User Specific QoS and Its Application in Resources Scheduling for Wireless System

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Abstract. This paper describes user specific QoS requirements that are a critical innovation for improving spectral utilization for wireless systems. An adaptive scheduler is presented that incorporates user specific QoS requirements in the spectral allocation of resources. In this paper, we focus on voice applications, and demonstrate that by dynamically adapting MAC scheduling algorithms to the user specific QoS requirements, user satisfaction, as measured by the user specific Mean Opinion Score (MOS), is maximized. OPNET LTE system simulations have been performed for a set of AMR VoIP users with assigned specific QoS target levels. Simulation results show that significant MOS improvements can be achieved if such user specific QoS requirements are considered in the MAC scheduler. Furthermore, when targeted to maximize spectrum utilization and combined with AMR codecs matched to the auditory characteristics of users, higher system capacity, at comparable MOS levels, may be achieved.

Keywords: User specific QoS, Cross layer scheduler, MOS, AMR.

1 Introduction

In today's wireless 4G LTE networks, the spectral allocation of resources is either independent of the application's specific Quality of Service [QoS] requirements and of the users' specific perceived QoS, or at most relies on a set of pre-defined fixed priorities[1, 2]. Although in these standards, the MAC and the PHY layers have an increased role in optimizing the usage of the spectral resources and implementing link quality-aware techniques, nevertheless, optimization is still largely independent of the application context, the users' requirements, and the users' perception of performance degradation. In particular, the standards do not take into account the Quality of Service (QoS) required by different applications and their users, beyond simply assigning fixed priorities to traffic classes. Indeed, from the user's perspective, the QoS required by different applications can be quite variable. Similarly, for a given application type, different users may require different levels of QoS.

As a motivating example, consider the fact that the perceived voice quality of different languages may differ substantially when allocated the same data rate and the same Bit Error Rate (BER), because of the different spectral content of such

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languages and because of a particular user's auditory spectral response (with variations typically due to aging), making the user more or less sensitive to a particular type of distortion. Consequently, the same amount of degradation, as experienced by individual applications and their users, may have substantially different perceptual effects. Another example is the varying talk environments, where some users have a conversation under very noisy conditions, while some other users converse under very quiet conditions, thus making users more or less sensitive to packet losses. If the same amount of spectral resources is allocated to users in very noisy and quiet backgrounds, then a highly degraded user experience will likely be incurred in the noisy environment. As another example, consider that people from different age groups normally have different sensitivity to high frequency content[3], which can be exploited to maximize the system capacity by reducing the bit rate for users with reduced frequency sensitivity.

Furthermore, we observe that some previous studies (e.g. [4–7]), which use the QoS characteristics of an underlying application (typically expressed as a function of the Mean Opinion Score [MOS]), allocate average spectral resources to applications, independently of the application's actual specific QoS requirement. Though, in the literature, there are MAC schedulers that take into account instantaneous data rates and user's QoS [8, 9], to date no user-specific QoS requirements have been considered in the MOS functions and in the MAC scheduler. Thus, in such schemes, especially for applications with widely varying QoS requirements (even for the same type of application), either the spectral resources are not efficiently utilized or the MOS is significantly degraded.

Based upon the user specific requirements, in this paper, we will derive a user specific MOS formula and present a novel user specific QoS-aware cross-layer scheduler that maximizes user satisfaction (MOS) through dynamically adapting MAC scheduling algorithms to these user specific QoS requirements. Here, we focus on voice applications in the context of 4G LTE wireless systems. Moreover, we also address improving system capacity by observing that some users are less sensitive to the high frequency content.

The paper is organized as follows. In Section 2, the VoIP E-Model algorithm is described. A brief summary of prior work on the MAC scheduler is presented in Section 3. In Section 4, our user specific MOS formula is derived and user specific QoS aware scheduling approach is described. Section 5 presents our user specific frequency sensitivity research. Section 6 presents the OPNET LTE system simulation setup. In Section 7, the system simulation results of the user specific QoS scheduler are shown. Finally, our conclusions and future research directions are presented in Section 8.

To summarize, it is the purpose of this paper to introduce and evaluate the performance of an adaptive scheduler that incorporates user-specific QoS requirements in the spectral allocation of resources to optimize the MOS and/or the system capacity.

