Hindawi Publishing Corporation
EURASIP Journal on Wireless Communications and Networking
Volume 2008, Article ID 521834, 9 pages
doi:10.1155/2008/521834

Research Article

Broadcast Reserved Opportunity Assisted Diversity Relaying Scheme and Its Performance Evaluation

Xia Chen,[1] Honglin Hu,[1] Shengyao Jin,[1] and Hsiao-Hwa Chen[2]

[1] *Shanghai Research Center for Wireless Communications (SHRCWC), Shanghai 200050, China*
[2] *Department of Engineering Science, National Cheng Kung University, 1 University Road, Tainan City 701, Taiwan*

Correspondence should be addressed to Hsiao-Hwa Chen, hshwchen@ieee.org

Received 29 December 2007; Accepted 2 March 2008

Recommended by Jong Hyuk Park

Relay-based transmission can over the benefits in terms of coverage extension as well as throughput improvement if compared to conventional direct transmission. In a relay enhanced cellular (REC) network, where multiple mobile terminals act as relaying nodes (RNs), multiuser diversity gain can be exploited. We propose an efficient relaying scheme, referred to as Broadcast Reserved Opportunity Assisted Diversity (BROAD) for the REC networks. Unlike the conventional Induced Multiuser Diversity Relaying (IMDR) scheme, our scheme acquires channel quality information (CQI) in which the destined node (DN) sends pilots on a reserved radio resource. The BROAD scheme can significantly decrease the signaling overhead among the mobile RNs while achieving the same multiuser diversity as the conventional IMDR scheme. In addition, an alternative version of the BROAD scheme, named as A-BROAD scheme, is proposed also, in which the candidate RN(s) feed back partial or full CQI to the base station (BS) for further scheduling purpose. The A-BROAD scheme achieves a higher throughput than the BROAD scheme at the cost of extra signalling overhead. The theoretical analysis given in this paper demonstrates the feasibility of the schemes in terms of their multiuser diversity gains in a REC network.

1. INTRODUCTION

Recently, multihop relaying transmission has attracted considerable attention due to its potential to enhance coverage and capacity as well as its flexibility if compared with single-hop transmission. The primary advantage of the multihop relaying comes from the reduction in the overall path loss between a base station (BS) and a destined node (DN). Another benefit of the multihop relaying is its path diversity gain achieved by selecting the most favorable multihop path in the shadowed environment. This diversity gain will increase as the number of potential relaying nodes (RNs) increases, and as the possibility of finding an RN with a lower path loss increases as well. The approach of augmenting cellular communication coverage with multihop relaying, which is referred to as relay enhanced cellular (REC) network, has been considered in many B3G/4G standardization-related researches [1–3].

In an REC network, where multiple mobile terminals act as RNs, the multiuser diversity gain can be exploited. The multiuser diversity was first introduced by Knopp and Humblet [4], then extended by the works done by Tse [5, 6], as a means to provide diversity against channel fading in multiuser packet-switched wireless networks. The multiuser diversity works based on the fact that, in a wireless cellular network with multiple users whose channels vary independently, it is likely that there is a user with a "very good" channel at a given time. Assume that we allow some degree of flexibility to delay transmissions until a user's channel condition is improved. The gain can be achieved by allocating the majority of system resources to a good user at that given time. This approach has been adopted for the downlink design of CDMA2000 and WCDMA systems, that is, 1xEV-DO [7] and high-speed downlink packet access (HSDPA) [8]. Nevertheless, the aspects related to the fairness among the users also have to be considered. To address the fairness issue, some proper scheduling methods should be adopted, for example, proportional fair (PF) scheduling [9].

The multiuser diversity gain can only be exploited once in a single-hop network. However, in a multihop cellular network, there is an opportunity to exploit multiuser diversity in each hop. To achieve the multiuser diversity in a multihop network, a relaying method was proposed in [10], where the multiuser diversity is exploited in each hop by selecting the next RN based on the instantaneous channel quality. However, selecting only one RN reduces the opportunity of capturing a good channel in the next hop. Hence, [11] suggested that a BS should coordinate the cooperative relaying method, namely, induced multiuser diversity relaying (IMDR). The scheme works based on the assumption that there likely exist a certain number of mobile RNs in a cellular network. The IMDR uses the broadcast feature of the wireless channel to induce the multiuser diversity through a two-phase process. However, in this scheme, in order to get the knowledge of channel quality information (CQI), it needs complicated interaction protocol among potential RNs as well as the DN. Moreover, it might result in unnecessary data broadcasting, thus wasting power and causing interference.

In this paper, we propose a more efficient relaying scheme, called broadcast reserved opportunity assisted diversity (BROAD) scheme. In this scheme, the BS first broadcasts to all possible RNs and DN such that a resource opportunity is reserved for the DN. Next, the DN which needs relaying broadcasts its pilots on the reserved resource opportunity, and all the volunteer RNs probe the channels between the DN and themselves on the reserved opportunity. Then, the BS broadcasts data packets. The volunteer RNs with good channels from the BS and to the DN receive the data, and the RNs without good links remain silent to save energy. Finally, these RNs with good channels forward the data to the DN. The multiuser diversity could be retained with much less cost than that needed in the IMDR scheme. In addition, based on the proposed BROAD scheme, an alternative version named as A-BROAD scheme is also suggested, in which the candidate RNs can feed back the full or partial CQI to the BS for further scheduling purpose. Therefore, the BS can make efficient scheduling to achieve much better throughput performance. In addition, the BS can avoid useless feedback/broadcasting because the BS only broadcasts data packets to the most capable RN(s).

