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A Self-adaptive Packet Scheduling Algorithm for Hybrid-traffic in Heterogeneous Wireless Networks

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Abstract

In heterogeneous wireless network environment (HWNE), multi-mode terminals through access control and handoff technology, are always in the optimal network. However, when the users set, while a competition optimal network bandwidth limited, easily lead to network congestion and quality of service (QoS) decrease. To solve this problem, this paper configures QoS policies for heterogeneous network system agents, with the change of network resources dynamically adjusts traffic scheduling strategy. The main contribution of this paper is that a novel self-adaptive packet scheduling algorithm PFM-LWDF is proposed, which improve the complex scheduling hierarchical structure in the existing research work [1-3] with a hybrid service QoS guarantee. Based on maximum weighted priority delay correction algorithm, the algorithm considers throughput, delay and packet loss rate, and respectively assigns weighting factor. Simulation results show that the proposed algorithm is superior to the existing schedule algorithms in terms of throughput, delay and packet loss rate.

Key words: *HWNE; Strategy agent; Packet scheduling; Resource allocation; QoS*

1. Introduction

Future communications will be wireless communications by the 3G, 4G and other heterogeneous networks composed. The near-far effect, the shadow effect of the Doppler effects and other factors lead multi-mode mobile terminals to the random variations of communication network signal strength in the communication channel, so that the other voice and video users have some QoS issues (call blocking services, or the interrupt service). To avoid these problems, the multi-mode terminal can select and switch to the optimal network through handoff and admission control technology. However, if a large number of multi-mode terminals are switched to the same kind of optimal network will lead to the optimal network congestion. As a result, the multimode terminals abandon the optimal network and preferably choose suboptimal network. The user iterations will make the network QoS seriously decline, such as increased service delay, increased packet loss rate, and decreased throughput. In HWNE, packet scheduling and resource allocation is critical to optimize QoS and ensure the users' fairness.

There are a lot of related researches on resource scheduling and allocation algorithms. RR(Round Robin) algorithm [4], Max C/I (Maximum Carrier to Interference ratio) algorithm[5] and PF (Proportional Fair) algorithm[1] are conventional resource scheduling algorithms. PF algorithm only applies to non-real-time traffic scheduling. Then [6]

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improves PF algorithm to solve the problem, but packets can not be scheduled opportunely. [2] proposes maximum weighted delay first algorithm M-LWDF (Modified Largest Weighted Delay First). [7] proves that [2] improves the throughput performance on the expense of fairness among users. And [8] proposes EM-LWDF (Enhanced Modified Largest Weighted Delay First) algorithm to strengthen the fairness of packet scheduling. Although the algorithm is suitable for scheduling hybrid traffic, it is only suitable for real-time services. Then, [8] proposes a scheduling algorithm based on Quality of Experience (QoE) metrics for real-time and non-real-time traffic scheduling. But it has not been used for HWNE, and only considers the LTE network. The scheduling algorithm based on utility function [9] solves the radio resource management issues in HWNE, but it is only suitable for real-time traffic. At the expense of QoS performance, TF-RNS(Temporal Fairness based Real/Non-real time Scheduling) algorithm with an independent and hierarchical structure [3] schedules the real-time and non-real-time traffic packet utilizing M-LWDF and PF algorithms respectively in the first level scheduling process, but the scheduling hierarchical structure is also too complex to realize. As a whole, the existing packet scheduling algorithms are not suitable for hybrid-traffic (real / non-real time traffic) in HWNE.

This paper proposes a QoS strategy agent that dynamically adjusts packet scheduling strategy with the change of network resources in HWNE, taking into account both the heterogeneity of networks and users' mobility. Compared to the existent scheduling algorithms, this paper proposes a PFM-LWDF (the Proportional Fair Modification of Largest Weighted Delay First) algorithm. The main controbution is that the proposed algorithm is used for hybrid-traffic in HWNE, and especially it improves the complex scheduling hierarchical structure of TF-RNS [3].

