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Call admission control with opportunistic scheduling scheme

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Summary

In this paper, a rate-based admission control scheme for a single shared wireless base station with opportunistic scheduling and adaptive modulation and coding (AMC) is proposed. The proposed admission scheme maintains minimum average rates of the admitted users, i.e., new users will be admitted if the base station has enough resources to support the required minimum average transmission rates of all users. The proposed scheme relies on an analytical model for the average per-user rates of an opportunistic scheduling in an unsaturated scenario, where some queues may be empty for certain periods of time. We provide extensive simulation results to demonstrate the accuracy of the base analytical model on which our admission scheme relies. Copyright © 2009 John Wiley & Sons, Ltd.

KEY WORDS: call admission control; opportunistic scheduling; quality of service

1. Introduction

Provisioning quality of service (QoS) over the last mile connection for mobile users while maintaining high spectrum utilization are challenging problems that require efficient radio resource management schemes. As shown in Figure 1, a typical resource management system for a last mile wireless access network incorporates three main subsystems for: (1) an access control subsystem in order to regulate the incoming traffic streams within agreed bounds of users; (2) an admission control subsystem to avoid overloading by limiting the number of users; and (3) dynamic channel resource allocation subsystem, typically, a scheduler, for effective sharing of the channel resources resource allocation among multiple users.

From this perspective, admission control has been a major and challenging research topic in wireless access networks [1–5]. It is a non-trivial problem, in particular, due to the random variations of the capacity and user mobility. To this end, most of the existing works investigate the impacts of user-mobility and handoff on the admission policies for the cellular networks. However, to the best of our knowledge, there

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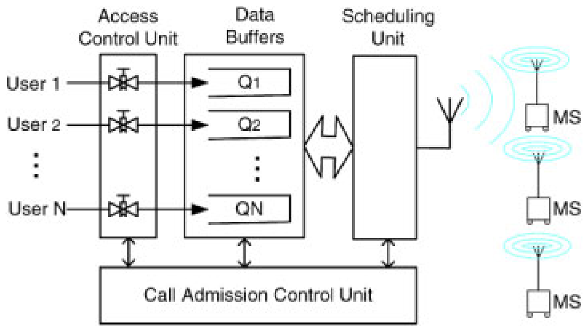

Fig. 1. Resource management system.

is little work on the interaction of admission control and scheduling scheme, which is the main focus of this paper.

Developing an efficient admission control scheme requires knowledge of an accurate model of the scheduling subsystem (in general, dynamic resource allocation unit) and the incoming traffic specification, determined by the access control unit. On the other hand, rate-based admission control schemes are contingent to the information of achievable per-user rates. The achievable per-user rate represents the long-term average transmission rate of user as a function of the number of admitted users and the average qualities of wireless channels. Having the information of the achievable per-user rates, a rate-based admission scheme can assess the impact of admitting a new user on the QoS to the new and the existing users. Thus, the network operator can improve the system utilization, thereby its revenue, by a less conservative admission policy. In other words, such an analytical model allows the network operator to confidently increase system load making sure that the minimum rate requirements of the users will be be violated.

The transmission capacity of a base station depends on the quality of channels of the admitted users and the scheduling strategy. Modeling the achievable per-user rate in an unsaturated case, where the base station may not have data for transmission to some users for some periods of time, is a challenging problem due to the randomness of traffic streams, wireless channels, and the scheduling scheme. For broadcast fading channels, where a single base station is shared by multiple users, it has been shown in References [6] and [7] that the optimal scheduling strategy, in order to maximize the total bandwidth utilization, is to transmit to a single user with the best channel quality, using adaptive modulation and coding (AMC), in each scheduling epoch (i.e., time slot). This can be considered as an *opportunistic service discipline* that relies on the partial channel state information (CSI) provided by the mobile users through a feedback channel to make scheduling decision, i.e., select a user for transmission and its corresponding modulation and coding scheme. Opportunistic scheduling has been employed by several existing wireless scheduling schemes [8–15]. Thus, designing a proper admission policy that can utilize the opportunistic scheduling gain to serve more users is an important and non-trivial problem.