The rest of the paper is organized as follows. Section 2 gives a brief description of the system model. In Section 3, for comparison purpose, the conventional IMDR scheme is introduced and our BROAD scheme is proposed. The system performance is analyzed and the feasibility of achieving multiuser diversity is discussed in Section 4. In Section 5, we give the simulation results and make overhead comparison of the IMDR scheme and our BROAD scheme. Finally, we conclude the paper in Section 6.

2. SYSTEM MODEL

We consider an REC network with a circular cell whose radius is D. The BS is located at the center of the cell, with a maximum transmit power level of P_T. The BS transmits a signaling channel that can be received by all user nodes in the coverage area. In our modeling, there are a total of U mobile users, distributed uniformly in the coverage area. Here we suppose that all the mobile users could act as RNs. The probability density function (pdf) of the user's distance d from the BS is given by

$$\Pr(d) = \frac{2d}{D^2}, \quad 0 \le d \le D. \tag{1}$$

Each packet has a large delay tolerance and includes the identity (e.g., physical address) of the DN. All the nodes in the network are assumed to be equipped with single-element antenna, and the transmissions between all the nodes are constrained to a TDD mode; that is, any node cannot transmit and receive simultaneously. Let r and t denote the received and the transmitted signals, respectively, and let n denote the additive white Gaussian noise (AWGN) with zero mean and variance of N_0. We have the received signal as

$$r = \sqrt{P_T}\, ht + n, \tag{2}$$

where h can be the channel between either the BS (acting as source) and the DN, the BS and the potential RN, or the potential RN and the DN. h is modeled by taking into account three effects [12]: the shadowing effects s, the attenuation due to the distance d, and the small-scale random fading effect z as

$$h = \sqrt{K \frac{1}{d^{\lambda}}}\, z\sqrt{s}, \tag{3}$$

where λ is the path loss exponent, ranging from two (free space) to four, and K is a constant depending on the antenna design. The shadowing component is assumed to have a log-normal distribution whose pdf can be described as [12]

$$f_s(x) = \frac{1}{x\delta_s\sqrt{2\pi}}\, e^{-(\ln x-\mu_s)^2/2\delta_s^2}, \tag{4}$$

with μ_s and σ_s being the mean and standard deviation of $\ln x$. Without loss of generality, we assume $\mu_s = 0$, meaning that the median of s is one. For the small-scale fading, we assume a non-line-of-sight (NLOS) scenario and z is a zero-mean unit-variance complex Gaussian random variable.

3. INDUCED MULTIUSER DIVERSITY PROTOCOLS

In this section, we first give a brief review of how the conventional IMDR scheme works, and then introduce our proposed BROAD scheme. These two schemes can both induce the multiuser diversity in a multihop cellular network, but operate in quite different patterns.

3.1. Conventional IMDR scheme

The conventional IMDR scheme is shown in Figure 1. It is based on the assumption that there exists a large amount of mobile RNs in a cellular network. The IMDR uses the broadcast feature of wireless channel to induce multiuser diversity. First, the data packets are broadcasted by the BS with its maximum bit rate. Some users in the cell coverage area are likely to receive the data packets. These users, acting as RNs, wait till the occurrence of a "good channel" to

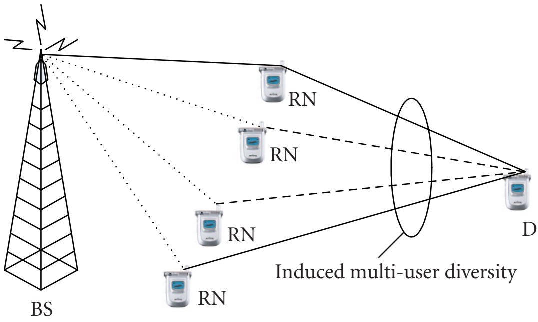


Figure 1: Conventional IMDR scheme.

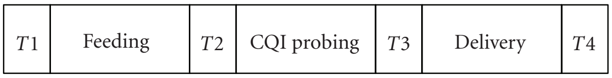
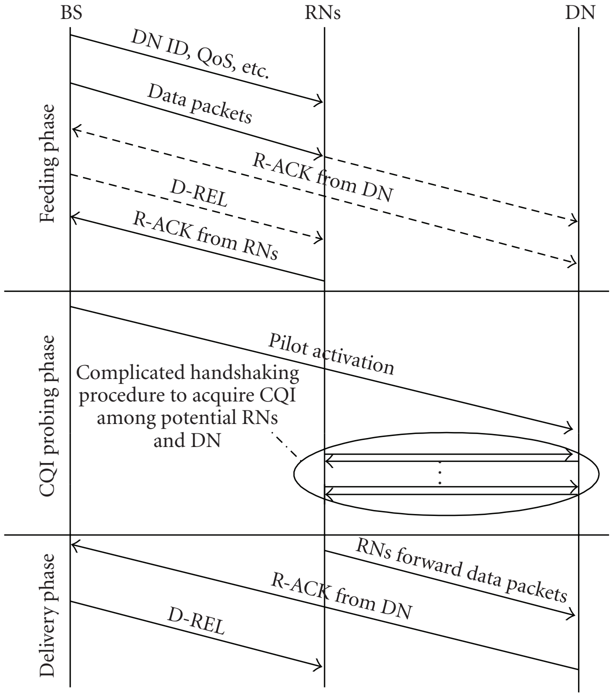


Figure 2: Detailed time-span of the IMDR scheme.