2 E-Model Algorithm

The E-Model algorithm [10] is a computational model for objective call quality assessment, is described in the G.107 recommendation by the ITU-T. The computation of the MOS is defined as follows:

$$\mathrm{R} = R_0 - I_d - I_{eff} \tag{1}$$

where R is the transmission rating factor, which combines all transmission parameters relevant for the considered connection. R_0 is the basic signal-to-noise ratio which has a default value of 93.2 [11, 12], I_d represents the impairments due to delay, which is the same for all the codec modes, and I_{eff} represents the effect of packet losses and depends on the codec (e.g. AMR, G.711) that is used.

$$I_d = 0.024d + 0.11(d - 177.3)U(d - 177.3) \tag{2}$$

where d is the end-to-end delay in milliseconds and U is the unit step function [12].

For AMR codecs [10],

$$I_{eff} = I_e + (95 - I_e)\left(\frac{100P_{pl}}{\frac{100P_{pl}}{BurstR} + B_{pl}}\right) \tag{3}$$

where P_{pl} represents packet loss ratio, $BurstR$ is the Average length of observed bursts in an arrival sequence to the Average length of bursts expected for the network under "random" loss ratio. In this paper we assume the packet loss is independent and hence we set $BurstR = 1$. B_{pl} is the robustness factor which is set to 10 for all AMR codec modes. I_e is defined for all AMR codec modes in[13], where eight AMR-NB codec modes are defined in LTE [14].

For G.711 codecs [12],

$$I_{eff} = 0 + 30\ln\left(1 + 15P_{pl}\right) \tag{4}$$

R is converted to MOS according to (5):

$$\mathrm{MOS} = \begin{cases} 1, & when\ R < 0 \\ 1 + 0.035R + R(R-60)(100-R) \\ \cdot 7 \cdot 10^{-6}, & when\ R \in [0, 100] \\ 4.5, & when\ R > 100 \end{cases} \tag{5}$$

3 Current MAC Scheduler Approaches

3.1 The MAC Scheduler

The MAC Scheduler is a key component of the LTE Evolved NodeB (eNodeB). The function of the scheduler is to facilitate the allocation of the available spectral resources (e.g., time and frequency resources), while striving to satisfy the QoS requirement of all the users.

Two of the main functions of the LTE radio scheduling are dynamic packet scheduling and link adaptation [8, 9], where the scheduler needs the input of the link adaptation module to select the appropriate Modulation and Coding Scheme(MCS) for channel dependent scheduling. In dynamic packet scheduling, the time-frequency domain resources are distributed dynamically among the active users to get their packets scheduled at the MAC layer. The packet scheduling comprises two scheduling components [8, 9]. They are done sequentially in each scheduling time unit, known as Transmission Time Interval (TTI) in LTE (TTI = 1ms). The first component is the time domain scheduler (TDS) and the second is the frequency domain scheduler (FDS). Such a split is driven simply by the consideration of lower complexity and independent configurations for both domains. The objective of the time domain scheduler is to choose a subset of all users requesting frequency resources, while the objective of frequency domain scheduler is to allocate physical resources for the candidate users provided by the time domain scheduler. Several basic scheduling algorithms exist both in time and frequency domains[8][9]:

1. Round-Robin scheduling algorithm

Users are served in a Round-Robin way so that each user is served fairly but at the expense of system throughput and spectral efficiency.

2. Maximum C/I scheduling algorithm

Users with the maximum C/I [Carrier-to-Interference power ratio] are served first. This kind of scheduling aims to achieve maximum benefits in terms of system throughput and spectral efficiency but comes at the expense of fairness.

3. Proportional-fair (PF) scheduling algorithm

PF scheduling algorithm aims to tradeoff the system throughput for the users' fairness. The PF priority metric is calculated by dividing the predicted user's throughput, which is the instantaneous supportable data rate, by the estimation of the user's past average throughput.

3.2 LTE Baseline Scheduler

The benchmark for performance comparison is the LTE baseline scheduler, where the time domain and frequency domain schedulers are as follows:

1. Time Domain Scheduler

Since the VoIP service is a real time service, it is served and scheduled in real time with the highest priority compared with other non-real time services. But, VoIP users can tolerate a certain amount of delay without being scheduled strictly in real time. The pre-defined scheduling delay is set to 80ms in the LTE baseline scheduler.

2. Frequency Domain Scheduler

Each user has a C/I metric for each sub-band in the system bandwidth and is sorted for each sub-band among all the scheduled users. A max C/I approach is used in the LTE baseline scheduler where each sub-band is first allocated to the user that has the highest C/I , then to the user with the second and third highest C/I, and so on until all the resources of this given sub-band are allocated.

