논문 2011-48TC-11-9

LTE를 위한 서비스 클래스를 고려한 스케줄링 기법

(Service Class-Aided Scheduling for LTE)

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요 약

LTE는 다양한 서비스 클래스를 가지고 QoS를 지원한다. 각각의 트래픽 클래스에 대해 BER 요구사항이 크게 다르다. 이는 다양한 클래스의 트래픽에 대해 전송 전력이 상이함을 의미한다. 본 논문에서는 우선순위와 목표 BER을 고려하여 서비스 클래스를 지원하는 새로운 LTE를 위한 스케줄러를 제안한다. CQI와 QCI에 의해 각 사용자당 크래픽 클래스에 대한 목표 BER로 부터 최소 전송 전력이 할당된다. 따라서 사용자의 과거 사용 전송율과 트래픽의 우선순위와 같은 다른 정보를 이용하여 점유 채널의 확률이 결정된다. 서비스 클래스 스케줄링의 시뮬레이션 결과는 최대전송율 및 비례균일과 비교될 것이다. 실험 결과는 서비스 클래스 기반의 스케줄링이 전체 시스템 수율을 개선할 수 있음을 보여주고 있다.

Abstract

LTE (Long Term Evolution) supports QoS (Quality of Service) with several service classes. For each class of traffic, a big difference exists on BER (Bit Error Rate) requirement. This leads to a considerable difference in transmission power for various classes of traffic. In this paper, a novel scheduler is designed and proposed for LTE which supports CoS (Class of Service) with the consideration of priority as well as target BER. By the CQI (Channel Quality Indicator) and QCI (QoS Class Identifier), a minimum transmission power is assigned from the target BER for each class of traffic per each user. Hence, with the other information such as user's used rate in the past and the priority of traffic, the probability of occupying channels is determined. The simulation results of Service Class scheduling are compared with that of Maximum Rate and Proportional Fair. The results show that the service class-aided scheduling can improve the throughput of whole system significantly.

Keywords : Class of Service, Power Control, Scheduling, QoS, LTE, OFDM

Ⅰ. Introduction

The success of the Internet in the late of the previous century had a profound impact on the development of wireless network. From the demand of customers and the development of wireless technology that provides a very high bandwidth for wireless such as LTE. The IP-based services are more and more going wireless. In other words, the IP traffic will transmit over wireless transmission. It leads to wireless network must support almost the characteristics of this traffic. The IP based network uses packet as a key element of all type of traffic. Because volume of Internet traffic is always huge, it is very likely congestion in network. Consequently, there is a high probability of drop for any packet. Furthermore, in packet network for the same connection the traffic can transmit via multi-paths or different conditions that have different delay parameter, resulting in a fluctuation in time of transmission (jitter). To overcome these problems, the

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접수일자: 2011년6월27일, 수정완료일: 2011년11월14일

service class is used to guarantee the quality of each type of service in packet networks. There are two standards of class of service: Type of service (ToS) and Differentiated Service that use n bits of packet header to support 2^n classes. Class of service determines the priority, the delay, and the probability of drop for packet. Nowadays, class of service is “mandatory” for employing IP based service, and becomes an important characteristic in packet network. Therefore, wireless network also should support class of service to guarantee QoS.

Although LTE has been designed as a completely packet-oriented multi-service system without the reliance on circuit-switched connection-oriented protocols prevalent in its predecessors [5], it is complicated to deploy class of service due to the channel variation over time, frequency and space. A feasible method is using scheduling in wireless network as a cross layer that adapts both the channel variation in wireless network and class of service in packet network. To the best of our knowledge, in published literatures on service class scheduling, the authors mainly focused on delay to meet the requirement of some applications that demand tightly on latency. However, these methods have not concerned about other issues such as the throughput of system, how many classes should be created, as well as the fairness among the classes. Moreover, there are some characteristics of class of traffics. For example, different classes of traffic will require different BER and it leads to difference in Signal to Noise Ratio (SNR) at the receiver or transmission power at the transmitter. Therefore, in this paper a novel service class-aided scheduling in combination with power control is proposed and its performance is investigated in terms of throughput performances.

Ⅱ. Current Scheduling

A fundamental difficulty in wireless network is allocating scarce resources among different users while there is a constraint in total power. There are three main methods of scheduling proposed for LTE: maximum rate, proportional fair and delay-limited capacity[5]. The first concentrates on getting the maximum throughput for whole users, while the second tries to get the same rate for every user and the last concentrates on delay rather than throughput of system.