- - -: Denoting the signal procedure if the DN can receive data packets in the feeding phase

Figure 3: Conventional IMDR protocol illustration.

transmit the data packets to the DN with high bit rate. Transmitting to multiple RNs induces multiuser diversity into the system; thus this scheme is named as IMDR [2].

Note that it is unavoidable for each potential RN to get the CQI between the DN and itself, so as to judge whether it can deliver the data to the DN with a particular bit rate or not. Therefore, the phase to probe the CQI cannot be ignored. In order to explain the conventional IMDR scheme more clearly, we illustrate its detailed time-span in Figure 2, where the whole process is divided into three main phases, that is, the feeding phase, the CQI probing phase, and the delivery phase [3]. In Figure 2, all the T spans indicate the signaling duration. The signaling procedure of the conventional IMDR protocol is shown in Figure 3. Next, we describe the protocol in detail.

Step 1. As shown in Figure 3, during the $T1$, the BS broadcasts the DN information, including the DN ID, QoS requirement, and so forth.

Step 2. In the feeding phase, the BS broadcasts the data for the DN to all the potential RNs with the maximum bit rate $R_{\max}$ at maximum transmit power. Any user nodes which receive the data packets in the feeding phase act as the RNs in the delivery phase.

Step 3. During the $T2$, if the DN successfully receives the data, it will send back an R-ACK to the BS. Then, the BS will broadcast a D-REL to all the RNs, and all the RNs release this relay process.

Step 4. If there is no R-ACK signaling from the DN, in the CQI probing phase, the BS is kept inactive. Each RN continuously tracks the quality of the wireless link to the neighboring users as well as their identity. In this stage, all the RNs as well as the DN will broadcast pilots so as to acquire CQI, and hand-shaking protocols are needed between them. Note that more complex protocols are required if some potential cooperative transmission techniques are adopted. In addition, the RNs need to find out the DN and measure the channel to the DN.

Step 5. During the $T3$, the hand-shaking is successfully built among the RNs to the DN.

Step 6. In the delivery phase, the BS is kept inactive and only the transmissions from the RNs to the DN are allowed. If an RN is able to achieve a transmission bit rate, greater than or equal to a threshold R_0 which is a system parameter and will be discussed later in Section 4, over the channel to the DN, then the RN transmits the data packets to the DN. The medium access control can be either a contention-based method or a BS coordinated non-contention-based method.

Step 7. During the $T4$, upon successful reception, the DN sends an R-ACK signal to the BS. Consequently, the BS broadcasts a data release (D-REL) signal, and other RNs release that data packet. If the BS does not receive R-ACK corresponding to a data packet in a predefined time interval, that data packet is considered lost and a D-REL signal is broadcasted by the BS. That data packet may be considered for retransmission later.

3.2. Proposed BROAD scheme

In the conventional IMDR scheme, in order to acquire the CQI, complicated handshaking signaling interaction would certainly incur among the potential RNs and the DN during the CQI probing phase. As can be seen from

Figure 3, after receiving the pilot activation signal from the BS, all the potential RNs will send their pilots through certain contention-based or centralized mechanism. The CQI probing procedure continued until each RN successfully built its connection to the DN and obtained the CQI to the DN.

However, in the proposed BROAD scheme, the DN is informed by the BS to transmit its pilots on a reserved resource opportunity in advance. Thus, the BROAD scheme can avoid the complex signaling interaction during the CQI probing phase. The time-span of the proposed BROAD scheme is illustrated in Figure 4. We can see from Figure 4 that the CQI probing in the BROAD scheme is proceeded in advance compared to that in the IMDR scheme. Figure 5 illustrates the detailed protocol. Next, we will describe the protocol step by step.

Step 1. as shown in Figure 5, during the $T1$, the BS broadcasts the DN information, including the DN ID, QoS requirement, and so on. In addition, the BS broadcasts that the DN will broadcast its pilots on some reserved opportunities, that is, resource blocks. Here, it is assumed that the downlink-broadcasted control signaling could normally reach the DN, but not vice versa.

Step 2. in the CQI probing phase, the DN broadcasts its pilots on the reserved opportunity and the RNs probe their channels to the DN. Note that in this stage, the BS does not need to be absolutely inactive as in the conventional IMDR, but only needs to be inactive on the reserved resource opportunity assigned to the DN. Moreover, this stage does not need the complex hand-shaking protocols between the RNs and the DN, as those in the IMDR scheme.

Step 3. during the $T2$, if the BS receives the pilots from the DN during the CQI probing phase and finds that the data could be directly sent to the DN now, rather than by relaying, then the BS will broadcast a D-REL to all the RNs, and all the RNs release this relay process.

$T1$	CQI probing	$T2$	Feeding	$T3$	Delivery	$T4$

FIGURE 4: Detailed time-span of the BROAD scheme.

