

# Analysis of Reverse Link Capacity Enhancement for CDMA Cellular Systems Using Two-Hop Relaying

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**SUMMARY** A routing algorithm, utilizing two-hop relaying when necessary, is proposed to enhance the system capacity of code division multiple access (CDMA) cellular systems. Up to now, multihop relaying is applied to cellular systems mainly with the aim of decreasing the transmit power of each mobile station or extending the cell coverage area. Here, in this paper, potential benefit of multihop relaying is studied so as to increase the system capacity. A condition for the interference to be reduced by changing single-hop connections to two-hop connections is analyzed. In addition, a new route selection criterion maximizing the amount of interference reduction is proposed. Simulation results reveal that the proposed criterion is superior to the conventional criterion minimizing the total transmit power in respect of the amount of interference reduction. By using this criterion, an efficient routing algorithm for two-hop CDMA cellular systems is proposed to enhance the system capacity. Simulation results also indicate that by using the proposed routing algorithm in combination with a call admission control, the system capacity is increased even under heavy traffic conditions.

**key words:** *two-hop relaying, multihop cellular systems, CDMA cellular systems, capacity enhancement*

## 1. Introduction

In recent years, there has been lots of interest in applying a relaying function to conventional wireless cellular systems, in which all mobile stations (MS's) are directly connected to base stations (BS's), because of its various advantages. For example, the transmit power of an MS can be reduced or the coverage area in cellular systems can be enhanced with the same transmit power.

In addition to the power reduction, Toumpis et al. showed that the capacity of wireless networks might be enhanced using the relaying in combination with spatial frequency reuse [1]. With rapid advancement of the Internet and wireless access technologies, available frequency band suitable for wireless communications is getting more and more scarce. Therefore, increasing the system capacity is a big issue for the design of future wireless systems.

There are some works related to cellular systems with multihop relaying. For example, in [2], Aggélou et al. proposed to integrate relaying functions with GSM cellular systems. In [3], Wu et al. introduced stations dedicated to relaying for high bandwidth usage. In [4], opportunity driven multiple access (ODMA) is proposed to enhance the coverage by allowing MS's beyond the reach of the cell coverage

to reach the BS. Moreover in [5], [6], multihop CDMA cellular systems have been analyzed.

In most of these studies [2], [4]–[6], the main purpose of using multihop relaying for reverse link transmission is the coverage enhancement rather than the capacity improvement. As an example, the routing algorithms that choose the route with the minimum total path loss [4] or the minimum total transmit power [7] are adopted but the interference power at each BS is not taken into consideration. Therefore, these routing algorithms may decrease the radiated power. However, the interference power at BS's, which limits the user capacity, does not necessarily decrease.

In this paper, we pay attention to the reverse link (up-link) capacity enhancement in CDMA cellular systems as a result of interference reduction by introducing two-hop relaying. We propose an interference evaluation method using forward link (down-link) geometry [8]. We then analyze the condition for the interference of reverse link to be reduced by changing some single-hop connections to two-hop connections and propose to use the route with the maximum amount of interference reduction as a route selection criterion. By using this criterion, we also propose an effective routing algorithm for two-hop CDMA cellular systems with the aim of enhancing the system capacity.

The remainder of this paper is organized as follows: In Sect. 2, the condition for the interference to be reduced by introducing two-hop relaying is analyzed. In Sect. 3, the proposed two-hop relaying method is described. In Sect. 4, the performance of two-hop cellular systems is reported. Sect. 5 concludes the paper.

## 2. Analysis of Reverse Link Interference Reduction by Introducing Two-Hop Connections

In this section, we analyze the condition for the interference to be reduced by changing some single-hop connections to two-hop connections.

### 2.1 Underlying Assumptions

Figure 1 shows single-hop and two-hop CDMA cellular systems. All MS's are assumed to communicate with BS. In two-hop cellular systems, an MS and a BS can communicate with each other by using an intermediate MS as a repeater. An MS is assumed to be able to relay only one signal. An MS that acts like a radio repeater is called a relaying station (RS).