We first present traditional TF-RNS algorithm in the next section, Section 3 proposes the scheduling algorithm including network model, QoS strategy configuration, packet scheduling scheme and resource allocation scheme. Section 4 gives a simulation of the algorithm and shows how it outperforms among the typical PF algorithm, M-LWDF algorithm and TF-RNS algorithm. At last, section 5 concludes the paper.

2. Traditional TF-RNS Algorithm [3]

Based on resource allocation target with fair service time, it proposes a TF-RNS algorithm with an independent and hierarchical structure [3]. TF-RNS scheduling framework is shown in Figure1.

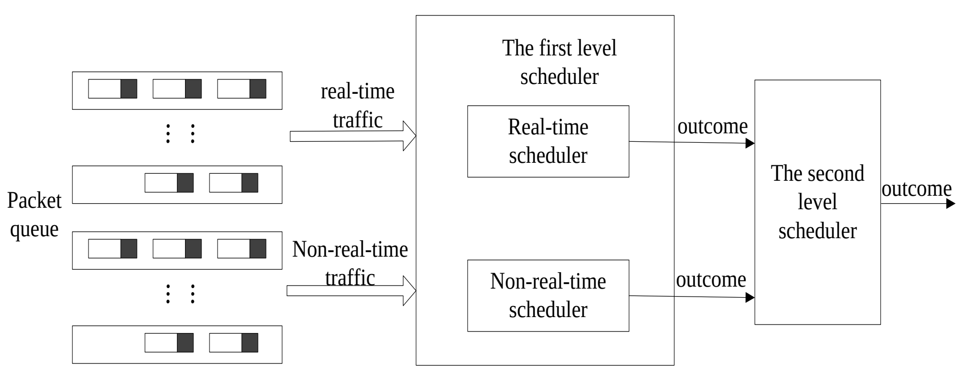

Figure 1. TF-RNS Scheduling Framework

In the first level scheduling process, it schedules the real-time and non-real-time traffic packet utilizing M-LWDF and PF algorithms respectively. Real-time scheduler utilizes a modified M-LWDF scheduling strategy. Real-time user's priority P_R is as follows:

$$P_R = \max_k \{-\frac{\log(d_k)}{T_k} * \frac{SNR_k(t)}{\overline{SNR_k}} * W_k(t)\}; k \in B_R(t) \quad (1)$$

Non-real-time scheduler utilizes a modified PF scheduling strategy. Non-real-time user's priority P_N is as follows:

$$P_N = \max_k \{\frac{SNR_k(t)}{\overline{SNR_k}}\}; k \in B_N(t) \quad (2)$$

$SNR_k(t)$ is SNR of user k at the slot t, $\overline{SNR_k}$ is average SNR, d_k is packet loss rate, T_k is packet transmission delay, $W_k(t)$ is packet waiting time, $B_R(t)$ is the set of real-time users, $B_R(t)$ is the set of non-real-time users.

In the second level scheduling process, according to the requirements of the following inequality, it makes real-time and non-real-time user get a fair service

$$\left| \frac{S_R(t_1,t_2)}{M} - \frac{S_N(t_1,t_2)}{N} \right| \le \delta, \delta \ge 0 \quad (3)$$

$S_R(t_1,t_2)$ is M real-time users' service time during (t_1,t_2), $S_N(t_1,t_2)$ is N non-real-time users' service time during (t_1,t_2), δ is a constant.

Although TF-RNS algorithm is used for hybrid-traffic packet scheduling, but the secondary structure judging scheduling packet twice that increases packet transmission delay and packet loss rate. It is important to note that although the current work is derived from [9], there are two distinguished differences in the PFM-LWDF algorithm:

- The packet scheduling priority in this work is much simpler, which using one unified self-adaptive decision mechanism to calculate the priorities of real-time and non-real-time traffic.
- To avoid the second level scheduling judgment of TF-RNS algorithm, the transmission delay factor in the decision mechanism is proposed in this work, which ensure all users to be scheduled and be allocated resources fairly.

In HWNE, high throughput, low transmission delay and packet loss rate are critical to improve the QoS and ensure fair packet scheduling. PFM-LWDF algorithm considers transmission rate, delay and packet loss rate, and respectively assigns weighting factor for hybrid-traffic, which guarantee the performance for different traffic in proportion to the corresponding QoS requirements.