4 User Specific QoS Aware Scheduler

The novelty of the proposed cross layer scheduler is that it incorporates the user specific QoS requirements into the scheduling and differentiates the UEs' scheduling utilizing this user specific QoS information to improve system performance as described below. The cross layer scheduler is aware of the individual QoS requirements of the users, including those with the same application type, and uses this information to optimize the scheduling algorithm by giving higher scheduling priority to those users that are more sensitive to the voice quality. One of the differences with user specific QoS requirements addressed by the cross-layer scheduler in this paper is users different sensitivity to packet losses. Another is users different sensitivity to the high frequency content of the speech signal as a function of age and other factors, which is addressed in Section 5.

4.1 UE-Specific MOS Formula

Here we have assumed that different people have similar sensitivity to the end-to-end delay for VoIP applications, so that only UE specific sensitivity to packet losses is studied. To reflect different users sensitivity to packet losses, a UE specific sensitivity factor, α, is added to (1) so that the metric becomes:

$$R = R_0 - I_d - \alpha \cdot I_{eff} \tag{6}$$

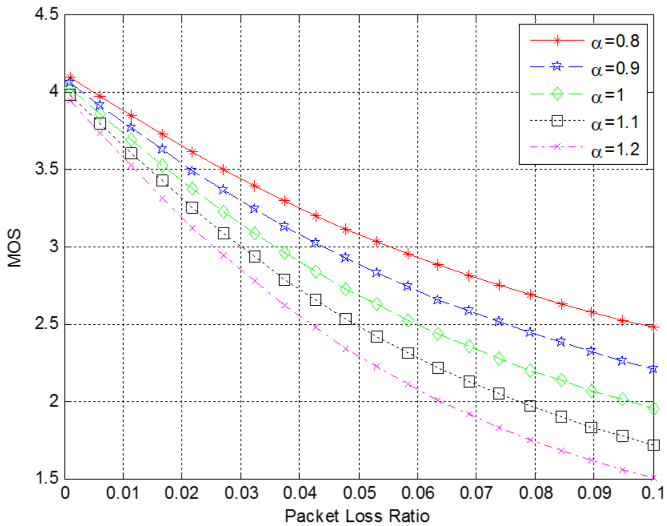

Fig. 1. MOS versus packet loss ratio for different sensitivity factors **α** for AMR 10.2K

In our simulation setup, with the configuration described in Table 1, without loss of generality and also for simplicity of illustration, the sensitivity factor α takes values from the following set $\{0.8, 0.9, 1, 1.1, 1.2\}$. The higher the value of the sensitivity factor (α) is, the user is more sensitive to the packet loss. When α takes the value of 1, it is a normal user. When α takes the value greater than 1, it is more sensitive to packet losses compared with the normal user. When α takes the value less than 1, it is less sensitive to packet losses compared with the normal user. For a given acceptable mouth-to-ear end-to-end delay of 150 ms, Fig. 1 shows the MOS as a function of packet loss ratio for different sensitivity factors **α** for AMR 10.2 Kbps. From Fig. 1, we can clearly see that with the same packet loss ratio and end-to-end delay, different users with different sensitivity factor α will have different MOS values, i.e. a different user experience. As the packet loss ratio becomes larger, the MOS difference also becomes larger. Comparing two extreme cases of α (e.g. α = 1.2 and α = 0.8), a significant difference can be observed for a wide range of packet loss ratios. The user specific QoS-aware scheduler can make use of this information to optimize the scheduling by giving higher priority to users with larger sensitivity factors.

4.2 Optimization Principles

Depending upon the optimization target, there are two kinds of schedulers. One is the MOS targeted scheduler that aims to maximize user satisfaction. The other is the spectral utilization targeted scheduler that aims to maximize system capacity, while maintaining an acceptable MOS level at the same time. In this paper, we focus on the MOS targeted scheduler, while the capacity targeted scheduler is the focus of future work.

With AMR10.2K VoIP users as the example, according to the ITU-T G.107 E-model, the MOS value depends upon both the packet loss ratio and delay. Fig. 2 illustrates the relationship between the MOS value, the delay, and packet loss ratio.

