Power Saving in Multiuser Adaptive Modulation Transmission with Quantized Feedback

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Abstract. A transmitter power saving mechanism is presented in this paper where an Adaptive Modulation (AM) strategy is performed by the system. The power saving is accomplished by fixing a predefined Quality of Service (QoS) indicator in the system through the demanded application Symbol Error Rate (SER). The mutliuser system capability is also exploited to achieve larger power saving values, by scheduling the user with the best channel characteristics at each time instant. The feedback values from the receiver are not perfect and show some quantization error, to match with realistic systems. The obtained results are encouraging as they show a great decrease in the system power budget. The system saved power is presented through a closed form expression and compared its results to computer simulations where a very tight performance is obtained.

Keywords: Adaptive Modulation, Opportunistic Transmission, Quantized Feedback, Power Saving.

1 Introduction

Energy efficiency in wireless systems is a very interesting and timely topic in the research arena. The wireless network interface consumes a significant amount of energy that is continuously increasing mainly due to the transmitter operation at the Base Station (BS). Wireless operators consume a huge amount of power and the electric bill constitutes a large portion of the network running costs [1]. Therefore, if we decrease the consumed power in BSs we will reduce the communication costs, and we will help in the environmental care by reducing the CO_2 emissions.

The main characteristic of the wireless channel is its variability over the time, so that several approaches have been considered to tackle with such channel variations. A strategy that is already implemented in realistic systems is the Adaptive Modulation (AM), where the transmitter is continuously changing the employed modulation to match it to the instantaneous channel conditions; where AM is also shown to increase the system performance [2].

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Such employment of AM is mainly devoted to increase the average data rate in the system, but other system objectives rather than the data rate are also interesting to the system operator. One of such objectives relates to the Quality of Service (QoS) of the customers within the network. A potential measure of the QoS is through the minimum rate per user where each served user is guaranteed a minimum Signal-to-Noise-Ratio (SNR), allowing to properly decode the intended data with a predefined Symbol Error Rate (SER) [3]. Regarding the minimum requirement per user, previous studies have shown that the user satisfaction is insignificantly increased by a performance higher than its demands, while on the other hand, if the provided resources fail to guarantee its requirements, the satisfaction drastically decreases [4]. Thus, an attractive transmission scheme is accomplished by meeting the minimum requirement for each scheduled user, while minimizing the total transmitted power.

Commercial systems are characterized by the availability of several users asking for service, and such Multiuser capabilities will be considered through an opportunistic scheduler, that selects the user with the best channel characteristics at each transmission time [5]. The opportunistic scheduler is shown to be an optimal technique in terms of data rate, and it remains to tackle its performance under QoS restrictions [6]. A Cross Layer (XL) strategy will be proposed to employ information from the channel characteristics in the QoS management. Moreover, an XL power saving philosophy is regarded; as for a given QoS per user, the system will be allowed to decrease the transmitted power by a continuous monitoring of the channel conditions. Therefore, it will be aware of the exact required power to meet each user's QoS requirements, with the consequent decrease in the overall transmitted power.

In this paper, a new power saving mechanism is presented for the Multiuser AM technique, where the user with best channel characteristics is selected and then the best modulation is employed on the basis of its channel quality and on a predefined SER demand. The channel quality is measured through the Signal-to-Noise-Ratio (SNR) value that is fedback from each user towards the scheduler at the transmitter side. The feedback values are subject to quantization errors [7] in order to match with realistic systems, where the SNR values must be quantized before their feedback process. As the AM technique is defined via modulation levels [2], then a power saving mechanism is presented, and its performance through a closed form expression is calculated, where no previous contribution in literature has obtained the power saving through a closed form mathematical formulation.

The remainder of this paper is organized as follows: while section 2 deals with the system model and the opportunistic scheduling at the transmitter side, in section 3 a review of the Adaptive Modulation (AM) procedure is discussed. Section 4 studies the quantization of the feedback values and the resultant wasted power, while Section 5 presents the proposed power saving technique and its performance through a closed form expression, followed by section 6 with the numerical results and simulations. The paper finally draws the conclusions in section 7.