1. Maximum Rate [1]

The maximum rate is achieved when the power allocated for each resource is the smallest. It means only the user with the best channel gain is scheduled. The total rate of system is $\sum_{n=1}^{N} R_n$, where Rn is the total rate allocated to user n in sub frame f. The probability of user n to occupy the channel k is a function given by

$$P(n,k) = f\left(\frac{r_n * h_k(n,f)}{power(n,k)}\right) \tag{1}$$

Where r is the requirement rate of user n, h(n,f) is the channel gain of user n in RB k of sub frame f. This equation is water-filling formula; the user n is selected when the channel gain is high while the power is low. The decision to decide which user will occupy the channel k is based on the user that has $\max_{n=1,2,\dots N} P(n,k).$

The power(n,k) is the power to allocate user n on the RB k and it can be calculated by the following formula[5]:

$$power_{n,k} = \frac{1}{\lambda_k} - \frac{N_0}{\left|h_k(n,f)\right|^2} \tag{2}$$

The total power for all users is limited by $\sum_{n=1}^{N} power_n < P.$ The λ_k is a constant chosen to satisfy the average per-user power constraint. The advantage of this method is that the throughput is the high however there is unfairness among users because only the users with best channel gain are scheduled and the users with worst channel gain may never be scheduled. Therefore, it is unused in reality.

2. Proportional Fair [5], [1]

Proportional fair tries to provide the same rate for every user by exploiting the parameter of used rate. The probability of user n to occupy the channel k is given by:

$$P(n,k) = f\left(\frac{h_k(n,f)}{T(n,f) * power(n,k)}\right) \tag{3}$$

Where T(n,f) is the used rate of user n in the sub frame f. If the user already transmits a high traffic T(n,f), the probability to occupy the channel will decreases. The T(n,f) can be computed in the long term average user throughput by [5]:

$$T(n,f) = (1-\frac{1}{t_c})T(n,f-1) + \frac{1}{t_c}\sum_{m=1}^{M} R_n(m,f)\mathrm{I}(n,m)$$
$$\begin{cases} I(n,m) = 1, \textit{if user n occupies RB m} \\ I(n,m) = 0, \textit{other wise} \end{cases} \tag{4}$$

Tc is the time window over which fairness is imposed. R(m,f) is the achievable rate by user n in RB m and subframe f [5]:

Rn(m,f)=log[1+ SNRn(m,f)] (5)

The decision to decide which user will occupy the channel k is based on the user that has $\max_{n=1,2,...N} P(n,k)$. The total power for all users is limited by $\sum_{n=1}^{N} power_n < P.$ The advantage of this method is that every user has the same rate and it is used in real systems such as HSDPA and EVDO [9], but the throughput is smaller than the maximum rate.

3. Delay-Limited Capacity

Although proportional fair introduces some fairness to the systems, this form of fairness may not guarantee the delay for applications that have a very tight latency constraint[5]. Therefore, another metric is needed, and one such example is “delay-limited capacity” that tries to control the delay time for traffic. This is done by applying service class scheduling[2]. This method prioritizes users with waiting time larger than average. The probability for one user is given by the exponential rule[9]:

$$P(n,k) = \frac{\log(1+(\frac{C}{I})_{n,k})^2 e^{\frac{a\omega_n - a\varpi}{1+\sqrt{a\varpi}}}}{\lambda_n} \tag{6}$$

Where the λ_n is the throughput of user n, C/I is the Carrier to Interference ratio of user n on channel k, ω_n is defined as the waiting time for user n, ϖ is the average waiting time for users in the same class, a is a factor allowing to tune the impact of delay.

The 3GPP/3GPP2 has defined nine traffic classes mainly according to their resource type, priority, delay, and packet error loss rate[5]. Obviously, service class scheduling made a considerable improvement in terms of delay-control for traffic. However, there are still many advantages if a service class scheduling is applied more efficiently. The aspect of packet error rate control will be considered in the next section in this paper to improve the throughput of system.

Ⅲ. Proposed Service Class-Aided Scheduling

We propose a service class scheduling that concerns both BER parameter and priority of data in combination with power control. The Figure 1 shows the flow chart of scheduling scheme.