3. PFM-LWDF Algorithm

3.1. PFM-LWDF Algorithm Model

In this paper, we propose a PFM-LWDF Algorithm including QoS strategy configuration (in Section 3.2), the scheduling stradgety (in section 3.3) and the resource allocation stradgety (in Section 3.4). Firstly, we present the QoS framework of PFM-LWDF in Figure 2, which is the same as [10]. It is mainly composed of ANQM (Access Network QoS Manager) and IANQM (IP core network Access Network QoS Manager). ANQM is used to monitor QoS performance of local access network. IANQM is used to monitor QoS performance among heterogeneous access networks, and makes the decision to select the appropriate access network when mobile users need to switch to another network.

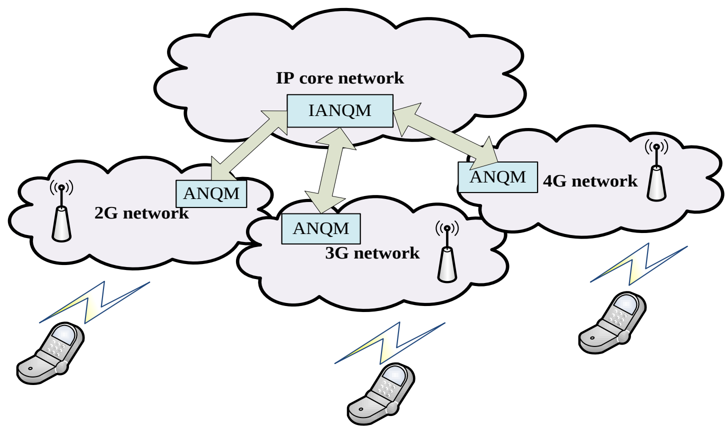

Figure 2. QoS Framework of HWNE

Based on ANQM, the paper proposes a QoS strategy agent that adjusts the scheduling strategy dynamically. The principle block diagram of QoS strategy agent is shown in Figure 3.

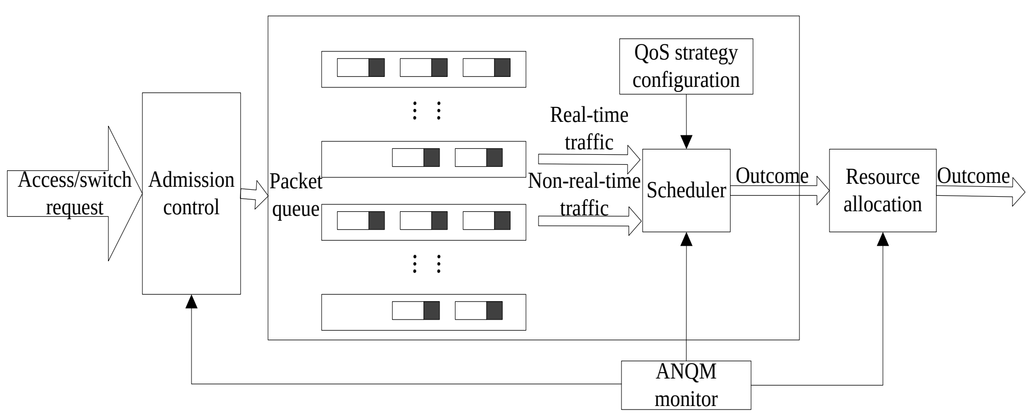

Figure 3. Principle Block Diagram of the QoS Strategy Agent

According to the information of packet queue, the scheduler gets the appropriate scheduling strategy from QoS strategy configuration. It calculates and sorts traffic packet priority $P_{i,j}$. ANQM monitors users' access, the status of scheduler and the resource allocation.

3.2. QoS Strategy Configuration

The QoS strategy agent in the proposed algorithm adjusts the priority weighting factor to change the traffic packet scheduling priority in accordance with the performance of HWNE, the actual value and the demand value of transmission rate, delay and loss rate.