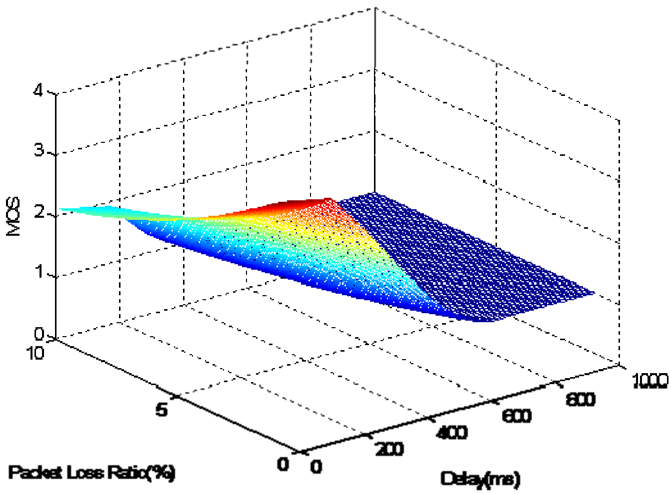

Fig. 2. MOS as a function of packet loss and delay for AMR10.2K

The higher the delay, or the higher the packet loss ratio, the lower the MOS value. Thus, the MOS can be improved either through the optimization of the time domain scheduler or frequency domain scheduler to reduce the delay or packet loss ratio respectively if the user-specific QoS requirement information is known by the scheduler. To be more specific, when a given UE has higher QoS requirement (e.g. higher sensitivity factor), the scheduler can give a higher scheduling priority to this UE in the time domain, i.e. scheduling delay or buffering delay will be set to a predefined small value (e.g. 20ms in the proposed scheduler) and/or higher scheduling priority to this UE in the frequency Domain. For example, if several users have the same C/I metric in a certain sub-band, the user with a higher QoS requirement will be assigned a preferred sub-band with the highest priority.

4.3 Proposed Scheduler

Based on the above optimization principles, the time and frequency domain scheduler can be optimized by using the UE specific QoS requirements as follows:

1. Time domain scheduler

If a given UE is more sensitive to packet losses, this user will be scheduled with a smaller weight on the buffering delay (e.g. 20ms buffering delay in the proposed scheduler).

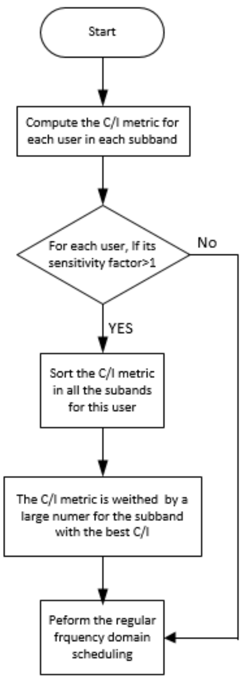

Fig. 3. Workflow of the optimized frequency domain scheduler

2. Frequency domain scheduler

If a given UE is more sensitive to packet losses, the C/I metric for the best sub-band of this user will be weighted in the proposed scheduler so that the user can be allocated this best sub-band with much higher priority. The UE specific weighted metric scheduling can also be easily extended to other baseline schedulers. Fig.3 shows the workflow of the optimized frequency domain scheduler. From Fig.3, we can also find that the extra operations resulting from the user specific QoS awareness scheduling are only the weighting operation and sorting operation in all the sub-bands for each packet losses sensitive user. Therefore, the extra complexity is low.

5 User-Specific Frequency Sensitivity QoS Study

Another very promising area of research is a user-specific frequency sensitivity QoS study. For humans, the audible range of frequencies is usually between 20 Hz and 20 kHz. However, there is considerable variation between individuals - especially at the high frequency end, which is primarily affected by a gradual decline with age. Elderly people are normally less sensitive to high frequencies, while younger people are more sensitive to higher frequencies. Fig. 4 shows the hearing loss as a function of the frequency and age[3]. This difference in the sensitivity to higher frequencies can be utilized to further increase system capacity. A frequency sensitivity factor β is defined as the ratio of highest sensitive frequency of a given user to the standard sampling rate 8 KHz. If a user has a frequency sensitivity factor less than 1, the sampling rate can be reduced to 8β KHz, the data rate will be reduced, then the system capacity (i.e. number of concurrent users) will be increased correspondingly. An OPNET experiment was performed to determine the capacity improvement.

6 System Simulation Setup

6.1 System Simulation Configuration

The system simulation was run using the OPNET 17.5 Modeler[15] with the LTE modules. The system simulation configuration is partly based upon LTE macro-cell system simulation baseline parameters [16] as shown in Table 1. In this paper, one single cell with 24 AMR VoIP users was tested for a downlink cross layer scheduler, with an ideal uplink receiver.