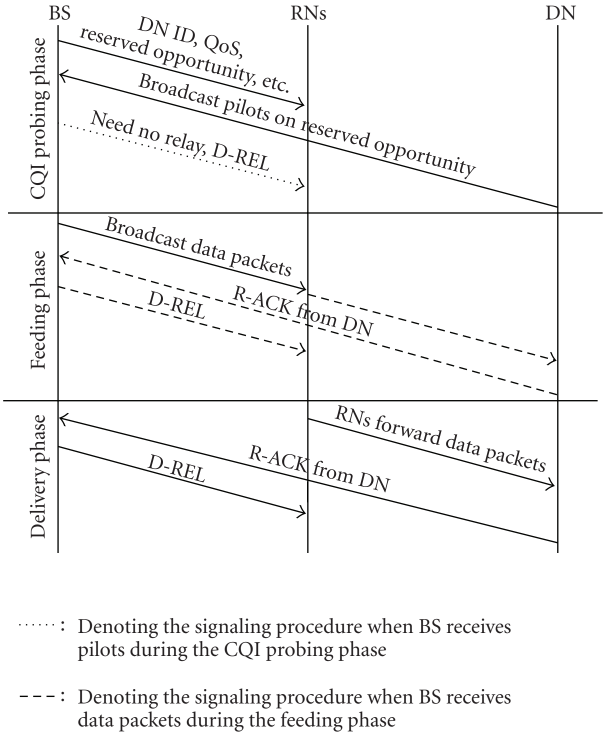


FIGURE 5: Illustration of the proposed BROAD protocol.

Step 4. if the BS notices that the DN still needs the relaying, in the feeding phase, the BS broadcasts the data for the DN to all the RNs with the maximum bit rate and maximum transmit power. Note here that since the RNs all know the channel information to the DN, those RNs which could not offer the relaying could be inactive for this specific relaying process. These capable RNs receive the data from the BS. Here, we should note an alternative procedure for our proposed BROAD scheme, namely, alternative BROAD (A-BROAD). That is, during the $T2$ (Step 3), if an RN finds that it is suitable to act as an RN for the DN (by evaluating the channel between the BS and the DN), it could report the channel information to the BS for more sophisticated scheduling. Those RNs which find their channel worse than a threshold keep silent. Then, in the following feeding phase (Step 5), the BS could send the data to the selected RNs by the dedicated channels, rather than through the broadcasting channel. Note that the broadcasting channel normally could not support a huge amount of dedicated data for a specific user. Moreover, the BS thus could easily manage advanced cooperative relaying schemes among the selected RNs. The A-BROAD scheme is especially useful for the scenario where there does not exist a large amount of RNs near the DN, or, namely, fixed relay station scenario. Note in this case that the IMDR scheme is not efficient and even could not work, because it might happen that none of the RNs could act as the RN for the DN. Comparably, in the enhanced A-BROAD scheme, since the BS could receive the feedback from those candidate RNs, the BS could easily decide whether it needs to broadcast the data to the DN or not; in other words, useless feeding/broadcasting could be avoided.

Step 5. during the $T3$, if the DN successfully received the data, it will send back an R-ACK to the BS. Then, the BS will broadcast a D-REL to all the RNs, and all the RNs release this relay process. (Here if the RNs could hear the R-ACK from the DN, they could release the relaying process directly. Hence the relay process can be terminated, and Steps 6 and 7 can be saved.) Otherwise, hand-shakings between the RNs and the DN should be built.

Step 6. this step is the same as Step 6 in the IMDR scheme.

Step 7. this step is the same as Step 7 in the IMDR scheme. However, if the RNs could hear the R-ACK from the DN, all the RNs could release the relaying process directly.

From the above description of conventional IMDR and our proposed BROAD schemes, we can see clearly that our scheme has the following advantages.

(1) Our scheme can greatly simplify the procedure of CQI probing compared with conventional IMDR scheme, thus saving a lot of overhead as well as reducing the delay.

(2) In the feeding phase, since all the RNs have already known whether they could offer help as an RN or not, only those which could act as an RN will buffer or decode the received data. The other RNs could ignore the broadcasting, thus reducing the overhead.

(3) In the CQI probing phase, the BS does not need to be inactive on all the radio resources. For example, when OFDMA is applied, the BS only needs to avoid using the dedicated subcarriers assigned to the DN for CQI probing. Note that in the IMDR scheme, since all the users need to broadcast on at least part of the subcarriers if they use FDM mode, they have to occupy the full band. Otherwise, TDM mode should be used and delay will be involved.

(4) The BS has two chances to send the D-REL to the RNs during the whole process, that is, in Steps 3 and 5. Comparably, it is not possible to send the D-REL during Step 5 in the IMDR scheme.

4. SYSTEM PERFORMANCE ANALYSIS

As for (1), the expression of the SNR is straightforward. The SNR at the receiver can be expressed as

$$\gamma = \frac{|h|^2 P_T}{\delta_n^2} = |h|^2 \frac{\eta D^\lambda}{K}, \tag{5}$$

where, for a particular user location, the parameters s and d in (3) are fixed, and η is the median of SNR when the mobile is at the maximum d (i.e., D, the apex of the hexagonal cell), defined as

$$\eta = \frac{K P_T}{\sigma_n^2 D^\lambda}. \tag{6}$$

Thus, h is equal to a scalar multiplied by z which takes a unit-variance Rayleigh distribution. Therefore, h is a complex Gaussian random variable. Its squared magnitude is exponentially distributed and the pdf of γ is

$$f(\gamma) = \frac{1}{\overline{\gamma} e^{-\gamma/\overline{\gamma}}}, \quad \gamma \geq 0, \tag{7}$$

where $\overline{\gamma}$ is easily derived as

$$\begin{aligned}\overline{\gamma} &= \frac{\eta D^\lambda}{K} E\left[|h|^2\right] \\ &= \frac{\eta D^\lambda}{K} K d^{-\lambda} s E\left[|z|^2\right] = \eta \left(\frac{D}{d}\right)^\lambda s.\end{aligned} \tag{8}$$