QoS policy configuration firstly considers to be able to transmit hybrid-traffic of heterogeneous network firstly, and then to guarantee all the traffic packets' QoS. For example, if voice and data traffic are transmitted in the 2G network, the voice traffic have a better QoS and the transmission rate of the data traffic is slower, so that the delay and packet loss rate are relatively larger. In the situation, to improve the data packet's QoS, we set the weighting factor of the loss packet to a higher value properly. In 4G, if the cost issue is ignored, all the hybrid traffics are transmitted with a better performance. However, in order to obtain better QoS such as faireness, we should investigate the characteristics of the hybrid-traffic. Real-time traffic, such as voice and video traffic, requests a much higher packet transmission rate and a little end-to-end delay. Delay priority weighting factor α_j and rate priority weighting factor γ_j in PFM-LWDF are appropriately increased. Non-real-time traffic, such as data traffic, has a lower transmission rate and a relatively higher end-to-end delay. Thus the α_j and γ_j are appropriately decreased. This way not only satisfies all traffic's QoS requirements but also improves the hybrid-traffic's scheduling efficiency. Therefore, QoS policy configuration makes the proposed algorithm be suitable for HWNE.

3.3. Packet Scheduling Strategy of PFM-LWDF

To avoid unfairness caused by two kinds of decision mechanisms [9], this paper calculates packet scheduling priority using one unified decision mechanism that suitable for real-time and non-real-time traffic. The QoS strategy agent adjusts the priority weighting factor to ensure that the traffic packets are received successfully and users get better fairness in HWNE. In PFM-LWDF, the scheduler allocates resource according to the scheduling priority of the packet. Therefore, the scheduler needs to calculate the scheduling priority of the packet queue to be transmitted. Packet queue scheduling priority can be expressed as follow [11].

$$P_{i,j}(t) = a_j * \frac{t - t_{i,j}}{T_j} + b_j * u(\bar{h}_j - \tilde{h}_{i,j}) * \frac{\bar{h}_j - \tilde{h}_{i,j}}{\bar{h}_j} \tag{4}$$

In (4), i , j respectively represents user and type of traffic, $P_{i,j}$ is traffic scheduling priority, a_j, b_j are weighting factor of transmission delay and throughput. $\bar{h}_j$ is expected throughput, $\tilde{h}_{i,j}$ is the actual average packet throughput. But packet loss rate was not considered into the scheduling priority [11], and throughput considered as a priority judgment factor was inappropriate. In this paper, we also consider transmission rate to timely schedule the traffic packet with slow transmission rate. Our objective in this work is to jointly consider the above factors by designing a total scheduling priority function for HWNE.

In PFM-LWDF, the function of packet queue scheduling priority can be expressed as follow.

$$P_{i,j}(t) = \arg\max_{i,j}\{\alpha_j * \frac{t - t_{i,j}}{T_j} + \beta_j * \frac{d_{i,j}}{D_j} + \gamma_j * u(R_j - r_i(t)) * \frac{R_j - r_i(t)}{R_j}\} \quad (5)$$

In (5), α_j, β_j, γ_j are priority weighting factors of transmission delay, packet loss rate and transmission rate. $\alpha_j + \beta_j + \gamma_j = 1$. $t_{i,j}$ is the queue packet header generation time, t is scheduling time. T_j, D_j, R_j are the traffic packets' maximum allowable transmission delay, packet loss rate and average transmission rate respectively. $u(*)$ is unit step function. $d_{i,j}$ is packet loss rate of packet queue before the scheduled time. $r_i(t)$ is channel transmission rate at the time t.

In HWNE, transmission capacity of each network is not the same. Based on ANQM test results for different traffic, QoS strategy agent appropriately adjusts the priority weighting factor α_j, β_j, γ_j to provide better QoS. Equation (5) considers the performance requirements of transmission delay, packet loss rate and transmission rate, and also considers the actual situation of network. Thus, it makes real-time adjustments to QoS in the scheduling process.