We propose a rate-based admission control scheme. The proposed scheme is coupled with an opportunistic scheduling scheme. To address the problem, we propose an analytical model for per-user rate of an opportunistic scheduling scheme in an unsaturated case. The model is developed in two steps. In the first step, we develop two analytical models, with different features, for a saturated case. In the second step, assuming that users do not have backlogged data for some random periods of time, we obtain an analytical model for the unsaturated case. For the achievable per-user rate in a saturated case, we assume a quasi static Rayleigh fading model for the wireless channels from base station to mobile users. This means that the received signal power by a mobile user, or its channel quality, remains constant for an entire time slot, and it can be modeled by an exponentially distributed random variable. Thus, the quality of a channel in each time slot, in terms of the Signal to noise and interference ratio (SINR) value at the receiver, can be modeled by an exponentially distributed random variable. On the other hand, the maximum achievable rate of user depends on the SINR value at the receiver and the characteristics of the physical layer. In general, it is difficult to obtain analytical models for the achievable rate as a function of the SINR value in practical systems [16]. However, there are reliable simulation results for the existing wireless networks. In this paper, without loss of generality, we use the simulation results for the physical layer of QUALCOMM's CDMA/HDR system from Reference [16]. With a similar set of information, the results of this paper can be extended to other systems. Using the model for the achievable rates *versus* the SINR values and the probability distribution function (pdf) of the SINR at the receiver of a mobile user, we obtain the conditional achievable per-user rate of a user, given the maximum SINR of the other competing mobile users. We obtain the pdf of the maximum SINR for the competing users and derive the unconditional achievable per-user rate of a single user.

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Then, we develop two models for the saturated case. For the first model, we approximate the achievable rates as a piecewise linear function of the SINR values. We assume statistically identical Rayleigh fading channels for mobile users. This assumption is applicable for a system with a proper power allocation mechanism to maintain equal average channel quality for all users. The result of the first model is a closed form formula for the achievable per-user rate of an opportunistic scheduling scheme. For the second model, we relax the aforementioned assumptions. In other words, we use a precise function to model the achievable rates *versus* the SINR values. We also consider statistically non-identical wireless channels for different users. Thus, the result of the second model is more general than the result of the first model. However, the second model requires more computations to obtain per-user throughput. We present the Monte Carlo simulation results to demonstrate the accuracies of the proposed base analytical models. Based on this model, the proposed admission scheme computes the expected average rate of every user when a new user arrives with an admission request. If the expected rate of all users are still above the predefined minimum rate, the new user can be accepted; otherwise the request for admission will be rejected.

The remainder of this paper is organized as follows. In Section 2, we present our system model. We propose an admission control policy, and develop two analytical models of the achievable per-user rate in Section 3. In Section 4, we present our simulation results to verify the accuracy of the proposed models of the achievable rates in both saturated and unsaturated cases. Concluding remarks are given in Section 5.

2. System Model

We consider admission control for the downlink of a single base station with multiple mobile users, as shown in Figure 2. The base station transmits to only one mobile user in each time slot, and the channels are quasi static flat fading ones. Therefore, the received signal power by a user is a random variable which remains constant for an entire time slot. The pdf of received signal power depends on the fading model, as explained in the following.

Prior to discussion of system specifications, we summarize the major notations that will be used throughout the paper in Table I. For a Rayleigh fading

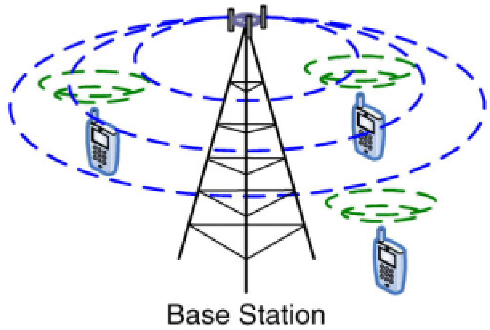

Fig. 2. System model.

Table I. Notations.

Symbol	Definition
α	Received signal power by a mobile user
Ω	Mean of α
x	Received SINR
λ	Mean of x
R_A	Achievable transmission rate of a user
R	Actual transmission rate of a user after scheduling
S	Scheduling status (0 not scheduled; 1 scheduled)
$\bar{R}$	Per-user rate
p	Probability of empty queue

model, the pdf of the received signal power, denoted by random variable α, is given by

$$f(\alpha) = \frac{1}{\Omega} e^{\frac{-\alpha}{\Omega}} \tag{1}$$

where Ω is the average received power by a mobile user [17]. Assuming a constant noise and interference power, the SINR at the receiver of a mobile user have an exponential distribution. For a Rayleigh fading model, the pdf of the SINR at the receiver of a mobile user, denoted by random variable X, can be modeled by an exponential distribution as follows:

$$f_X(x) = \lambda e^{-\lambda x} \tag{2}$$

where λ is the average SINR of the received signal by a mobile user.

In an opportunistic scheduling scheme, mobile users estimate their received SINR from a pilot signal and report it back to the base station through a feedback channel. These values can be used as a good estimation of the channel conditions for a few upcoming time slots. Comparing the SINR values for different users, an opportunistic scheduler selects a user with the best

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Table II. Maximum achievable rates for frame error rate (FER) of 1%.