6.2 System Simulation Scenarios

Two scenarios were designed and simulated as described in Table 2. In Scenario 1 users have different packet loss sensitivity factors affecting voice quality, while in Scenario 2 in Table 2 user have different frequency sensitivity factors affecting voice quality.

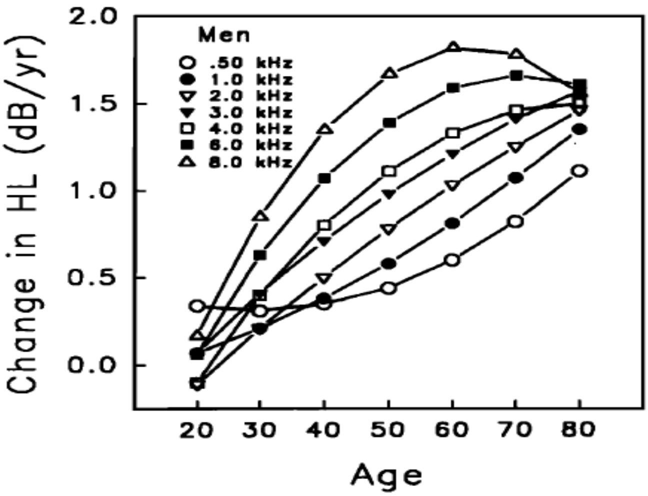

Fig. 4. Hearing loss [HL] as a function of frequency and age [3]

7 Simulation Results

The simulation results for Scenario 1 are shown in Fig. 5-6. The average MOS of all 24 UEs are plotted in Fig. 5. From the figure, we see that greater MOS improvement can be achieved for UEs with larger sensitivity factors and relatively poor MOS (e.g. around 39% MOS improvement for UE24). A view of the MOS of UE24 changing with the time was plotted in Fig.6. It can be seen that the proposed scheduler greatly improves the MOS for UEs that are more sensitive to packet losses and have a relatively poor MOS at the same time. Since UEs with poor MOS need to improve their MOS, the user specific QoS-aware scheduler is very effective in improving the MOS to the desired level.

Table 1. System Simulation Configuration

Parameter	Assumption
Cellular Layout	1 Cell
Cell Radius	1Kilometer
Path loss model	3GPP suburban Macrocell
Mobility model	Random Way Point (RWP) with speed of 0.1km/h
Carrier Frequency	Uplink:1920MHz Downlink:2110MHz
System Bandwidth	5MHz
Channel model	ITU Pedestrian A
Total BS TX power	40dBm
UE power class	23dBm
VoIP codec modes	AMR12.2,AMR10.2K, and mixed codec modes
Number of Users	24 VoIP Users
Scheduler	Dynamic scheduling The proposed scheduler and LTE baseline scheduler
Other assumptions	Ideal uplink receiver(no block error and packet loss) , PDCP compression disabled

Table 2. System Simulation Scenarios

Scenarios	Assumption
Scenario 1	24 AMR10.2K VoIP Users, each user randomly takes a value for the sensitivity factor α, where $\alpha \in \{0.8, 0.9, 1, 1.1, 1.2\}$, the proposed scheduler and LTE baseline scheduler. Sensitivity factor α is taken in the test as follows: UE index — Sensitivity Factor α 1-2 — 0.8 3 — 0.9 4-6 — 1 7 — 1.1 8-11 — 1.2 12-14 — 0.9 15 — 0.8 16 — 1 17 — 0.8 18 — 0.9 19 — 1 20 — 1.1 21 — 1.2 22 — 0.9 23 — 0.8 24 — 1.2
Scenario 2	24 G.711 VoIP users with a freqeuncy sensitivity factor β = 1 24 quasi-G.711 VoIP users with a freqeuncy sensitivity factor β = 0.75, 0.5, 0.25 respectively

Fig.7 plots the approximate capacity improvement (i.e. number of supportable users) as a function of frequency sensitivity factor β. In the simulation, a rough mapping from the Physical Downlink Shared Channel (PDSCH) load to the system capacity improvement can be done according to the following formula:

$$\text{Capacity impovement for factor } \beta(\%) = \frac{1/(\text{load for factor } \beta)}{1/(\text{load for factor } \beta = 1)} - 1 \tag{7}$$

From Fig.7, we can see that more than 100% capacity improvement can be achieved with a sensitivity factor β of 0.25, while an increase of around 30% can be achieved with a sensitivity factor β of 0.5 and 0.75.

