison at different traffic loads with the number of Mobile Stations increasing from 8 to 18.

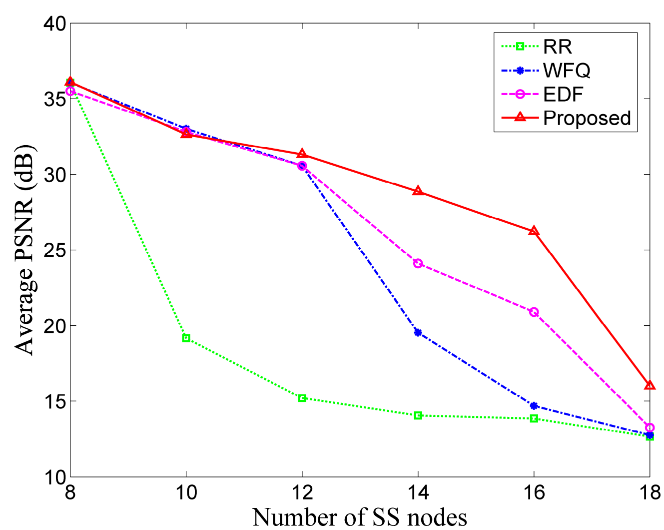

Fig. 3. Average PSNR Comparison

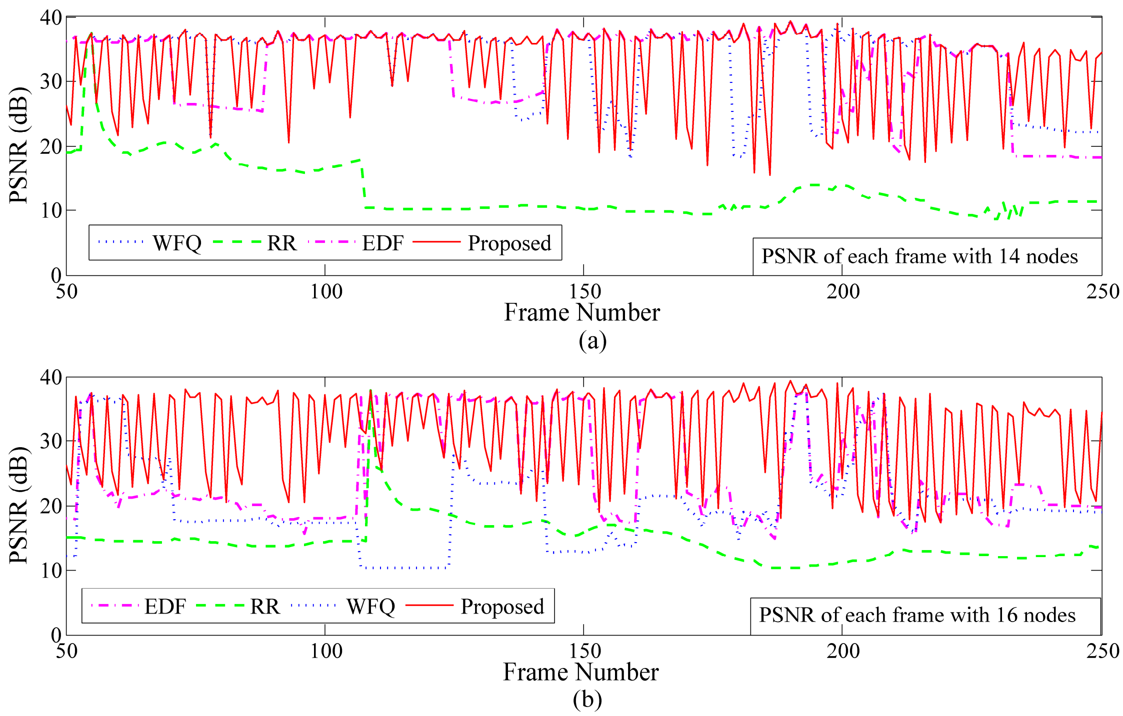

Fig. 4. PSNR Comparison of Each Frame

It is clear that the PSNR values of our proposed algorithm are higher than those of the other three representative scheduling algorithms. Especially when the system is congested gradually, the video quality of our proposed algorithm declines more slowly.

Fig.4 (a) and (b) represent the PSNR of each video frame in the case of 14 SS nodes and in the case of 16 SS nodes respectively. Due to losing more B frames (less important frame packets) in our proposed scheduling algorithm, the red curve fluctuates more frequently than those of the others. But it does not present the successive low value intervals in our proposed algorithm， while it appears in the EDF, WFQ and RR algorithms. This is because our algorithm takes better protection on the important packets such as I frames and some important P frames. Those frames are crucial in the decoding process, and they are frequently used as the references of other video frames. Hence, loss of those important frames could lead to the appearances of successive low value intervals in PSNR. Consequently, the PEDF scheduling algorithm can have good performance for H.264 video transmission over WiMAX network, especially in the condition of overload.