Hence, the short-term averaged throughput can be obtained from

$$\overline{Y} = \log_2(1+\overline{\gamma}) = \frac{1}{\ln 2} \ln(1+\overline{\gamma}). \tag{9}$$

Then, we derive the cumulative distributive function (cdf) of $\overline{Y}$ over log-normal shadow fading s, conditioned on d. It is obvious that the $\overline{Y}$ is a monotonic function of $\overline{\gamma}$. Assuming that the variables y and γ_0 are related by $y = (1/\ln)2 \ln(1+\gamma_0)$, as in (9), we have

$$\Pr(\overline{Y} \leq y \mid d) = \Pr(\overline{\gamma} \leq \gamma_0 \mid d). \tag{10}$$

As we noted that $\overline{\gamma}$ is a monotonic function of s, and s is a log-normal random variable, after some mathematical manipulation as in [13], the cdf of $\overline{Y}$ conditioned on d can be well approximated by a Gaussian cdf of the form

$$\Pr(\overline{Y} \leq y \mid d) = 1 - \frac{1}{2} erfc\left(\frac{y - m_y}{\sqrt{2\delta_y}}\right), \tag{11}$$

where m_y and δ_y can be expressed as

$$\begin{aligned} m_y(d) &= -\frac{1}{\ln(2)} \ln\left(\frac{d^\lambda}{\eta D^\lambda}\right), \\ \delta_y &= \frac{\delta_s \ln(10)}{10 \ln(2)}. \end{aligned} \tag{12}$$

It is observed that given system and propagation parameters, the mean of the distribution is a simple function of d. We also see that the standard deviation is related linearly to δ_s.

As an example, in order to illustrate the influence of user location on the spectral efficiency, we plot the cdf of short-term averaged throughput when $d/D = 0.05$, 0.10, 0.95, respectively, as shown in Figure 6. From the figure, it is noted that for users at different locations, their spectral efficiency can differ quite a lot. Given an outage probability requirement, the users which are located near the BS can receive with several times higher bit rate than those located far from the BS. Hence, for such a scenario with enough high user density, it is reasonable to assume that in each time instant there exists at least one user which can receive the transmitted data packets with a bit rate of $R_{\max}$ in the feeding phase, as claimed in the conventional IMDR scheme or our proposed BROAD scheme.

As proved in [11], because of the induced multiuser diversity, the IMDR or our proposed BROAD as well as A-BROAD scheme can improve the system throughput compared to the single-hop transmission if

$$\frac{1}{R_0} < \xi\left(\frac{1}{R_{\mathrm{av}}} - \frac{1}{R_{\max}}\right), \tag{13}$$

where R_{av} is the average BS transmission rate for single-hop transmission with the proportional fairness (PF) scheduling, and ξ is defined as the medium access control gain, which shows the average portion of the radio resource (e.g., transmission time) that can be allocated to the competitors for

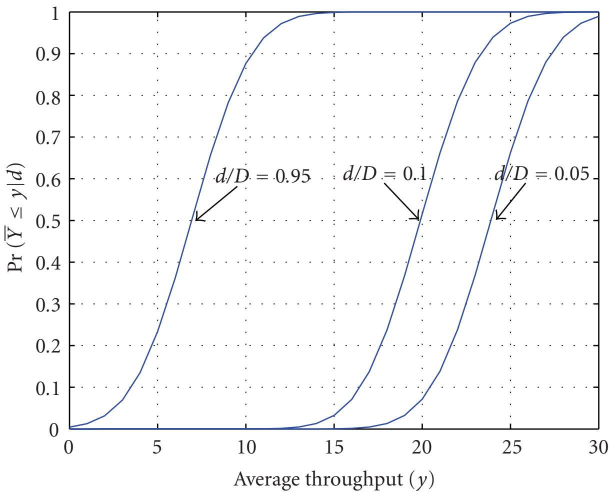


Figure 6: Comparison of the cdf of short-term averaged throughput across users, at preselected distances such that $d/D = (0.05, 0.10, 0.95)$.

a shared medium. For the non-contention-based medium access control mechanisms, $\xi = 1$. The detailed proof can be found in [11].

It is noted from Figure 6 that the outage probability mainly depends on the location of the users from the BS. The nearer the user is located from the BS, the smaller the outage probability will be at a certain bit rate. Like the conventional IMDR scheme, the proposed BROAD scheme also assumes that there exits at least one potential RN which can receive with a bit rate of $R_{\max}$. The selection of $R_{\max}$ is quite subtle. On one hand, if $R_{\max}$ is very large, then only a few users in the coverage area can receive the data packets in the feeding phase; on the other hand, decreasing $R_{\max}$ will increase the number of potential RNs but will also reduce the overall throughput. The transmission rate $R_{\max}$ may also be adjusted based on the number of potential RNs; if the data packets are not received by a reasonable number of mobile users, the $R_{\max}$ should be decreased.