SINR (dB)	Data rate (kbps)	Modulation	Effective code rate
−12.5	38.4	QPSK	1/48
−9.5	76.8	QPSK	1/24
−6.5	153.6	QPSK	1/12
−4.0	307.2	QPSK	1/6
−1.0	614.4	QPSK	1/3
1.3	921.6	8PSK	16/49
3.0	1228.8	QPSK	2/3
7.2	1843.2	8PSK	2/3
9.5	2457.6	16QAM	2/3
32	5600	Extrapolated	(See the text please)

channel condition for transmission in each time slot. The scheduler also decides the transmission rate for the selected user based on the estimated value of the SINR and the characteristics of the physical layer, such as modulation and coding schemes. The mapping between the value of SINR and the achievable transmission rate is often obtained from the system level simulations. In this paper, we use the results of system level simulation of QUALCOMM's CDMA/HDR system from Reference [16], as shown in Table II. This table summarizes the SINR required to transmit at a certain rate over a wireless channel with 1.25 MHz of bandwidth and frame error rate of 1%. We consider that there is a power control system in place to account for discrepancies due to near far problem. This will eliminate unfairness of max-rate scheduling. In other words, the base stations will transmit with higher power to far users to compensate for their higher paths loss.

Upon arrival of a new user, the admission control unit decides to grant or deny admission permit. The decision is made based on the current information of the system and the analytical model for estimation of the achievable per-user rates. If admission of the new user does not degrade the achievable per-user rates the users below their requirement, the new user can be admitted into the system.

3. The Proposed Admission Control Scheme

We propose two analytical models for the achievable per-user rates in a saturated case in Subsection 3.1. Then, we extend the results to an unsaturated case to develop a admission control scheme in Subsection 3.2.

3.1. Per-user Rate: Saturated Case

The first model uses a piecewise linear approximation of the achievable transmission rate *versus* the SINR value, with the assumption that all channels are statistically identical ones. The second model is more general and accurate in the sense that it uses a precise model for the achievable transmission rates *versus* the SINR values, and considers statistically non-identical channels.

3.1.1. The first model

We develop the model in three steps. First, we model the achievable transmission rate *versus* the SINR value, as given in Table II, using a piecewise linear function. Then, we obtain the conditional expected value of the transmission rate of a user, conditioned on the maximum SINR of the other competing users. Finally, we obtain the unconditional expected value of the transmission rate using the pdf of the maximum SINR of the competing users.

Let random variable R_A represent the achievable transmission rate of a user. As given in Table II, R_A is a function of the SINR value at the receiver which has been plotted in Figure 3. In the figure, each row of Table II is represented by a circle in a two-dimensional space. We also extend the information in Table II by extrapolation in order to account for the higher SINR values that are not given in the table. It can be seen that the simulation points (results) can be connected by three line segments, denoted by L_1, L_2, and L_3. The number of line segments can be different for different sets of simulation results. Each line segment can be

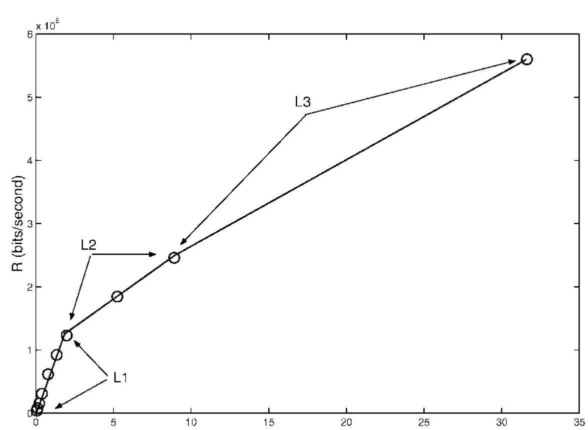

Fig. 3. Piecewise linear modeling of the achievable rates *versus* SINR values.

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represented by

$$R_{\mathrm{A}} = aX + b \tag{3}$$

where X is a random variable representing the SINR. We can obtain (a, b) pairs for L_1, L_2, and L_3 for any particular simulation data. For instance, for the simulation results in Table II

$$\begin{aligned} &L_1 : (689 \times 10^3\,\text{kbps}, -700\,\text{kbps}),\\ &L_2 : (178 \times 10^3\,\text{kbps}, 871 \times 10^3\,\text{kbps}),\\ &L_3 : (140 \times 10^3\,\text{kbps}, 1200 \times 10^3\,\text{kbps}) \end{aligned} \tag{4}$$

With Equation (3), we can obtain the conditional expected value of the transmission rate of a user given the maximum SINR of the other competing users. We consider a scheduling scenario with N users, and denote by the random variable X_i the estimated SINR of the ith user in the next time slot. An opportunistic scheduler selects the ith user for the next time slot if

$$X_i > X_j, \quad j = 1, \ldots, N, \quad j \neq i \tag{5}$$

We define a new random variable Z as the maximum SINR of all other $(N-1)$ competing users. For all users' SINR values having identical pdfs

$$Z = \max(\underbrace{X, \ldots, X}_{N-1}) \tag{6}$$

The pdf of random variable X is given by Equation (2); thus, the cumulative distribution function (cdf) and pdf of Z can be given by

$$\begin{aligned} F_Z(z) &= (1 - \mathrm{e}^{-\lambda z})^{N-1}, \quad z \geq 0\\ f_Z(z) &= (N-1)\lambda \mathrm{e}^{-\lambda z}(1 - \mathrm{e}^{-\lambda z})^{N-2}, \quad z \geq 0 \end{aligned} \tag{7}$$