3.4. Resource Allocation Strategies

In PFM-LWDF, we effectively allocate users' communication channel to guarantee the transmission performance. Channel transmission capacity $C_i(T)$ is expressed by $C_i(T) = r_i(t) * T$, T is resource allocation period. The channel $n_{i,j}$ assigned to traffic j of user i is shown by the following formula [11],

$$n_{i,j} = \frac{w_{i,j}}{C_i(T)} * \left[\frac{T_j - (t - t_{i,j})}{T}\right]^{-1} \quad (6)$$

$w_{i,j}$ is traffic packet size. The channel n_i assigned to all traffics of user i is shown by the following formula,

$$n_i = \sum_j \frac{w_{i,j}}{C_i(T)} * \left[\frac{T_j - (t - t_{i,j})}{T}\right]^{-1} \quad (7)$$

The channel n assigned to all users that waiting to transmit is shown by the following formula,

$$n = \sum_i \sum_j \frac{w_{i,j}}{C_i(T)} * \left[\frac{T_j - (t - t_{i,j})}{T}\right]^{-1} \quad (8)$$

This paper compares the total number of channels in the system with the users' number of channels to planning resource allocation. Assume that total channel number of the system is N_t. If $(N_t - n) > 0$, channel resources is sufficient. If $(N_t - n) \le 0$, the system will temporarily block new users. Therefore, system resources will be legitimately allocated.

3.5. Steps of PFM-LWDF Algorithm

PFM-LWDF algorithm consists of the following steps:

Step1 The system accesses new user and divides the traffic packets into real-time queue and non-real-time queue.

Step2 QoS strategy agent adjusts the priority weighting factors $\alpha_j, \beta_j, \gamma_j$, to make the actual level of QoS for different traffic in proportion to corresponding QoS requirements.

Step3 Scheduler calculates the scheduling priority by Equation (5), and sorts scheduling priority in the order from highest to lowest.

Step4 Compare the total number of channels in system with the current number of channels to transmit all users. If the former is greater than the latter, traffic packets participate in resource allocation by scheduling priority. Otherwise, the system refuses to access new users.

Step5 Return step4. If the former is greater than the latter, the system allows new users to access the network system. Then, return step1.

4. Simulation and Evaluation

4.1. Simulation Scenarios

The heterogeneous networks simulation environment consists of 2G (GSM/GPRS), 3G (WCDMA), 4G (LTE), and WLAN. In order to reduce the complexity of the simulation, we choose WCDMA as the optimal network in the location area. 2G, 4G, and WLAN users switch to WCDMA. Each network has different traffic, such as voice traffic, video traffic and data traffic. The mobile terminal evenly distributed within the WCDMA cell and randomly selects the initial direction to move at a speed of 3 km/h. It alters moving direction with probability 0.3 per 10s. The new direction randomly was selected in the range $[-\pi/2, \pi/2]$. Its trajectory obeys random moving model. Through a large number of simulations, we respectively assigns three sets of data $\{0.4,02,0.4\}$, $\{0.35,0.3,0.35\}$, $\{0.2,0.4,0.4\}$ to the priority weighting factor of voice, video and data traffic. Other parameters are set as follows.

Table 1. Simulation Parameters

Parameter Name	Parameter Values	Parameter Name	Parameter Values
Simulation Users N	40,80,120,160,200, 240,280,320,360,400	Scheduling Period	5ms
Voice Traffic Maximum Delay	50ms	Voice Traffic Maximum Packet Loss Rate	10^{-2}
Voice Traffic Average Rate	64kbps	Delay Weighting Factor	0.4, 0.35, 0.2
Video Traffic Maximum Delay	600ms	Video Traffic Maximum Packet Loss Rate	10^{-3}
Video Traffic Average Rate	640kbps	Packet Loss Rate Weighting Factor	0.2, 0.3, 0.4

Data Traffic Maximum Delay	2s	Data Traffic Maximum Packet Loss Rate	10^{-3}
Data Traffic Average Rate	1.28Mbps	Rate Weighting Factor	0.4, 0.35, 0.4

4.2. Evaluation Indicators

The performance of hybrid-traffic packet scheduling algorithm can be assessed from the following several main aspects [12].