From QoS Class Identifiers (QCI), the BER target of each class to guarantee the packet error rate can be defined by a vendor or a service provider. So, the minimum SNR(n,k,c) of user n with class c on channel k at the receiver that is depending on BER target is also determined. The relationship between

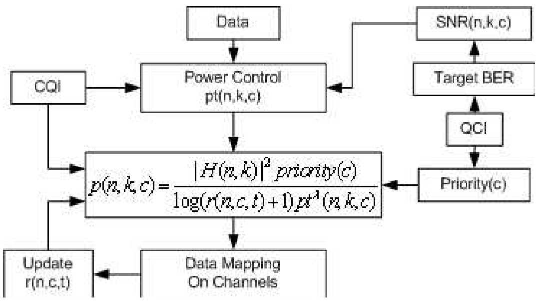

그림 1. 서비스 클래스 스케줄링을 위한 플로우차트
Fig. 1. Flow chart for service class scheduling.

BER and SNR at the receiver of a AWGN with fading channels is given by:[11]

$$\overline{P}_b = \int_0^\infty P_b(\gamma_b)p(\gamma_b)d\gamma_b \quad (7)$$

Where $P_b(\gamma_b)$ is the AWGN bit error probability, the quantity γ_b is called the SNR per bit, $p(\gamma_b)$ is probability density function of fading channel. Approximately, $P_b(\gamma_b)$ is also a function of γ_b. For example with BPSK modulation:[11]

$$P_b = Q(\sqrt{2\gamma_b}) \quad (8)$$

Q(z) is defined as the probability that a Gaussian random variable x with mean zero and variance one exceeds the value z:

$$Q(z) = p(x \ge z) = \int_z^\infty \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} dx \quad (9)$$

Thus, integrating over the distribution yields the average probability of error for BPSK in rayleigh fading:[11]

$$\overline{P}_b = \frac{1}{2}[1 - \sqrt{\frac{\overline{\gamma}_b}{1+\overline{\gamma}_b}}]$$

With the Taylor expansion for $x = \frac{1}{\overline{\gamma}_b}$, $x_0 = 0$:

$$f(x) = \sqrt{\frac{\overline{\gamma}_b}{1+\overline{\gamma}_b}} = (1+x)^{-1/2}$$

$$= f(x_0) + f'(x_0)(x-x_0) + f''(x_0)\frac{(x-x_0)^2}{2} + ...$$

$$= 1 - \frac{x}{2} + g(x^2) \approx 1 - \frac{x}{2}.$$

When $\overline{\gamma}_b$ *is high, we have*: $g(x^2) \approx 0$

$$So, \overline{P}_b \approx \frac{x}{4} = \frac{1}{4\overline{\gamma}_b} \quad (10)$$

From SNR at the receiver, the minimum transmission power pt(n,k,c) is also determined:.

$$SNR_{rx} = \frac{P_{rx}}{P_{noise}} = \frac{P_{tx} - P_{loss}}{P_{noise}} \quad (11)$$

Due to the class of services, we propose a new power control scheme: the transmission power is adjusted upon the priority of service. In other words, the more important services generally require higher quality of transmission or higher power:

$$pt(n,k,c) = [\frac{1}{\lambda_k} - \frac{N_0}{|h_k(n,f)|^2}]\frac{1}{priority(c)^\alpha} \quad (12)$$

Where α is a factor to tune the difference in quality among various classes.

The purpose of scheduling is to map the data on the radio channels; it means the probability p(n,k,c) for the class c of user n to occupy the channel k is needed to be calculate. From the priority parameter of QCI, the priority of class c is expressed in the formula priority(c)= $10^{No.Class-c}$. This formula is used to make the decision impact of priority on the probability p(n,k,c) comparing with other factors. In other words, it will guarantee that the higher priority traffics always be transmitted before the lower priority ones.

Now the probability of each user to occupy each channel p(n,k,c) can be calculated. Because the factors calculating the metric are measured in different units such as decibels for power, bit per second for data rate and the channel gain. They are normalized and modified to indicate the impact on the metric and the correlation on each other:

$$P(n,k,c) = \frac{|H(n,k)|^2 \; priority(c)}{\log(r(n,c,t)+1)pt^\lambda(n,k,c)} \quad (13)$$

and the power constraint $\sum_{n=1}^{N} P_n < P$. P(n,k,c) is the probability of class c of user n to occupy channel k. And λ is a constant which can be adjusted to express the importance of power constraint. For example, the issue of power constraint for uplink is more important than for down link. R(n,c,t) is the used rate of class c of user n over the time t. Once channel k is mapped with class c of user n that has the highest probability P(n,k,c), the r(n,c,t) must be updated.