Let random variable R represent the transmission rate of a user in a time slot. Hence

$$R = S \times R_{\mathrm{A}} \tag{8}$$

where

$$S = \begin{cases} 1 & \text{if } X > Z,\\ 0 & \text{otherwise} \end{cases} \tag{9}$$

The random variable S is equal to one if the user is selected for transmission in the next time slot. Given $Z = z$ as the condition, the conditional expected value of R is given by

$$\mathrm{E}[R|Z = z] = \int_z^{\infty} R_{\mathrm{A}} f_{X|Z}(x|Z = z)\mathrm{d}x \tag{10}$$

where $f_{X|Z}(x|Z = z)$ is the conditional pdf of X. Since X and Z are independent

$$f_{X|Z}(x|Z = z) = f_X(x) \tag{11}$$

Thus,

$$\begin{aligned} \mathrm{E}[R|Z = z] &= \int_z^{\infty} R_{\mathrm{A}} f_X(x)\mathrm{d}x\\ &= \int_z^{\infty} R_{\mathrm{A}} \lambda \mathrm{e}^{-\lambda x}\mathrm{d}x \end{aligned} \tag{12}$$

If random variable X is in a certain vicinity such that R_a can be approximated by one of the line segments in Equations (3) and (4), then

$$\begin{aligned} \mathrm{E}[R|Z = z] &= \int_z^{\infty} (ax + b)\lambda \mathrm{e}^{-\lambda x}\mathrm{d}x\\ &= (az + \beta)\mathrm{e}^{-\lambda z}, \text{ where } \beta = \frac{\lambda b + a}{\lambda} \end{aligned} \tag{13}$$

Finally, using the pdf of Z, we can obtain the unconditional expected value of R by

$$\begin{aligned} \bar{R} &= \int_0^{\infty} \mathrm{E}[R|Z = z] f_Z(z)\mathrm{d}z\\ &= \Gamma \int_0^{\infty} (az + \beta)\mathrm{e}^{-2\lambda z}(1 - \mathrm{e}^{-\lambda z})^{N-2}\mathrm{d}z \end{aligned} \tag{14}$$

where $\bar{R} = \mathrm{E}[R]$ and $\Gamma = (N-1)\lambda$. To obtain a closed form formula for $\mathrm{E}[R]$, we expand $(1 - \mathrm{e}^{-\lambda z})^{N-2}$ as

$$(1 - \mathrm{e}^{-\lambda z})^{N-2} = \sum_{k=0}^{N-2} \binom{N-2}{k} (-1)^k \mathrm{e}^{-k\lambda z} \tag{15}$$

Substituting Equation (15) into Equation (14), we have

$$\begin{aligned} \bar{R} = (N-1)\lambda \int_0^{\infty} &(az + \beta)\mathrm{e}^{-2\lambda z}\\ &\times \left[\sum_{k=0}^{N-2} \binom{N-2}{k} (-1)^k \mathrm{e}^{-k\lambda z}\right] \mathrm{d}z \end{aligned} \tag{16}$$

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By reorganizing Equation (16), we obtain

$$\bar{R} = \Gamma a \int_0^{\infty} \left[\sum_{k=0}^{N-2} \binom{N-2}{k} (-1)^k z \mathrm{e}^{-(k+2)\lambda z} \right] \mathrm{d}z + \Gamma \beta \int_0^{\infty} \left[\sum_{k=0}^{N-2} \binom{N-2}{k} (-1)^k \mathrm{e}^{-(k+2)\lambda z} \right] \mathrm{d}z \tag{17}$$

Solving the integrals in Equation (17) gives us

$$\begin{aligned} \bar{R} &= -\Gamma a \sum_{k=0}^{L} \binom{L}{k} (-1)^k \frac{\lambda k z + 2\lambda z + 1}{(k+2)^2 \lambda^2} \mathrm{e}^{-(k+2)\lambda z} \Big|_0^{\infty} \\ &\quad - \Gamma \beta \sum_{k=0}^{L} \binom{L}{k} (-1)^k \frac{1}{(k+2)\lambda} \mathrm{e}^{-(k+2)\lambda z} \Big|_0^{\infty} \\ &= \Gamma a \sum_{k=0}^{L} \binom{L}{k} (-1)^k \frac{1}{(k+2)^2 \lambda^2} \\ &\quad + \Gamma \beta \sum_{k=0}^{L} \binom{L}{k} (-1)^k \frac{1}{(k+2)\lambda} \\ &= \frac{L+1}{\lambda} \sum_{k=0}^{L} \binom{L}{k} (-1)^k \frac{\beta \lambda k + 2\beta\lambda + a}{(k+2)^2} \end{aligned} \tag{18}$$

where $L = N - 2$. Equation (18) is the unconditional expected value of transmission rate for a user, or the achievable per-user rate of opportunistic scheduling scheme.