Next, we will analyze the probability of existing M potential RNs which can receive with $R_{\max}$ error-free (e.g., quite low outage probability). Since the outage probability has a strong connection with the location of users, we assume that the potential RNs which can receive with $R_{\max}$ during the feeding phase are located within a certain radius (e.g., $d/D = 0.10$) from the BS. Meanwhile, during the delivery phase where the data packets should eventually be delivered to the DN, the RNs should be located in the intersection area of the two circles which center at the BS and the DN, respectively. In other words, the shaded area in Figure 7 is regarded as the *effective area* for the potential RNs. Finding the probability of existing M potential RNs which can receive with $R_{\max}$ is equivalent to computing the probability of existing M users within the intersection area. The area, denoted by $\rho(d_{\mathrm{SD}}, d_{R_{\max}})$, can be divided into two parts: ρ_1, the lighter shaded area which is the sector $\langle \mathrm{ASB} \rangle$ from the circle S, and ρ_2, the darker shaded area which is the addition of the two small areas in circle D enclosed by the arcs $\widehat{\mathrm{AS}}$ and $\widehat{\mathrm{SB}}$. The area of the sector $\langle \mathrm{ASB} \rangle$ is given by

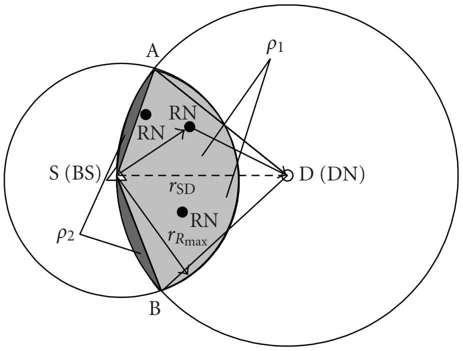


Figure 7: Illustration of areas where RN is capable of receiving with $R_{\max}$.

$$\rho_1 = \phi d_{R_{\max}}^2, \tag{14}$$

where ϕ is the angle $\angle \mathrm{DSB}$. From the isosceles triangle $\Delta \mathrm{DSB}$, it is straightforward to see that this angle is given by $\phi = \arccos(d_{R_{\max}}/2d_{\mathrm{SD}})$. The second part ρ_2 from the circle D can be calculated as the total sector area $\langle \mathrm{DSA} \rangle$ minus the triangular area $\Delta \mathrm{DSA}$. Hence, the area ρ_2 can be given as

$$\rho_2 = 2\left[\left(\frac{\pi}{2} - \phi\right) d_{\mathrm{SD}}^2 - \frac{d_{R_{\max}}}{2}\sqrt{d_{\mathrm{SD}}^2 - \frac{d_{R_{\max}}^2}{4}}\right]. \tag{15}$$

Adding the two parts together, we get the total area expressed as

$$\begin{aligned} \rho(d_{\mathrm{SD}}, d_{R\max}) &= \rho_1 + \rho_2 \\ &= d_{R_{\max}}^2 \arccos\left(\frac{d_{R_{\max}}}{2d_{\mathrm{SD}}}\right) + \pi d_{\mathrm{SD}}^2 \\ &\quad - 2d_{\mathrm{SD}}^2 \arccos\left(\frac{d_{R_{\max}}}{2d_{\mathrm{SD}}}\right) - d_{R_{\max}}\sqrt{d_{\mathrm{SD}}^2 - \frac{d_{R_{\max}}^2}{4}}. \end{aligned} \tag{16}$$

Since we have U users uniformly distributed in a circular area of radius of D, the probability of finding M $(M \le U)$ users in the area $\rho(d_{\mathrm{SD}}, d_{R_{\max}})$ is given by

$$\Pr\left(d_m \le d_{R_{\max}}\right) = \left(\frac{\rho(d_{\mathrm{SD}}, d_{R_{\max}})}{\pi D^2}\right)^M. \tag{17}$$

It is observed from (17) that for a given M, the probability is related to $d_{R_{\max}}$ and d_{SD}, that is, the distance from the BS to the DN. In order to guarantee a high probability of existing M users receiving with $R_{\max}$, the parameter $R_{\max}$ should be selected discreetly. As for the number of RNs among the M potential relays, which have the ability to forward the data packet to DN, it is related to several aspects, for example, the parameter R_0, the user mobility, as well as $\tau_{\max}$, which is defined as a maximal tolerant delay of the data packets. Hence, it is quite difficult to obtain a probability distribution function of how many

Table 1: Simulation parameters.

Cell radius	1000 m
Carrier frequency	2 GHz
FFT size	512
Bandwidth	5 MHz
Standard deviation of log-normal fading	8 dB
Propagation loss exponent	4
Time slot length	0.5 ms
Channel model	TU
Mobility	[30 90 150 210] km/h

Table 2: Number of dropped packets versus mobility for $\tau_{\max} =$ 50 milliseconds.

	Mobility of users			
	30 km/h	90 km/h	150 km/h	210 km/h
Number of dropped packets	352	298	217	143

Table 3: Number of dropped packets versus $\tau_{\max}$ for velocity = 90 km/h.

	$\tau_{\max}$			
	25 ms	50 ms	75 ms	100 ms
Number of dropped packets	418	367	312	257

RNs among the M potential RNs will have the ability to forward the data packets with a bit rate greater than R_0. It is assumed that within the interval $\tau_{\max} \to \infty$, the data packets transmitted to the RNs will be delivered to the DN eventually. That is, if $\tau_{\max} \to \infty$, a packet can be kept waiting in a potential RN until the occurrence of a very high rate channel to the DN. For a moderate value of $\tau_{\max}$, the mobility is very important. The higher the user's mobility is, the higher the probability of a high bit rate channel in the second hop will be. For a given mobility profile, a larger value of $\tau_{\max}$ results in a more efficient exploitation of the mobility.