(1) The average packet delay:

$$AvgD = \frac{1}{n}\sum_{q=1}^{n}(t_{qr} - t_{qs}) \tag{9}$$

q is the serial number of packet queue, n is the total number of packet queue that transmit successfully, t_{qr} is the time to receive packet queue for destination node, t_{qs} is generation time of packet queue header.

(2) The average packet loss rate:

$$AvgP_d = \frac{1}{n}\sum_{q=1}^{n}\frac{p_{qs} - p_{qr}}{p_{qs}} \tag{10}$$

p_{qs} is the total number of packets in the q th queue that sent successfully, p_{qr} is the total number of packets in the q th queue that received successfully.

(3) Users' average throughput:

$$AvgT_p = \frac{1}{N}\sum_{q=1}^{n}\frac{p_{qr}}{t_q} \tag{11}$$

N is the total number of users, t_q is time to transmit the q th queue.

4.3. Simulation Analysis

PFM-LWDF algorithm in the paper is compared with the typical PF algorithm, M-LWDF algorithm and TF-RNS algorithm.

Figure 4 shows Users' average throughput of hybrid-traffic with different packet scheduling algorithms. When the number of users is at the range of 40 to 80, the users' average throughput of four algorithms is almost the same due to the competition is not fierce. At the range of 200 to 400, users' average throughput tends to be saturated at the range of 2800kb/s to 3200kb/s. M-LWDF algorithm and the PF algorithm are significantly inferior to the PFM-LWDF algorithm and the TF-RNS algorithm. The average throughput of PFM-LWDF algorithm is more than 3100kb/s. PFM-LWDF algorithm adaptively adjusts rate weighting factor γ_j that respectively assigned 0.4, 0.35, 0.4 according to the voice, video and data traffic. It is better than TF-RNS algorithm under the same conditions.

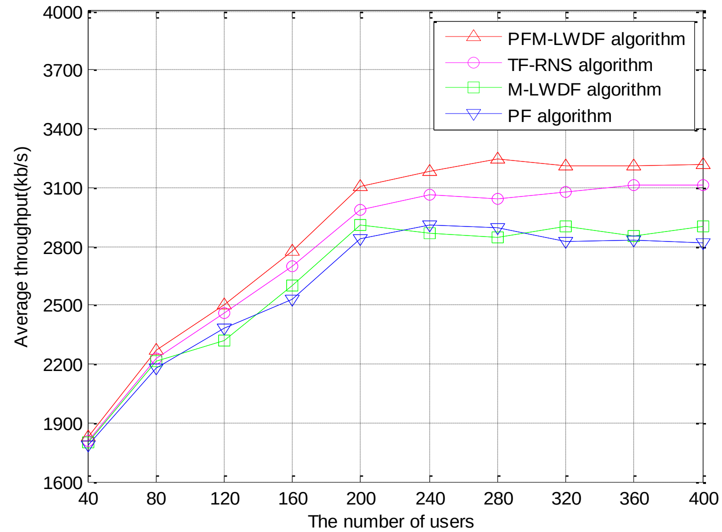

Figure 4. Average throughput of Hybrid-traffic

Figure 5 shows the average packet delay of hybrid-traffic with different packet scheduling algorithms. At the range of 40 to 280, there was little difference between the average packet transmission delay of PF algorithm and M-LWDF algorithm, and so are TF-RNS and PFM-LWDF algorithm. When the number of users increases, the traffic packets are in longer queues that increased queuing time, which greatly increase the delay of entire network. PFM-LWDF algorithm adaptively adjusts delay weighting factor α_j that respectively assigned 0.4, 0.35, 0.2 according to the voice, video and data traffic. Compared with the typical PF algorithm, M-LWDF algorithm and TF-RNS algorithm, the average transmission delay obtained by PFM-LWDF algorithm is less affected with system load's changing.