3.1.2. The second model

The approach for the second model is similar to the first model. However, the second model neither uses a specific approximation for R_{A} nor identical exponential distributions for all X_i. Let $R_a = h(x)$ be a general function that maps the value of SINR, denoted by x, to achievable rate, denoted by R_a. Thus, the general form of Equation (13) can be given by

$$\mathrm{E}[R|Z = z] = \int_z^{\infty} h(x) f_X(x) \mathrm{d}x \tag{19}$$

Assuming different pdfs for the SINR of different users, the general form cdf and pdf of Z in Equation (7) can be written as follows:

$$\begin{aligned} F_Z(z) &= F_{X_1}(z) \ldots F_{X_M}(z), \quad z \geq 0 \\ f_Z(z) &= f_{X_1}(z) F_{X_2}(z) \ldots F_{X_M}(z) + \\ &\quad f_{X_2}(z) F_{X_1}(z) F_{X_3}(z) \ldots F_{X_M}(z) + \\ &\quad \vdots \\ &\quad f_{X_M}(z) F_{X_1}(z) \ldots F_{X_{M-1}}(z), \text{ for } z \geq 0 \end{aligned} \tag{20}$$

where $M = N - 1$, $F_{X_i}(z)$ is the cdf of X_i, and $f_{X_i}(z)$ is the pdf of X_i. Thus, the general solution of per-user throughput can be given by

$$\bar{R} = \int_0^{\infty} \mathrm{E}[R|Z = z] f_Z(z) \mathrm{d}z \tag{21}$$

$\bar{R}$ can be obtained by using a variety of algorithms such as adaptive Simpson quadrature [18]. However, for numerical computation of Equations (19) and (21), we need to approximate the infinite upper bounds of the integrals. Fortunately, the arguments of the integrals in Equations (19) and (21) rapidly approach to very small values. This can be seen in Figures 4 and 5, which show the plot of the arguments of the integrals (19) and (21), respectively, for a Rayleigh fading channel. Thus, it is reasonable to replace the upper infinite bounds of the integrals in Equations (19) and (21) with some finite values. For instance, for our simulations in Section 4 we use a typical value of 100 for both of the integrals. This is reasonable for a range of SINR values between −12.5 and 10 dB from Figures 4 and 5.

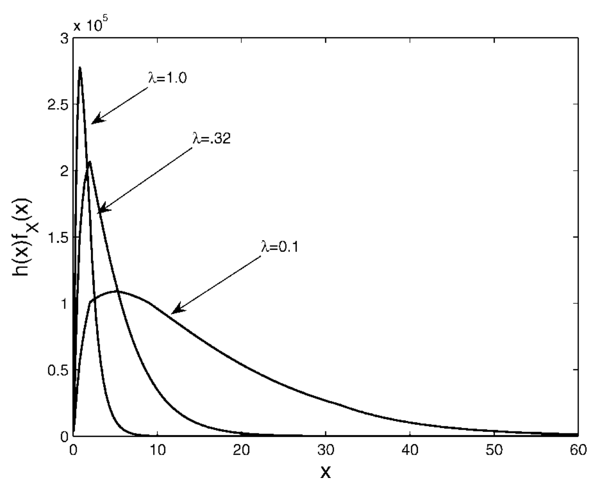

Fig. 4. Argument of integral (19).

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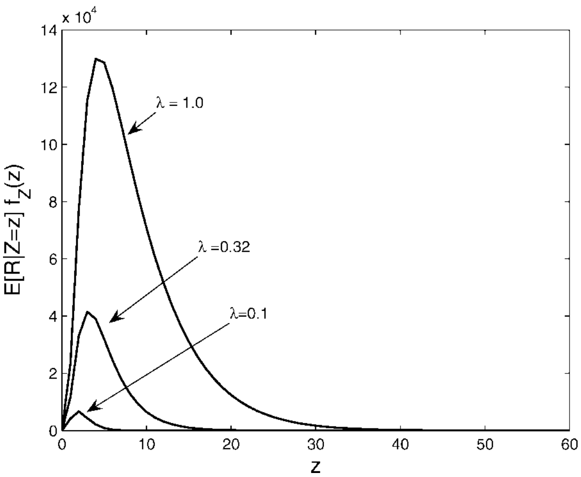

Fig. 5. Argument of integral (21).