2 System Model

We focus on the Downlink channel where N receivers, each one of them equipped with a single receiving antenna, are served by a transmitter at the Base Station (BS) also provided with a single transmitting antenna. A channel $h(t)$ is considered between each of the users and the BS where a quasi static block fading model is assumed, which keeps constant through the coherence time T_{coh}, and independently changes between consecutive time intervals with independent and identically distributed (i.i.d.) complex Gaussian entries $\sim \mathcal{CN}(0,1)$. Let $s_i(t)$ denotes the uncorrelated data symbol to the i^{th} user with $E\{|s_i|^2\} = 1$, then the received signal $y_i(t)$ is given by

$$y_i(t) = h_i(t)\, s_i(t) + z_i(t) \tag{1}$$

where $z_i(t)$ is an additive i.i.d. complex noise component with zero mean and $E\{|z_i|^2\} = \sigma^2$. A total transmission power of P_t is considered, and for ease of notation, time index is dropped whenever possible.

2.1 Opportunistic Scheduling

A main scheduling policy in multiuser scenarios is the maximum throughput scheduling [5] [6], where the transmitter accomplishes a maximization of the system average rate. During the acquisition step, a known training sequence is transmitted for all the users in the system, and each one of the users calculates the received SNR, and feeds it back to the BS. The BS scheduler chooses the user with the highest SNR value to benefit from its current channel situation, and therefore improving the global system performance. As the user with the best channel conditions is selected for transmission, this scheme is also known as the *Opportunistic Scheduler* [5]. A modified version of this scheduler to fit within commercial systems has been already implemented in the cellular 3.5G HSDPA-HDR standards.

This opportunistic strategy is low complexity, and proved to be optimal [6] as it obtains the maximum average throughput (TH) as

$$TH = E\left\{\log_2(1 + \max_{1\le i\le N} SNR_i)\right\} \tag{2}$$

where $E\{.\}$ is the expectation (average) operator to denote the average value. Notice that the value of $\max_{1\le i\le N} SNR_i$ reflects the serving SNR that the user i obtains when it is selected for transmission (i.e., when it has the highest SNR over all the users). The SNR value calculated at each user follows

$$SNR_i = \frac{P_t\,|h_i|^2}{\sigma^2} \tag{3}$$

where the transmitted power value is set to unity along the paper until reaching the proposed power saving mechanism in section 5.

Based on such selection philosophy to deliver service to the users, the serving SNR distribution can be obtained from the SNR Probability Density Function (PDF) of i.i.d. complex Gaussian channels [5] [8], that is given as

$$b(x) = \sigma^2 e^{-(x\cdot\sigma^2)} \tag{4}$$

and the SNR Cumulative Distribution Function (CDF) is then formulated as

$$B(x) = 1 - e^{-(x\cdot\sigma^2)} \tag{5}$$

Since the opportunistic system searches for the user with the maximum SNR value over all the users, then the CDF of the serving SNR is stated as

$$F(x) = \big(B(x)\big)^N = \left[1 - e^{-(x\cdot\sigma^2)}\right]^N \tag{6}$$

and the PDF of the maximum SNR is therefore obtained as

$$f(x) = N\left[1 - e^{-(x\cdot\sigma^2)}\right]^{N-1}\left[\sigma^2 e^{-(x\cdot\sigma^2)}\right] \tag{7}$$

Considering the CDF of the serving SNR, the probability P_r for the SNR to be above some predefined threshold γ is as

$$P_r = 1 - \left[1 - e^{-(\sigma^2\cdot\gamma)}\right]^N \tag{8}$$

where the value of γ can be the lowest acceptable SNR value in each modulation step, as now explained.

3 Adaptive Modulation (AM)

The wireless channel is continuously fluctuating, thus a link adaptation is required to overcome the changes in the channel characteristics, in order to improve the performance in the wireless systems. The AM strategy [9] is accomplished by an instantaneous change in the employed modulation level, to match the BS transmitter parameters to the channel conditions subject to a predefined SER system performance. The introduction of AM in commercial standards is a fact with its presence in WLAN, WiMAX and LTE systems, among others.