5. SIMULATION RESULTS AND OVERHEAD COMPARISON

In this section, the simulation results are presented. In addition, the overheads of our proposed BROAD scheme and the conventional IMDR scheme are compared in detail.

5.1. Simulation results

We simulate a single-cell OFDMA-based system with a total of U active users uniformly distributed in the coverage area. In this simulation, the scheduling is initiated once there is a new data packet waiting to be transmitted. The detailed simulation parameters are presented in Table 1 and the scenario is based on the report of the WINNER project [14]. To show the effect of the multiuser diversity, we consider two other systems as benchmarks: one is round-robin scheduling scheme, that is, the BS transmits packets to the users in a round-robin fashion; the other is the so-called opportunistic scheduling scheme. To guarantee the fairness among the users, the opportunistic scheduling is combined with the proportional fairness (PF) criterion [9], and is referred to as the O-PF scheme in this paper.

As described in Section 3, the proposed BROAD scheme can induce the same multiuser diversity as the conventional IMDR scheme but at lower overheads. Hence, there is no difference between the two schemes in terms of the system throughput, which is defined as the data rate used to transmit data packets in this paper. Therefore, we only need to evaluate the performance of the proposed BROAD scheme.

In this simulation, the R_{av} is the average transmission bit rate of the O-PF scheme by the BS. In addition, it should be mentioned that $\tau_{\max} = 10$ milliseconds, and each user assumed a mobility of 30 km/h. If within the interval $\tau_{\max}$ there is no occurrence of such channel through which the potential RN is able to transmit the data packets with a bit rate greater than or equal to the system parameter R_0, then the data packets are considered lost.

Figure 8 illustrates the system throughput achieved by the O-PF, the BROAD, and the A-BROAD schemes versus the number of users in the coverage area. It should be mentioned that these throughput curves are actually normalized by the average achieved throughput of the round-robin scheme. From Figure 8, we can obviously observe that the BROAD scheme can achieve much better performance than the O-PF scheme. The gain indicates that our BROAD scheme can exploit the multiuser diversity efficiently. As expected, this throughput gain increases as the number of users increases. It is also observed that the A-BROAD scheme achieves the highest throughput, because for the proposed A-BROAD scheme, the BS can make sophisticated scheduling based on the CQI between the BS and potential RNs as well as the CQI between the potential RNs and the DN, which are fed back to the BS by the potential RNs.

We also simulate the number of dropped packets versus the mobility of users given a certain $\tau_{\max}$, which is shown in Table 2. In the simulation, the total number of users in a cell is $U = 80$, and the simulation runs for 5000 times. From Table 2, it is shown that as the mobility increases, the number of dropped packets decreases accordingly. In addition, given a certain mobility of users, we simulate the number of dropped packets versus $\tau_{\max}$, which is shown in Table 3. Apparently, the larger the value $\tau_{\max}$ is, the less the number of dropped packets will be. Obviously, both Tables 2 and 3 validate our above theoretical analysis.

5.2. Overhead comparison

Now we compare the overhead of our BROAD scheme with that of the conventional IMDR scheme. For the sake of simplicity, we make some general assumptions as follows:

(i) for OFDMA-based system with N subcarriers, divided into n sub bands, each subcarrier could transmit two bits;

(ii) M RNs in the area could receive the data packets from the BS, but only M RNs are capable of forwarding the data packets to the DN;

Table 4: Overhead comparisons between BROAD and IMDR.

Comparison items	IMDR	BROAD
1. In the CQI probing phase, if complex handshaking protocols are needed or not?	Needed (if M RNs probe, it will cost $2M \times N/n$ bits)*	Not needed, but at the cost of broadcasting $\log_2(n)$ extra bits to indicate the reserved sub-band
2. In the feeding phase, how many RNs receive the data packets from the BS?	All the M RNs	Only those capable m RNs (other $M-m$ RNs could be ignored, thus saving power)
3. Resource using efficiency in the CQI probing phase	Inefficient (BS needs to be inactive on all the n sub-bands reserved for the RNs)	More efficient (only 1 sub-band is reserved for probing; other n-1 sub-bands could be used)
4. In which step the relay process can be terminated?	Only in Step 3	Both Steps 3 and 5

*More time slots (bits) are needed if we take handshaking protocols into account. Furthermore, power consumptions at the M RNs as well as the interference to corresponding neighbor cells should be considered.

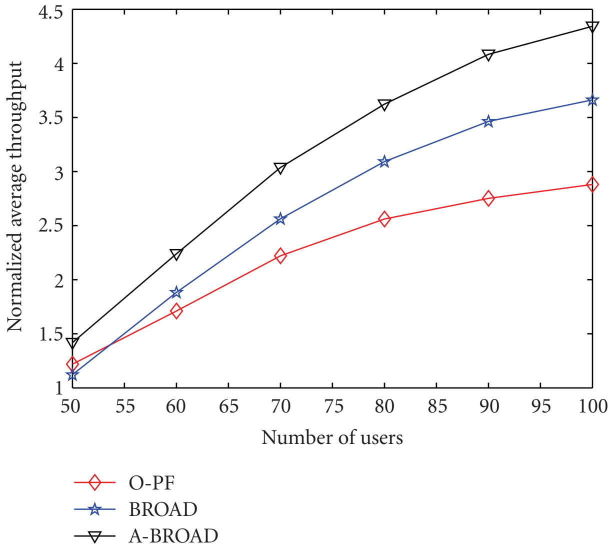


Figure 8: Normalized average achieved throughput versus the number of users.