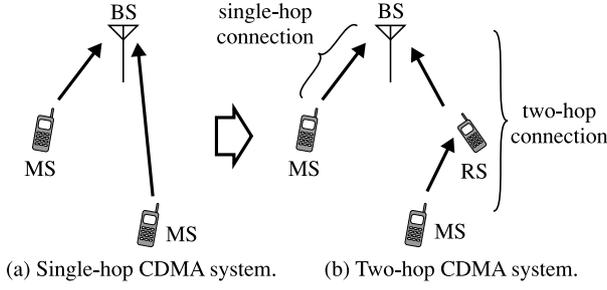
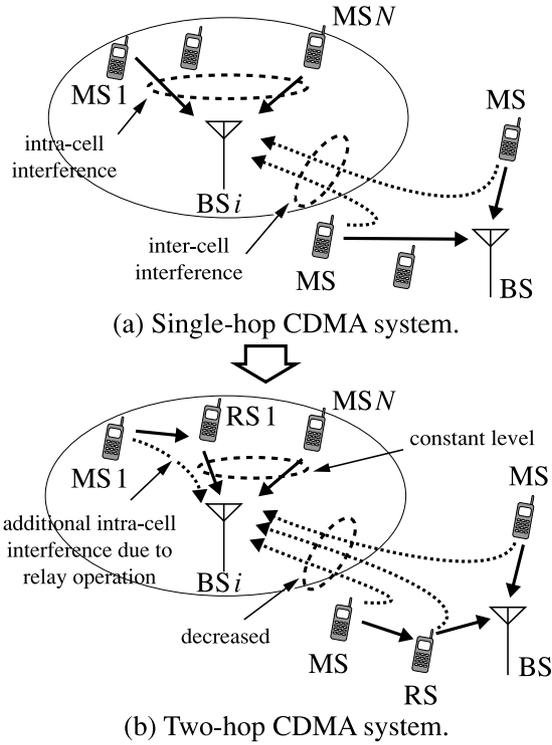
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**Fig. 1** Single-hop and two-hop CDMA cellular systems.

**Fig. 2** Interference in reverse link frequency.

In this paper, we deal with reverse link capacity of CDMA/FDD (frequency division duplex) systems. In order to enhance spectrum efficiency, the same frequency band that is pre-allocated is reused for relaying. In this section, an RS is assumed to be able to receive a signal from an MS and relay it to the BS simultaneously for the ease of analysis. More details and implementations are discussed in Sect. 3.1.

## 2.2 Intra-Cell Interference in Two-Hop Cellular Systems

First, we consider single-hop cellular systems as shown in Fig. 2(a); there are  $N$  MS's (MS 1 to MS  $N$ ) transmitting a signal to BS  $i$ . The interference power at BS  $i$ ,  $I_{1\text{hop}}$ , can be expressed as follows:

$$I_{1\text{hop}} = I_{\text{intra},1\text{hop}} + I_{\text{inter},1\text{hop}} \quad (1)$$

$$I_{\text{intra},1\text{hop}} = \sum_{m=1}^N P_{Mm} \quad (2)$$

where  $I_{\text{intra},1\text{hop}}$  and  $I_{\text{inter},1\text{hop}}$  are intra-cell interference and inter-cell interference, respectively.  $P_{Mm}$  denotes the received power at BS  $i$  from MS  $m$ . In CDMA systems, transmit power control is inevitable because of the well-known near-far problem. Therefore, we assume perfect power control from the MS's, i.e., all signals arrive at the BS with equal power  $S$ . For this reason, the interference power received by the BS from each MS is fixed. In this case, Eq. (2) is reduced to:

$$I_{\text{intra},1\text{hop}} = \sum_{m=1}^N P_{Mm} = NS. \quad (3)$$

Second, we consider two-hop cellular systems as shown in Fig. 2(b), where  $M$  MS's in the cell (MS 1 to MS  $M$ ) have two-hop links. In case RS  $m$  relays a signal from MS  $m$ , the interference level at BS  $i$ ,  $I_{2\text{hop}}$ , can be written as:

$$I_{2\text{hop}} = I_{\text{intra},2\text{hop}} + I_{\text{inter},2\text{hop}} \quad (4)$$

$$I_{\text{intra},2\text{hop}} = \sum_{m=1}^M (P'_{Mm} + P'_{Rm}) + \sum_{m=M+1}^N P_{Mm} \quad (5)$$

where  $P'_{Rm}$  and  $P'_{Mm}$  are the received power at BS  $i$  from RS  $m$  and MS  $m$ , respectively. In case that MS  $m$  communicates with BS  $i$  via RS  $m$ , the interference power at BS  $i$  caused by RS  $m$  is the same as that caused by MS  $m$  in single-hop cellular systems as a result of power control, i.e.,  $P'_{Rm} = P_{Mm} = S$ . Substituting this relationship into Eq. (5) yields:

$$I_{\text{intra},2\text{hop}} = NS + \sum_{m=1}^M P'_{Mm} > I_{\text{intra},1\text{hop}}. \quad (6)$$

Therefore, the total intra-cell interference increases by introducing relaying. Consequently, in the single-cell environment, the two-hop connection may not be helpful for capacity enhancement.