Notice that the selection of the user with the best SNR values is actually another way to adapt the transmitter processing to the channel properties. In this aspect, it follows the same strategy as AM schemes [9], with both strategies looking forward improving the wireless channel performance.

This paper employs the opportunistic scheduler and we consider it together with AM for the transmitter adaptation to the channel characteristics. We will later tackle this scenario to present a power saving strategy in a closed form expression.

Consider an AM scheme that offers W available rates $\{r_1, \ldots, r_W\}$, in ascending order [2]. Each rate can be used for transmission when the measured SNR of the particular link lies within its predefined SNR range. As an example, the w^{th} modulation is employed if the SNR is in the interval $[\gamma_w, \gamma_{w+1})$. Obviously, the SNR of a link is time-varying and depends on the instantaneous channel conditions, but the probability of a user being in each SNR range can be statistically estimated, as the channel distribution is known from equations in the previous section. More specifically, the probability $P_r(r_w)$ of a user being served through the w^{th} modulation, with $w \in [1, W]$, is equal to the probability of having a SNR below a threshold γ_{w+1} and above a threshold γ_w and can be calculated with the use of the CDF in Eqn.(8) as

$$P_r(r_w) = F(\gamma_{w+1}) - F(\gamma_w). \tag{9}$$

It is worth noting that the SNR value guarantees that the user's decoding process is successful. In that case a unit step function is used for the detection procedure, making the SER for the w^{th} modulation to relate to the SNR as

$$SER = \begin{cases} 0 & \text{if} \quad SNR \geq \gamma_w \\ 1 & \text{if} \quad SNR < \gamma_w \end{cases} \tag{10}$$

If we can calculate the probability of the serving SNR to be within each modulation interval, then we can employ such probability to get the closed form expression for the system power saving, as later seen in the following sections.

4 Feedback Quantization

To allow the feedback process from each one of the users to the BS, quantization on the SNR values is required in practical systems to decrease the number of feedback bits [10]. A scalar uniform quantization scheme is the easiest and most practical case, but when AM is employed, the thresholds of uniform quantization must be modified to match with the modulation thresholds. Such a modification is required to prevent any quantization level to extend over two regions for two different modulation types [11].

The quantization has the advantage of reducing the feedback load, but it also introduces uncertainty of the feedback values. Such uncertainty would drive several error kinds in the system [10], where in this paper we will concentrate on two of them: an erroneous user selection for the Opportunistic Scheduler, and a power loss in the amount of the transmitted power. The first effect relates to the probability to have S users in the highest quantization level, so that the BS will consider them with the same SNR value and the best user cannot be properly selected. In that case, one of the S users will be randomly chosen driving some data rate loss in the system [10].

The second kind of error is related to the required allocated power to satisfy the user QoS demands. If a user requests a minimum SNR, the BS will satisfy its QoS by allocating the required power on the basis of its instantaneous channel characteristics, as can be seen from Eqn.(3). If the available channel information at the BS is erroneous, then the BS must follow a worst case design [12] to guarantee the QoS satisfaction, with the consequent wasted transmitted power [12].

In order to calculate the amount of wasted power due to the worst case design, a modified CDF expression ($F_Q(x)$) to account for the quantization effect in the serving SNR is required, and obtained as:

$$F_Q(x)=\sum_{n=1}^{N}\binom{N}{n}\Big(B(\gamma_{w,t})\Big)^{N-n}\Big(B(\gamma_{w,t+1})-B(\gamma_{w,t})\Big)^{n-1}B(x) \tag{11}$$

for $\gamma_{w,t} \leq x < \gamma_{w,t+1}$, where $\gamma_{w,t}$ represents the t^{th} quantization threshold within the w^{th} modulation type in case that the number of quantization steps is larger than the modulation types. If for example, we have $W = 8$ modulation types and $T = 8$ quantization steps, then $\gamma_{w,t}$ will reformulate back to γ_w.