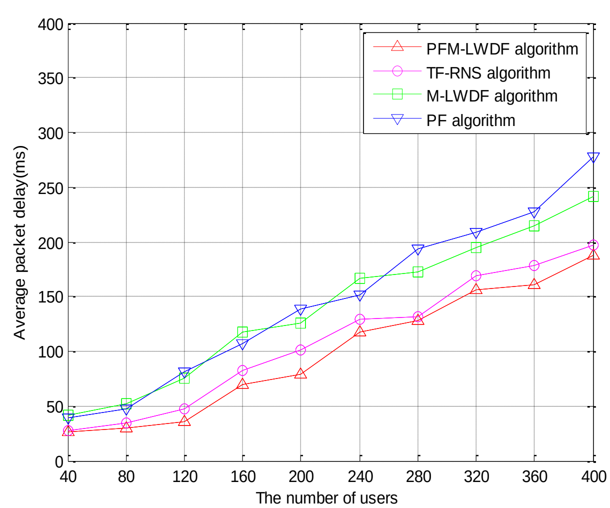

Figure 5. Average Packet Delay of Hybrid-traffic

Figure 6 shows the average packet loss rate of hybrid-traffic with different packet scheduling algorithms. At the range of 40 to 400, there was little difference between the average packet transmission delay of PF algorithm and M-LWDF algorithm. It can be seen that the average packet loss rate of PF and M-LWDF algorithm declined at a faster rate with increasing system load. PFM-LWDF algorithm adaptively adjusts delay weighting factor β_j that respectively assigned 0.2, 0.3, 0.4 according to the voice, video and data traffic. At the range of 160 to 400, PFM-LWDF algorithm can get smaller packet loss rate under the same conditions, which is better than TF-RNS algorithm at average 1.52%.

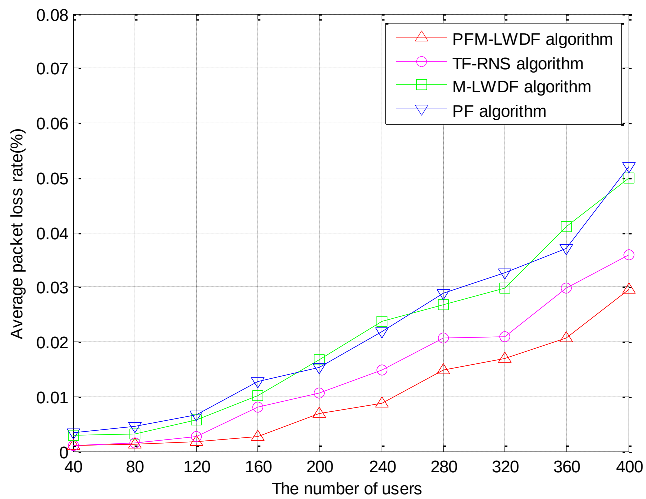

Figure 6. Average Packet Loss Rate of Hybrid-traffic

From the simulation results, PFM-LWDF algorithm is superior to the other three algorithms. PF scheduling algorithm aims at non-real-time traffic, resulting in the real-time traffic lack of timely service. But M-LWDF scheduling algorithm aims at real-time services, resulting in the non-real-time traffic lack of timely service. Both scheduling algorithms do not provide discriminative scheduling priority based on the different traffic. Therefore, it causes unfairness on the allocation of resources. The traffic with higher QoS requirements cannot be reliably guaranteed, and the traffic with lower QoS requirements are assigned too many resources.TF-RNS algorithm provides discriminative scheduling priority based on the different traffic, but the scheduling mechanism with Secondary judgment is too complex. PFM-LWDF algorithm makes real-time self-adaptive adjustments for schedule strategy to guarantee a better QoS.

5. Conclusion

In this paper, a QoS strategy agent is designed to dynamically adjust packet scheduling strategy in heterogeneous wireless network environment. A QoS-Guaranteed PFM-LWDF algorithm is proposed to schedule hybrid-traffic. Resource allocation strategy controls users' radio admission to make system resources legitimately allocate. From the simulation results, the PFM-LWDF scheduling algorithm has better improved throughput, packet loss rate and packet delay. It avoids unfair phenomenon and wasting system resources in hybrid-traffic packet scheduling process. The system performance is improved. To get the optimal system performance, improving resource scheduling algorithm alone is not enough. It is necessary to consider every link of the wireless resource management, including power control, network access and handoff, etc, which are the key points of future improvement and optimization.

Acknowledgements

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