8 Conclusion and Future Research

In this paper, we introduced the concept of user specific QoS requirements and demonstrated their importance and utility in spectral allocation and improving the perceived quality [MOS] for wireless systems. A user specific QoS MOS formula was defined and a novel user specific QoS aware scheduler with low complexity was described that significantly improves the MOS of VoIP users based on the user-specific

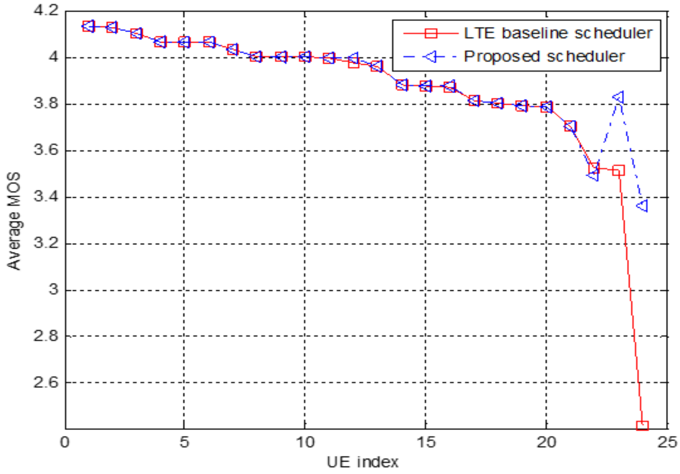

Fig. 5. Average MOS as a function of UE index for AMR10.2K

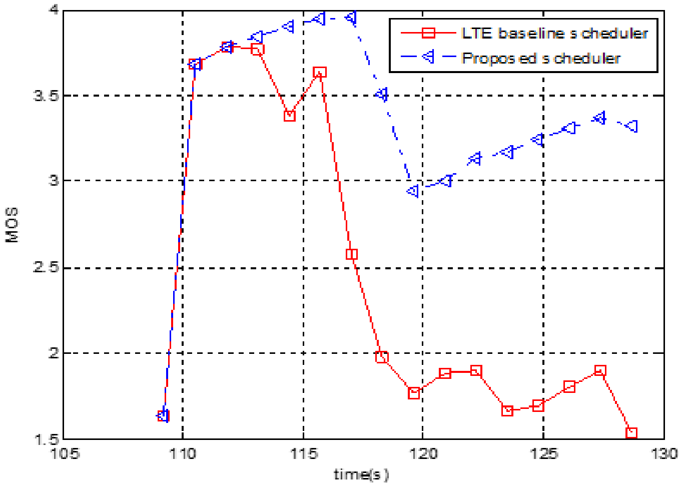

Fig. 6. MOS as a function of time for UE24 for AMR10.2K

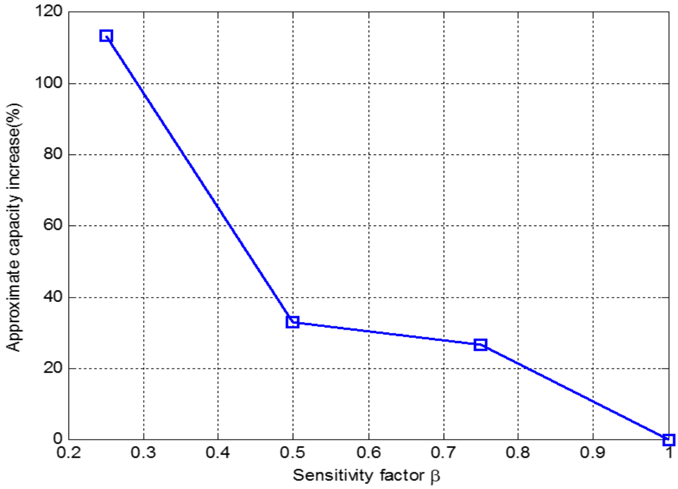

Fig. 7. Approximate capacity improvement as a function of frequency sensitivity factor β

QoS requirements, especially for UEs with relatively poor MOS. The simulation results presented here are only for voice users; however, the same scheduling algorithm will be extended to other applications [e.g., multimedia or data] as one of our future research directions. Moreover, when combined with AMR codecs matched to the different high frequency auditory characteristics of users, higher system capacity as well as comparable MOS levels may be achieved.

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