The modified PDF formulation can be written as

$$f_Q(x)=\sum_{n=1}^{N}\binom{N}{n}\Big(B(\gamma_{w,t})\Big)^{N-n}\Big(B(\gamma_{w,t+1})-B(\gamma_{w,t})\Big)^{n-1}b(x) \tag{12}$$

for $\gamma_{w,t} \leq x < \gamma_{w,t+1}$

4.1 Wasted Power Due to Quantization

As we said, the available channel information at the BS is uncertain due to the quantization process, while the BS must keep the QoS for the users, so that it will follow the worst case design which means allocating more transmitted power than required in order to guarantee the QoS for all possible cases. The difference between the worst case allocated power and the exact required power represents the value of **Wasted Power**, that its instantaneous formulation is given as

$$P_{waste}(x) = \left(\frac{\gamma_{w,1}}{\gamma_{w,t}}\right) - \left(\frac{\gamma_{w,1}}{x}\right) \tag{13}$$

where $\gamma_{w,1}$ is the first quantization threshold within the w^{th}.

But rather than the instantaneous measure, it is desired to have the average value that needs for the modified PDF in Eqn.(12), making the average value of total waste power as:

$$E\{P_{waste}\} = \sum_{w=1}^{W}\sum_{t=1}^{T_w}\int_{\gamma_{w,t}}^{\gamma_{w,t+1}}\left(\frac{\gamma_{w,1}}{\gamma_{w,t}} - \frac{\gamma_{w,1}}{x}\right)f_Q(x)dx \tag{14}$$

where as previously presented, T_w represents the number of the quantization levels in the w^{th} modulation region. Making some mathematical manipulations over the previous equation and through the Exponential Integral Function ϵ [13], we obtain a closed form expression for the average wasted power due to feedback quantization as

$$\mathrm{E}\{P_{waste}\}=\sum_{w=1}^{W}\sum_{t=1}^{T_w}\gamma_{w,1}\Bigg[A(w,t)-$$

$$-\sigma^2\sum_{n=1}^{N}\binom{N}{n}B(\gamma_{w,t})^{N-n}\Big(B(\gamma_{w,t+1})-B(\gamma_{w,t})\Big)^{n-1}\Big[\epsilon\big(-\sigma^2\gamma_{w,t+1}\big)-\epsilon\big(-\sigma^2\gamma_{w,t}\big)\Big]\Bigg] \quad (15)$$

where $\epsilon(a) = \int\limits_{-\infty}^{a} \frac{e^x}{x}dx$ is employed and the function $A(w,t) = \left(\frac{F_Q(\gamma_{w,t+1})-F_Q(\gamma_{w,t})}{\gamma_{w,t}}\right)$ is defined.

5 Power Saving Mechanism

Now that we have discussed the considered scenario with the AM transmission and the opportunistic scheduling, we present the power saving mechanism in this section along with its closed form mathematical expression. The paper will exploit the characteristics of the AM system that is defined in terms of intervals. Note that in practical systems, a predefined SER objective is based on the application, and as previously explained in Eqn. (10), this is related to a minimum SNR value, which we named as the SNR threshold. Taking the AM philosophy into account, the threshold for any modulation type represents the lowest SNR value that can satisfy the predefined SER value. Consider an AM scheme that offers W available rates, then each rate can be used for transmission when the measured SNR of the particular link lies within a predefined SNR range (e.g., Table I). This leads to divide the SNR range into regions.

The proposed power saving mechanism takes benefit from the SNR division into regions. In each region the same modulation type is employed for a predefined SER satisfaction. It can be seen from Table I that the satisfaction will be the same during the first interval either with $SNR = 6.78$ or $SNR = 10.33$, as in both cases the BPSK modulation is employed. Remind that the satisfaction marginally increases by a larger performance than the user demands [4]. Therefore if the BS detects an instantaneous SNR value higher than the threshold for a modulation type, it can decrease the transmitted power P_t in order to get the lowest SNR value within that modulation. As an example in BPSK, if the measured SNR is 10.33, which is above the SNR threshold 6.78, then the BS can decrease the amount of transmitted power to make the SNR value to move down to the SNR threshold (from 10.33 to 6.78) through the SNR expression in (3). Since the satisfaction remains the same, then the system has managed to save in the power budget.