3.4. Results on Loss Rate

In order to explain the performance of our scheduling algorithm more comprehensively, we make a comparison about the loss rate of video frame. Fig.5, Fig.6 and Fig.7 show the loss rate of video frame in the case of 12 SS nodes, 14 SS nodes and 16 SS nodes respectively. Experiments show that in the same traffic load condition, our proposed algorithm better protects the more important video packets against loss, and improves the video transmission quality accordingly.

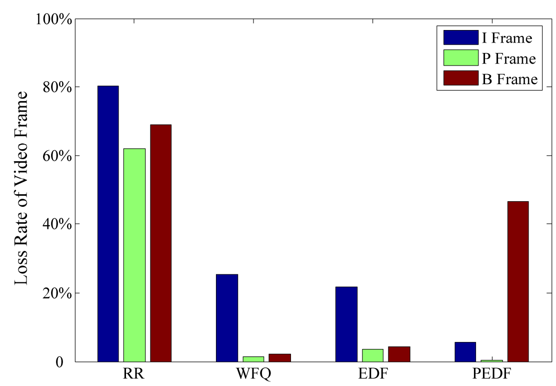

Fig. 5. Loss Rate of Video Frame (12 Nodes)

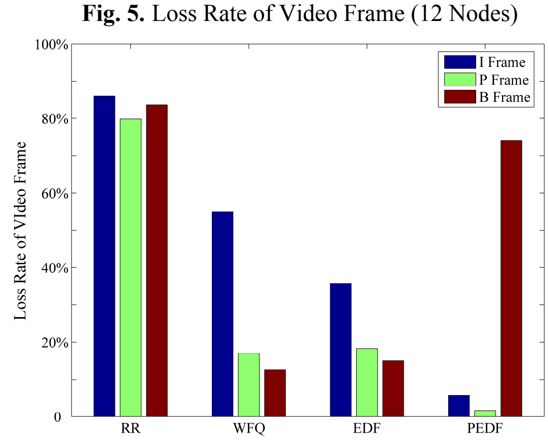

Fig. 6. Loss Rate of Video Frame (14 Nodes)

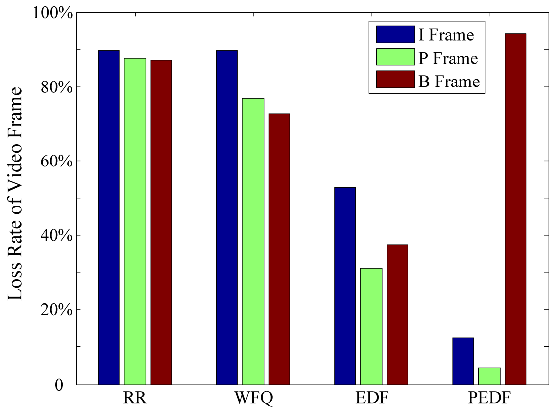

Fig. 7. Loss Rate of Video Frame (14 Nodes)

Fig.8 shows the loss rate of video frame in each case that the SS nodes increase from 8 to 18. With the increase of system workload, our PEDF selects the less important video frames such as the B frames to lose firstly. Only if the wireless transmission system is congested heavily, is it not able to protect the more important video packets in PEDF.

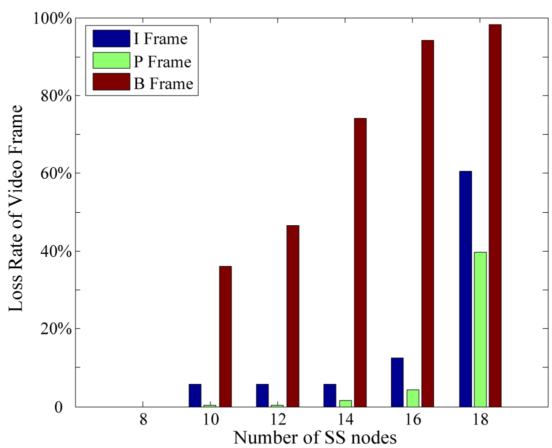

Fig. 8. Loss Rate of Video Frame (Each Case)

4. CONCLUSION

In this paper, we proposed a priority-based EDF scheduling algorithm for H.264 video transmission over WiMAX network. To meet the QoS requirements of the different video frames, an adaptive deadline is assigned to change the miss rate of packet dynamically in our algorithm. In this way, we can protect the more important video packets against drop. Simulation results show that the PEDF can achieve higher PSNR than the other three legacy algorithms, and the quality of reconstructed video can be improved significantly.

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