Since the minimum power transmission is utilized for each class of traffic, there will be a considerably saving power. This saving power is used to transmit more data comparing to the case of scheduling without power control in combination with class of service. In other word, the throughput of the whole system will increase. The channel capacity with total power constraint P, and the P(i,c) is the power for class c of user i to occupy channel k, is given by:

$$C = \max_{\{P_{i,c}\}:\sum_{i,c} P_{i,c} < P} \sum_{i=1}^{N} B\log(1 + \frac{P_{i,c}|h_i|^2}{N_0})$$

$$P_{i,c} = [\frac{1}{\lambda_k} - \frac{N_0}{|h_k|^2}]\frac{1}{priority(c)^{\alpha_c}} \qquad (14)$$

Ⅳ. Simulation Results

To measure the effect of proposal scheduling, two case studies have been done based on OFDM wireless system to compare following scheduling policies:

- Maximum rate scheduler
- Proportional Fair scheduler
- Service class scheduler

The main simulation parameters are listed on the following Table 1.

To compare the effect of schedulers, all users will be requested to receive the same data rate. It is assumed that all users are located at the order of distance from the base station. User 1 is 600m away from BTS, and the distance between two neighbor users is 100m. The interference between neighbor cells is avoided by frequency planning. The number of class of service increases from 1, 2, 4 and to 8.

표 1. 시뮬레이션 파라미터
Table 1. Simulation Parameters.

No. of Users	5
No. of class	2^n,n=1→3
Bandwidth	20 MHz
No. of sub-channels	80
No. of sub-carriers per sub-channels	12
Sub-frame duration	1ms
Channel model	4 path fading
Path loss model	L=128.1+ 37.6$\log_{10}$R(km)
Total BTS transmission power	43 dBm
Modulation	QPSK
Coding rate	1/2 Convolution coding
Channel Estimation	Perfect
Interference between neighbor cells	Avoidance

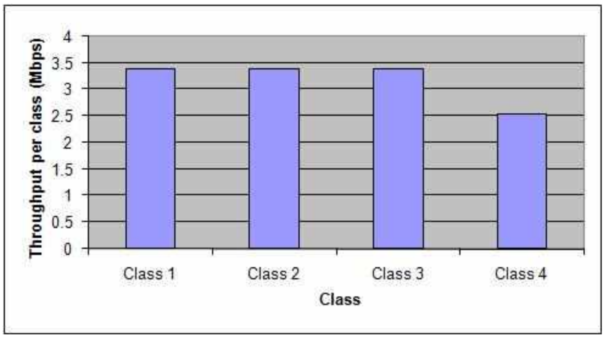

그림 2. 각 클래스별 수율
Fig. 2. Throughput for each class (Mbps).

In the case study one of four classes, the class 1 with target BER=0.00015 (SNR=32dB), class 2 with target BER=0.00039 (SNR=28dB), class 3 with target BER=0.00099 (SNR=24dB), and class 4 with target BER=0.0025 (SNR=20dB). In Figure 2, for all users the important class (class 1) has the higher data rate while the class 4 has the lowest one. Therefore, we can confirm that the scheduler prefers traffic with higher priority. In Figure 3, the lowest BER is always the most important class (class 1) and vice versa. That is, the important classes will have better quality of transmission. Comparing the throughput for each user among three method schedulers, it is can be seen that service class got the “fairness” better

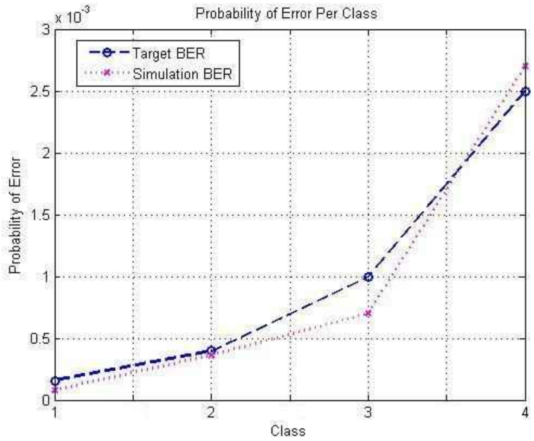

그림 3. 각 클래스별 비트오률
Fig. 3. Bit error rate for each class.