For unquantized feedback systems (i.e., the exact SNR value is perfectly known at the BS) and by assuming the measured SNR fits in the w^{th} interval, then the transmitted power will be linearly reduced from the total power

P_t to a lower value that will make the SNR expression in (3) to match with the SNR threshold in the w^{th} interval. Thanks to the linearity of expression (3), the resultant required power denoted as P_n considers the ratio between the measured SNR and the SNR threshold, making the saved power for unquantized feedback systems PS_{unQ} to be formulated as

$$PS_{unQ}(x) = P_t - P_n = P_t - P_t\left(\frac{\gamma_w}{x}\right) = P_t\left(1 - \left(\frac{\gamma_w}{x}\right)\right) \tag{16}$$

If we normalize the total power P_t to be unity, then the amount of saved power equals to

$$PS_{unQ}(x) = 1 - \left(\frac{\gamma_w}{x}\right) \tag{17}$$

which presents the amount of instantaneous saved power for the w^{th} interval for unquantized feedback systems. To characterize the system, we need for the average saved power $E\{PS_{unQ}\}$ and over all W SNR intervals, which is obtained as

$$E\{PS_{unQ}\} = \sum_{w=1}^{W} \int\limits_{\gamma_w}^{\gamma_{w+1}} \left(1 - \frac{\gamma_w}{x}\right) f(x) dx \tag{18}$$

which decomposes into

$$E\{PS_{unQ}\} = \sum_{w=1}^{W} \int\limits_{\gamma_w}^{\gamma_{w+1}} f(x) \, . \, dx - \sum_{w=1}^{W} \int\limits_{\gamma_w}^{\gamma_{w+1}} \left(\frac{\gamma_w}{x}\right) f(x) \, . \, dx \tag{19}$$

where $\gamma_{W+1} = \infty$. The first term easily relates to the CDF in Eqn.(6) as

$$E\{PS_{unQ}\} = 1 - F(\gamma_1) - \sum_{w=1}^{W} \int\limits_{\gamma_w}^{\gamma_{w+1}} \left(\frac{\gamma_w}{x}\right) f(x) \, . \, dx \tag{20}$$

that again with some mathematical manipulations and through the Exponential Integral Function ϵ [13], it reformulates as

$$\mathrm{E}\{PS_{unQ}\} = 1 - F(\gamma_1) -$$

$$- \sum_{w=1}^{W} \left(\sigma^2 \gamma_w \, N \sum_{n=0}^{N-1} (-1)^n \binom{N-1}{n} \Big[\epsilon\big(-\sigma^2 \gamma_{w+1}(n+1)\big) - \epsilon\big(-\sigma^2 \gamma_w (n+1)\big) \Big] \right) \tag{21}$$

Notice that in the quantized feedback systems the exact SNR value is not known at the BS, so that the BS needs to follow the worst case philosophy for its operation, which as already presented, will drive some wasted power due to quantization. Obviously, this leads us to conclude that the amount of saved power in the quantized feedback systems (i.e., realistic systems) will definitely be lower than the unquantized feedback systems. Such "reduction on saved power due to the quantization" is actually the wasted power due to quantization, which is already calculated in Eqn.(15). Therefore, we can represent the amount of saved power for quantized feedback systems PS_Q as follows:

$$PS_Q(x) = PS_{unQ}(x) - P_{waste}(x) \tag{22}$$

Notice that the amount of saved power for the quantized feedback system is calculated by the same way as the unquantized feedback system but with 2 small changes: replacing the exact SNR value x by the lower threshold for the quantization level $\gamma_{w,t}$ that contains the exact SNR value, where $\gamma_{w,t} \leq x < \gamma_{w,t+1}$; and considering that the number of quantization levels within an interval start at the modulation level itself (i.e., $\gamma_{w,1} = \gamma_w$). Therefore, with the amount of saved power in unquantized feedback systems given in Eqn.(17), while the quantized feedback system generates an amount of wasted power as in Eqn.(13), the saved power for quantized feedback can be written as:

$$PS_Q(x) = 1 - \left(\frac{\gamma_{w,1}}{\gamma_{w,t}}\right) \tag{23}$$

Also for the case of quantized feedback, we certainly need for the average saved power $E\{PS_Q\}$ in order to characterize the system performance over all the W SNR intervals, which is obtained as

$$E\{PS_Q\} = \sum_{w=1}^{W} \sum_{t=1}^{T_w} \int\limits_{\gamma_{w,t}}^{\gamma_{w,t+1}} \left(1 - \frac{\gamma_{w,1}}{\gamma_{w,t}}\right) f_Q(x) dx \tag{24}$$

that with some mathematical manipulations, the CDF expression in Eqn.(11) and Eqn.(21), it can be written as:

$$E\{PS_Q\} = \sum_{w=1}^{W} \sum_{t=1}^{T_w} \left(1 - \frac{\gamma_{w,1}}{\gamma_{w,t}}\right) (F_Q(\gamma_{w,t+1}) - F_Q(\gamma_{w,t})) \tag{25}$$

where such formulation stands as a closed form expression of the saved power within the proposed scenario. Next section will show the close match between the simulations and the mathematically obtained expression.

6 Simulations

The performance of the studied scheme is presented by Monte Carlo simulations, where the objective is to see the behaviour of the power saving mechanism in Opportunistic AM systems with quantized feedback. A Multiuser scenario is considered where the BS intends to communicate with a single user at a time. A total of $N = 10$ users are available in the system with i.i.d. channel characteristics. A noise variance of $\sigma^2 = 1$ is also assumed. The feedback from

Table 1. SNR Thresholds

Modulation Type	SNR Threshold γ (dB)
BPSK	6.78
QPSK	10.34
8QAM	14.21
16QAM	17.62
32QAM	20.84
64QAM	23.96

each user towards the BS is in terms of the received SNR value, where such value is quantized through a 7 bit uniform quantizer. A single application is tackled by the system where its SER is predefined to be 10^{-3}. A total antenna gain at transmitter and receiver of 15dB is also considered. Table I presents the mapping between the different modulation levels and the minimum required SNR for a predefined $SER = 10^{-3}$. The calculation of these numbers follow from the SER equation in [14, Chp.5].

Six different modulations are available at the transmitter side, where a continuous switch is accomplished among them to select the most appropriate one for each channel realization. The probability to employ each one of these modulations is shown in Fig. 1, where a shift to the high modulations is observed. Notice that the BS intends to select the user with the best channel characteristics at each transmission time, then the system is expected to increase its performance, this is why a shift to the right hand side is obtained.

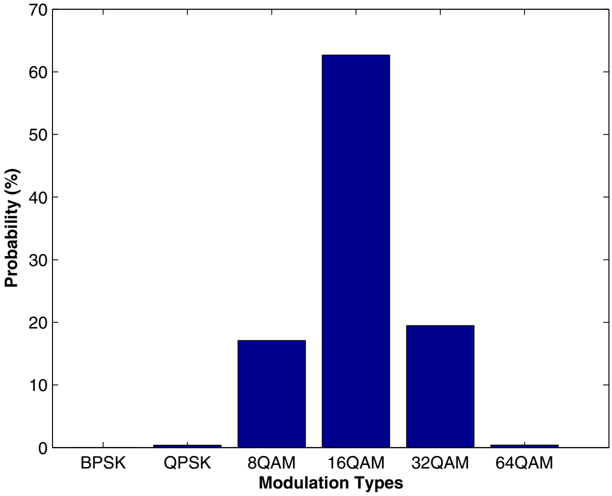

Fig. 1. The probability for each modulation to be selected among all the 6 available modulation kinds. An average $SNR = 1$ is considered to obtain the results.