3.2. Admission Control Scheme

In this section, we extend the results of the previous section to an unsaturated case, where users may not have backlogged data for random periods of time. The model is important in the design of an efficient admission control scheme to exploit statistical multiplexing gain. In fact, the saturated case provides a conservative estimation of the achievable per-user rates. Considering burstiness of the incoming traffic streams, we expect higher achievable per-user rates. Having the analytical model of the achievable per-user rates, we propose a rate-based admission control policy. In a rate-based admission control, a new call is admitted if the estimated rates of all users, including the new user, do not degrade below their minimum required values.

For the achievable per-user rate in an unsaturated case, we assume a target user with constant backlogged data and $N-1$ users with some random idle periods of time. Computing the achievable rate of the target user provides the achievable rate of a typical user considering the inherent multiplexing gain due to burstiness of the incoming traffic streams. Let p denote the probability that a user is in idle state with no data for transmission. Precise computation of p is a difficult problem. In practice, we have to use a combination of measurements and estimation based on historic data in order to obtain the value of p. We assume that this parameter is available by monitoring the status of the queues in Figure 1. This estimation can be done based on the historical knowledge of the base station about the average increase of p upon admission of a user with a certain traffic intensity. The input value of p to the admission scheme should be slightly smaller than the current value. This will reduce chance of system overload. The base station has to update its knowledge base after admission of the new user. Let I be a random variable representing the number of non-idle users in a time slot. That is, only I users will compete for transmission in that particular time slot. Therefore, random variable I is a binomial random variable. For homogenous traffic sources and statistically identical wireless channels, the probability mass function (pmf) of I is given by

$$\Pr\{I = i\} = \binom{N-1}{i}(1-p)^i \cdot p^{N-1-i} \tag{22}$$

Thus, the expected value of the achievable per-user rate of the target user with constant backlog is given by

$$\widetilde{R} = \sum_{i=0}^{N-1} \bar{R}(i+1)\binom{N-1}{i}(1-p)^i \cdot p^{N-1-i} \tag{23}$$

where $\bar{R}(i+1)$ is the per-user throughput of a user given by Equation (18) for a scheduling scheme with $(i+1)$ users. Hence

$$\bar{R}(i+1) = \frac{i-1}{\lambda}\sum_{k=0}^{i-2}\binom{i-2}{k}(-1)^k \frac{\beta\lambda k + 2\beta\lambda + a}{(k+2)^2} \tag{24}$$

Having the aforementioned model of the achievable per-user rates in an unsaturated case, the admission policy is outlined as follows:

1. The base station monitors the status of queues and estimates p. The estimation will be updated periodically.
2. Upon an admission request, the base station estimates the achievable per-user rate of the new and the existing users. This can be done by using Equations (23) and (24).
3. Based on the estimated rates, the reservation policy of the system, and the priority of the new call, i.e., if it is a new call or a handoff call, the base station decides to accept or deny the new call.

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Table III. Simulation parameters of the fading channels.

Parameter	Value
Carrier frequency	1800 MHz
Velocity of mobile nodes	5 Km/h
Sampling frequency	1000 samples per second
Length of a time slot	1.25 ms

4. Simulations

We simulate a network with a single base station and arbitrary number of users, as described in Section 2. A flat Rayleigh fading channel simulator, as specified by its parameters in Table III, is used to generate the wireless channels from the base station to the mobile users. The results from Table II have been used for mapping between SINR values and the achievable transmission rates. For each of the following simulation results, we run the simulation for about 10 million time slots in order to collect reliable data. We use simulation results to verify the accuracy of the proposed analytical models for the achievable per-user rates in saturated and unsaturated cases. Comparison of the results for the saturated and unsaturated cases also reveals the importance of considering multiplexing gain.

4.1. Saturated Case

In a saturated case, there is always data for transmission to all users. To demonstrate the accuracy of the first model given by Equation (18), we perform extensive simulations for different numbers of users and the average quality of wireless channels. Figure 6 shows the achievable per-user rate *versus* the number of users

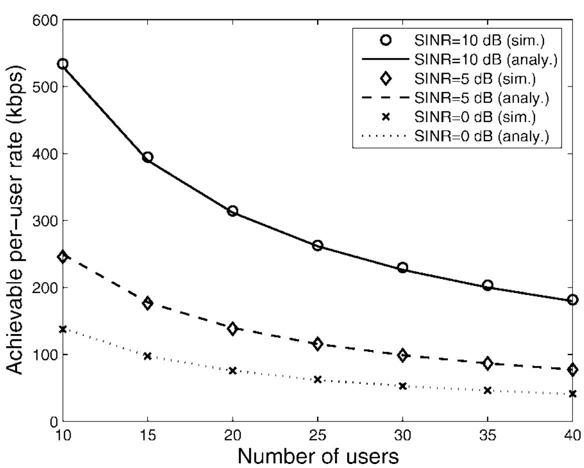

Fig. 6. Achievable per-user rate *versus* the number of users for a saturated case (the first model).