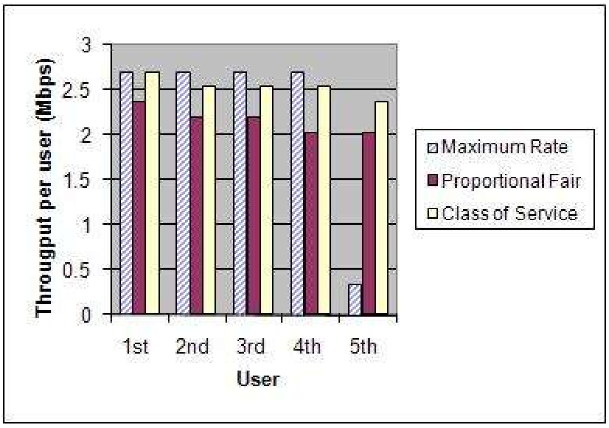

그림 4. 사용자별 수율
Fig. 4. Throughput for each user (Mbps).

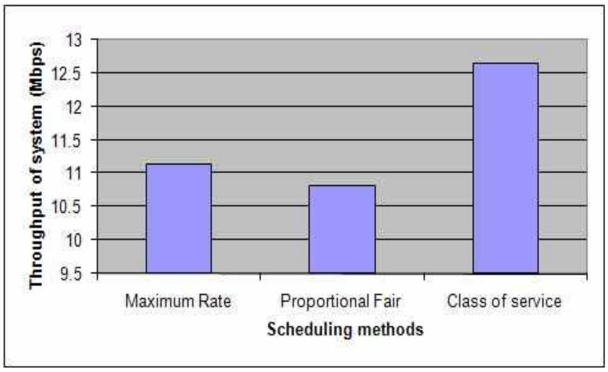

그림 5. 전체시스템 수율
Fig. 5. Throughput of the whole system (Mpbs).

than maximum rate and got "high rate" better than proportional fair method in Figure 4. The target BER=0.00015 is used for maximum rate and proportional fair schedulers. The user 5 throughput is

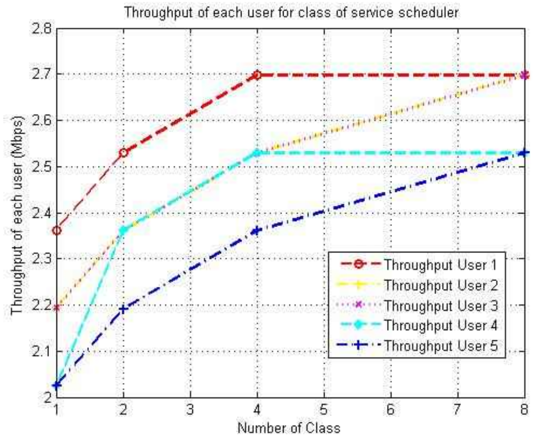

그림 6. 사용자의 수율
Fig. 6. Throughput of users.

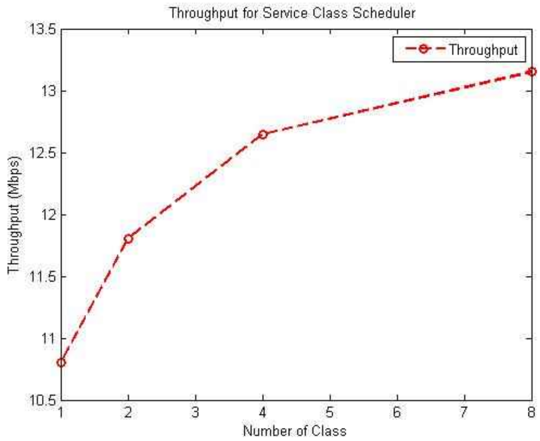

그림 7. 시스템 수율
Fig. 7. Throughput of system.

improved significantly with service class scheduler. Thus we can say that the fairness among users and the fairness among different services improve. Figure 5 shows that the total throughput of the system for service class scheduler is higher than both maximum rate and proportional fair. The proposed scheme improves in throughput of the whole system.

In the case study two, the number of classes increases from 1, 2, 4 and to 8, it can be seen that the fairness and throughput of system also increase. In Figure 6, when the number of class increases, the difference between user's throughput reduces. So, the fairness of sharing channel increases among users. Figure 7 shows that the throughput of system increases when the number of class increases.

V. Conclusion

In the paper, we summarized the service class - aided scheduling for LTE. We focus on the probability of error under AWGN with fast fading in the BPSK modulation. We also explained the service class concept and introduced novel scheduling which combine the priority of class for scheduler with the power control. Moreover, the importance of the number of classes as well as the fairness among classes and users are also addressed. From the simulation results, proposed service class-aided scheduler guarantees Quality of service (QoS) and also improves the fairness among users and the throughput of the system. It is really promising to deploy multi-media services efficiently on 4G wireless network.

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