Related to the amount of saved power within our strategy, Fig. 2 shows the percentage of saved power $E\{PS_Q\}$ from the available power at the transmitter side, and with respect to a variable number of available users in the system. Notice the amount of power that the system can save thanks to the multiuser availability. The multiuser gain has always been presented to enhance the average data rate of the system [5], while here we see that it can be also employed to achieve a great power saving in the system. Comparing the obtained results from simulations with the previously presented analysis, we notice the exact match between them, as the obtained mathematical results were not based on approximation, but on the exact system PDF and CDF expressions.

Remember that with the power saving we will drive the SNR value to the SNR threshold in the w^{th} interval, achieving the predefined SER value. As the SNR value will remain within the same AM interval, and as each interval is characterized by a single modulation level, then the throughput will be the same with and without the power saving mechanism. This is a very important characteristic, as the amount of power saving does not come at the price of lower system average throughput.

The effect of the SNR on the amount of saved power for a given number of users is shown in Fig. 3. It can be seen a continuous quasi-linear increase in the amount of saved power as the SNR raises. As the average SNR increases, the PDF of the serving SNR shifts to the right of Fig. 1 toward the regions of the higher modulation levels, thus the probability that the serving SNR lies in the 64QAM modulation level increases. Because of the 64QAM modulation level has the widest region (it starts at its threshold and it tends to infinity, as it is the largest possible modulation kind), then the serving SNR can lay farther

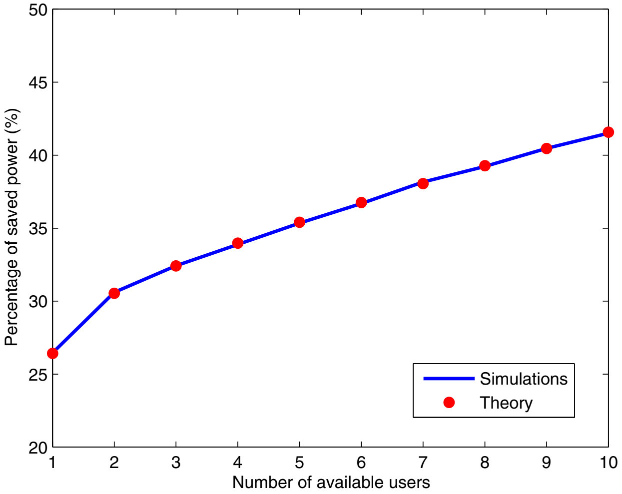

Fig. 2. The saved power for a scenario with a variable number of available users. The results are developed with an average $SNR = 5$ in the scenario.

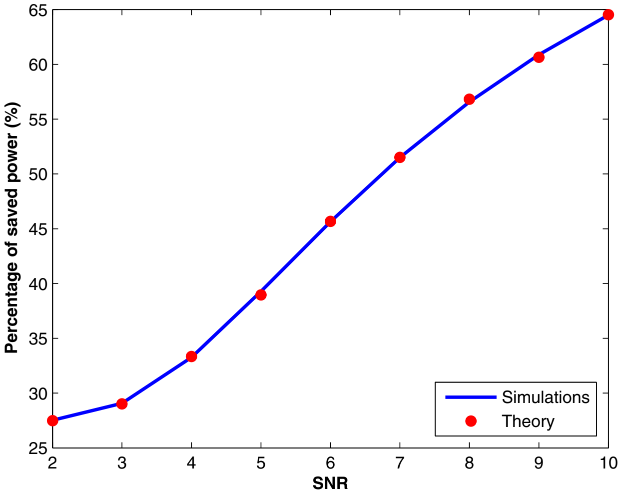

Fig. 3. The saved power for different values of the average SNR. A total of 8 users are in the system.

from the corresponding threshold, with the consequent increase in the amount of power saving, as can be seen in Fig. 3 and confirmed by Eqn.(25). We can also notice in the figure the exact match between the mathematically presented equations and the carried out simulations.