(iii) each RN probes in one sub band in the IMDR scheme;

(iv) the BS reserves one sub band for the DN to broadcast in the BROAD scheme.

Then, in Table 4, we give a list of comparisons between our BROAD scheme and the conventional IMDR scheme. Following Table 4, we could see that if $N = 300$, $n = 25$, $M = 25$, and $m = 5$, then the BROAD scheme could save at least $2 \times 25 \times 300/25 - 5 = 595$ bits.

The main difference between the A-BROAD scheme and the BROAD scheme is that capable RNs will feed back the CQI to the BS during $T2$ (Step 3). Then the BS can perform sophisticated scheduling; meanwhile useless feeding/broadcasting can be avoided since the BS has the CQI between the RNs and itself or even the CQI between the RNs and the DN. In addition, in the A-BROAD scheme, only a small number of RNs (e.g., two), rather than all the M RNs, will forward the data packets to the DN. Thus the overhead is further reduced. The enhanced A-BROAD scheme is especially useful for the scenario where there does not exist a large amount of RNs near the DN. If we assume 3-bit CQI for each sub band, the additional overhead for the A-BROAD scheme is the m capable RNs which feed back CQI of $3 \times n = 75$ bits to the BS. Thus, the total overhead for the A-BROAD scheme is $75 + 5 = 80$ bits, which is still far less than that of the IMDR scheme (at least 600 bits).

6. CONCLUSIONS

If compared to the conventional IMDR scheme, a more efficient relaying scheme, that is, broadcast reserved opportunity assisted diversity (BROAD) scheme, is proposed in this paper. In this proposed scheme, the DN sends pilots on certain reserved resource which is broadcasted by the BS in advance. The BROAD scheme can achieve the same multiuser diversity as the IMDR scheme but with a considerable less overhead. Furthermore, an enhanced A-BROAD scheme is proposed to achieve even better performance if potential RNs feed back CQI to the BS such that sophisticated scheduling can be made. We give a theoretical analysis for the feasibility of exploiting the multiuser diversity in a multihop relay enhanced cellular network. Simulation results and overhead comparisons show that our proposed schemes outperform the conventional IMDR scheme significantly.

ACKNOWLEDGMENTS

The authors would like to gratefully acknowledge the research grants from the Natural Science Foundation of Shanghai (no. 07ZR14104) and the National Science Council of Taiwan (NSC96-2221-E-006-345 and NSC96-2221-E-006-346).

REFERENCES

[1] R. Pabst, B. H. Walke, D. C. Schultz, et al., “Relay-based deployment concepts for wireless and mobile broadband radio,” *IEEE Communications Magazine*, vol. 42, no. 9, pp. 80–89, 2004.

[2] "IST-2003-507581 WINNER D3.4 version 1.0," June 2005, https://www.ist-winner.org/DeliverableDocuments/D3.4.pdf.

[3] CJK B3G Working Group White Paper, "Investigation on Requirements and Enabling Technologies for the IMT-Advanced Air Interface," v0. 2 CCSA Draft, November 2006.

[4] R. Knopp and P. A. Humblet, "Information capacity and power control in single-cell multiuser communications," in *Proceedings of IEEE International Conference on Communications (ICC '95)*, vol. 1, pp. 331–335, Seattle, Wash, USA, June 1995.

[5] D. N. C. Tse, "Multiuser diversity in the wireless networks," 2000, Wireless Communication Seminar, Stanford University, Stanford, Calif, USA.

[6] P. Viswanath, D. N. C. Tse, and R. Laroia, "Opportunistic beamforming using dumb antennas," *IEEE Transactions on Information Theory*, vol. 48, no. 6, pp. 1277–1294, 2002.

[7] Qualcomm, "1xEV: 1x evolution IS856 TIA/EIA standard airlink overview," November 2001.

[8] H. Holma, *WCDMA for UMTS: Radio Access for Third Generation Mobile Communications*, John Wiley & Sons, New York, NY, USA, 3rd edition, 2004.

[9] P. Larsson and N. Johansson, "Multiuser diversity forwarding in multihop packet radio networks," in *Proceedings of IEEE Wireless Communications and Networking Conference (WCNC '05)*, vol. 4, pp. 2188–2194, New Orleans, La, USA, March 2005.

[10] T. Park, O.-S. Shin, and K. B. Lee, "Proportional fair scheduling for wireless communication with multiple transmit and receive antennas," in *Proceedings of the 58th IEEE Vehicular Technology Conference (VTC '03)*, pp. 1573–1577, Orlando, Fla, USA, October 2003.

[11] K. Navaie and H. Yanikomeroglu, "Induced cooperative multiuser diversity relaying for multihop cellular networks," in *Proceedings of the 63rd IEEE Vehicular Technology Conference (VTC '06)*, vol. 2, pp. 658–662, Melbourne, Australia, May 2006.

[12] T. S. Rappaport, *Wireless Communication: Principles and Practice*, Prentice Hall, Upper Saddle River, NJ, USA, 2nd edition, 2001.

[13] S. Catreux, P. F. Driessen, and L. J. Greenstein, "Data throughputs using multiple-input multiple-output (MIMO) techniques in a noise-limited cellular environment," *IEEE Transactions on Wireless Communications*, vol. 1, no. 2, pp. 226–235, 2002.

[14] M. Failli, *COST 207: Digital Land Mobile Radio Communications*, European Communities, Luxemburg, Germany, 1989.