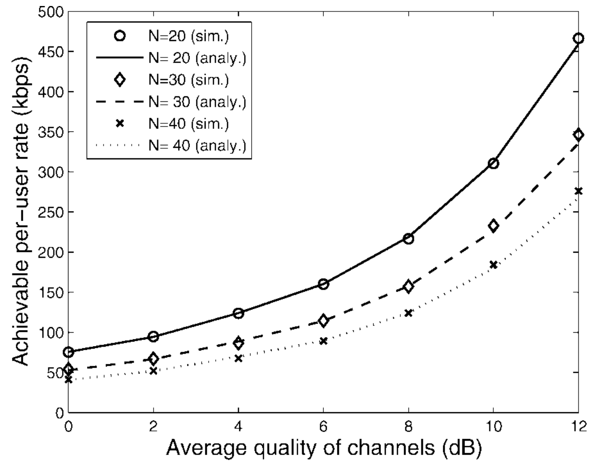

Fig. 7. Achievable per-user rate *versus* the average quality of wireless channels for a saturated case (the first model).

for different qualities of channels in terms of the SINR value. Figure 7 shows the achievable per-user rate *versus* the quality of channels in terms of SINR values for different numbers of users. It can be seen that the results of the first model in Equation (18) closely match the simulation results.

To demonstrate the accuracy of the second model, given by Equations (19) and (20), we simulate similar scenarios as that for the evaluation of the first model. Figures 8 and 9 show the results similar to that of Figures 6 and 7. It can be seen that both of the proposed models provide a very good approximation of the achievable per-user rate. To demonstrate the capability of the second model in the case of statistically non-identical channels, we simulate a scheduler for eight users with different average channel quality, as shown

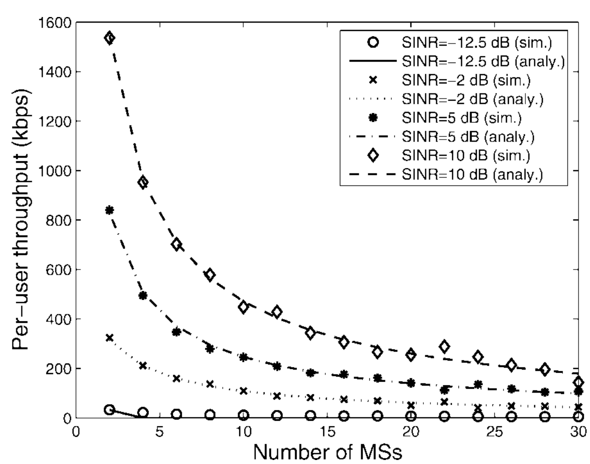

Fig. 8. Achievable per-user rate *versus* the number of users for a saturated case (the second model).

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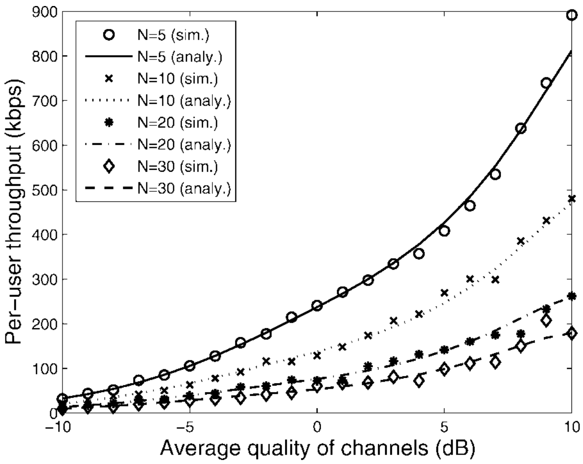

Fig. 9. Achievable per-user rate *versus* the average quality of wireless channels for a saturated case (the second model).

Table IV. Achievable per-user rate for a saturated case (eight users with different average quality of channel; the second model).

SINR(dB)	$\bar{R}$ (kbps), sim.	$\bar{R}$ (kbps), analy.
8	878	866
8	866	866
6	365	362
6	374	362
4	121	123
2	28	32
0	63	63
−4	0	0

in Table IV. This specifies a case that cannot be solved by Equation (18). Again, the results demonstrate a good match between the simulations and the analytical model.

4.2. Unsaturated Case

For the unsaturated case, we perform similar simulations to verify the accuracy of the extended model in Equations (22)–(24). On–off traffic sources, as shown in Figure 10, are used to generate the incoming traffic streams [19,20]. In the on-state, the source generates S bits/s, while in off-state, no data are generated. The parameter u represents the rate of transition from off-state to on-state; the transition rate from on-state to off-state is denoted by v. For the simulations, the activity factor of the incoming traffic streams are assumed to be 10%, i.e., $u/(u+v) = 0.1$. The data rate in on-state, S, is 500 kbps. In other words, the average arrival rate is roughly 50 kbps.