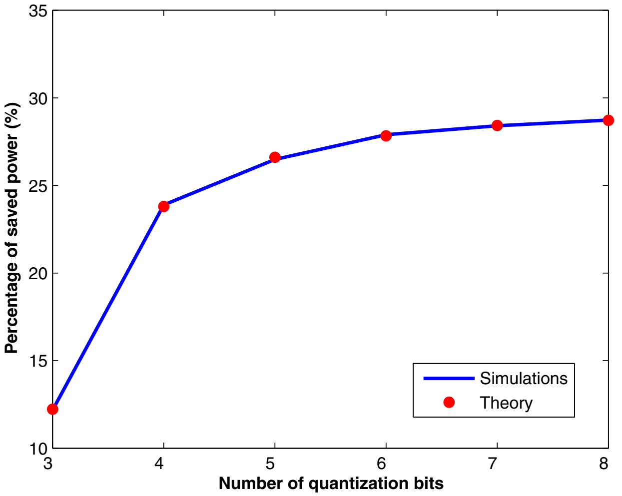

Fig. 4. The amount of saved power for a variable number of quantization bits. A total of 8 users are in the system with an SNR=1 value.

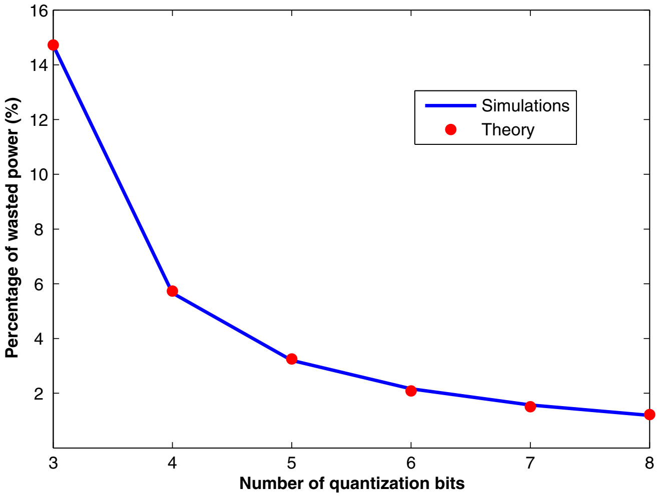

Fig. 5. The wasted power due to quantization for a variable number of quantization bits. A total of 8 users are in the system with an SNR=1 value.

All the above results are obtained under a 7 bits quantized SNR feedback values, which can be considered to be a high feedback load in some systems. Therefore, we will now present the performance of our system under other number of quantization bits. Fig. 4 and Fig. 5 show the amounts of saved power and wasted power for a variable number of quantization bits. From Fig. 4 we observe that for an increasing number of feedback bits, more saved power are obtained. This is because the quantization step is decreased and the SNR quantized version approaches to the actual SNR value, with the consequent decrease in wasted power due to quantization; a matter that is confirmed by Fig. 5 that clearly shows a decrease in the amount of wasted power due to quantization for an increasing number of feedback bits. All the figures show a perfect match between the simulations and the mathematically obtained closed from expressions, so that we obtained equations can totally replace the simulations need.

7 Conclusions

The paper proposed a Cross Layer power saving strategy that benefits from the Adaptive Modulation intervals, where a predefined Quality of Service indicator is fixed in terms of the maximum allowed SER value. The transmitted power is decreased to the minimum required level to match the SER demands, while a multiuser scheduling is accomplished to select the user with the best channel characteristics at each time instant. The employed channel characteristics metric is the SNR that each user measures for its channel, and feeds it back to the BS scheduler. The SNR values at the scheduler are subject to quantization before their feedback, a matter that matches realistic systems. Closed form mathematical expressions are obtained for the amount of the wasted power due to the quantized feedback and the amount of saved power in the system; where the simulations showed their exact match with the theoretical expressions. The system multiuser gain is presented as a potential resource to enhance the power efficiency of the system.

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