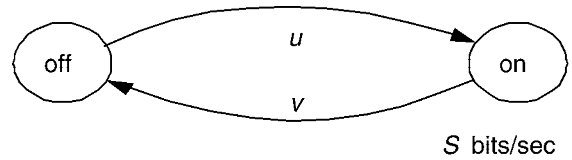

Fig. 10. On–off traffic source model.

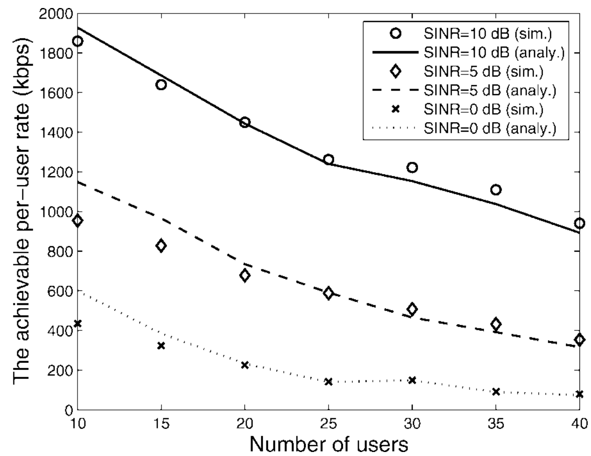

Fig. 11. Achievable per-user rate *versus* the number of users for an unsaturated case.

Figures 11 and 12 show the results similar to Figures 6 and 7 in an unsaturated case. However, the results of analytical models for an unsaturated case do not appear as smooth as the saturated case. This is due to the impact of measured parameter, p, the probability that a user is in idle state with no data for transmission. At each simulation stage, we have used the previously

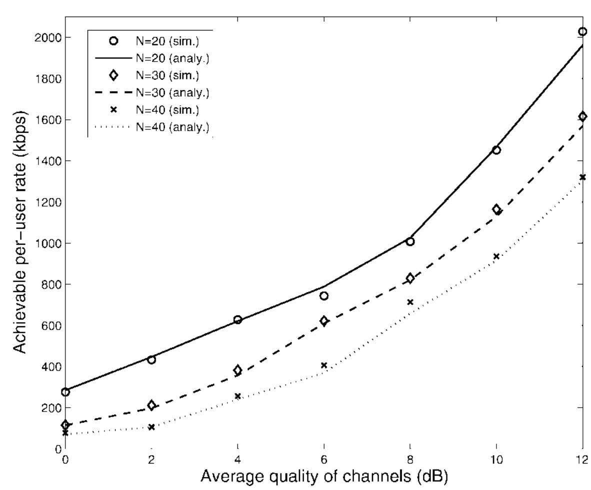

Fig. 12. Achievable per-user rate *versus* the average quality of wireless channels for an unsaturated case.

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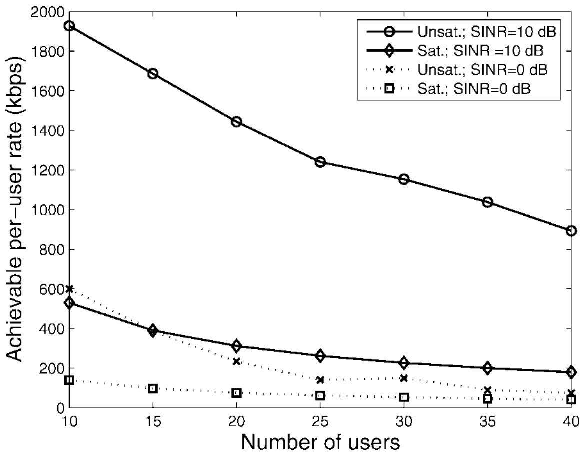

Fig. 13. Comparison of the achievable per-user rates for the saturated and unsaturated cases.

measured value of p for less number of users. It is also noteworthy to compare the achievable per-user rate for the saturated and unsaturated cases. The comparison results are shown in Figure 13, which demonstrate the inherent multiplexing gain in a system for many users with bursty traffic streams.

5. Conclusions

In this paper, we have proposed an admission scheme for a single base station that implements an opportunistic scheduler for dynamic resource allocation. The proposed scheme provides a reasonable analytical tool for the base station to utilize the inherent multiuser diversity gain of the opportunistic scheduler in order to admit as many users as possible while provisioning their QoS requirements in terms of minimum long-term average data rate. The proposed scheme is a direct application of the core analytical model for the achievable per-user rate of an opportunistic scheduler in an unsaturated scenario, where transmission buffer of some users may be empty for a certain period of time.

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