## 2.3 Inter-Cell Interference in Single-Hop Cellular Systems

Next, we evaluate interference at the BS taking into consideration inter-cell interference. When MS  $m$  transmits a signal to BS  $i$  as shown in Fig. 3(a), the received power at BS  $i$  from MS  $m$  is expressed as:

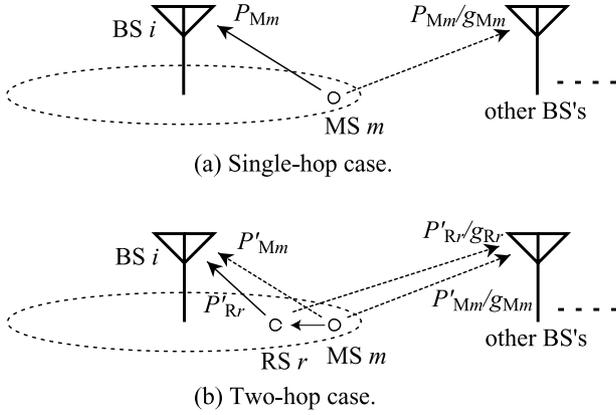
$$P_{Mm} = G_{mi} T_{Mm} \quad (7)$$

where  $G_{mi}$  is the power gain from MS  $m$  to BS  $i$  and  $T_{Mm}$  is the transmit power of MS  $m$ . In order to evaluate the interference power at the other BS's from MS  $m$ , it is necessary to measure the power gain from MS  $m$  to each BS.

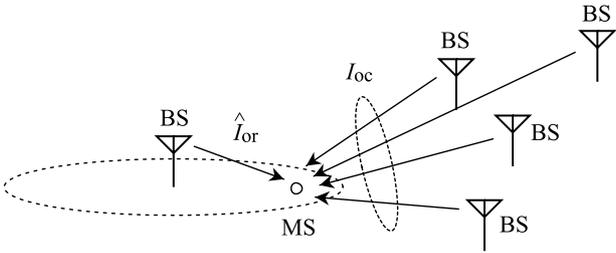
On the contrary, the total inter-cell interference power received by all the other BS's is given by:

$$\sum_{j \neq i} G_{mj} T_{Mm} = P_{Mm} \left| \frac{G_{mi}}{\sum_{j \neq i} G_{mj}} \right|. \quad (8)$$

To simplify this equation, we introduce forward link "geometry" [8] defined by



**Fig. 3** Analysis of interference with geometry.  $P_{Mm}$ ,  $P'_{Mm}$ , and  $P'_{Rr}$  represent the received power at the BS. As a result of power control,  $P_{Mm} = P'_{Rr}$ .



**Fig. 4** Forward link interference from the BS communicating with the MS,  $\hat{I}_{or}$ , and from the other BS's,  $I_{oc}$ .

$$g = \hat{I}_{or} / (I_{oc} + N_0) \quad (9)$$

where  $\hat{I}_{or}$  is the total received power density at MS in all code channels from the BS to which the MS belongs and  $I_{oc}$  is the total received power density at MS from all other BS's as shown in Fig. 4.  $N_0$  represents the thermal noise density. The value of geometry  $g$  is used to express the difference in the amount of interference, which depends on the location of the MS and  $g$  increases as the MS comes closer to the BS. In the following, we assume that the noise power density  $N_0$  is small enough in comparison to  $I_{oc}$ . When MS  $m$  communicates with BS  $i$ , geometry of MS  $m$  can be approximately written as:

$$g_{Mm} \simeq \hat{I}_{or} / I_{oc} = \frac{G_{im} T_{Bi}}{\sum_{j \neq i} G_{jm} T_{Bj}} \quad (10)$$

where  $T_{Bi}$  is the total transmit power of BS  $i$ . We assume that the total transmit power of all BS's is kept constant, i.e.,  $T_{Bi} = T_{Bj}$ , and we also assume that the difference between the power gain of reverse link and forward link is negligible, i.e.,  $G_{mj} = G_{jm}$ . Using these assumptions, Eq. (10) can be simplified as:

$$g_{Mm} = \frac{G_{mi}}{\sum_{j \neq i} G_{mj}}. \quad (11)$$

Substitution of this relationship into Eq. (8) yields:

$$\sum_{j \neq i} G_{mj} T_{Mm} = \frac{P_{Mm}}{g_{Mm}}. \quad (12)$$

Accordingly, the total interference power at all the other BS's can be expressed by fixed received power and geometry of the MS.

## 2.4 Inter-Cell Interference in Two-Hop Cellular Systems

Interference power of the two-hop case is considered as shown in Fig. 3(b). In case RS  $r$  whose geometry is  $g_{Rr}$  relays a signal from MS  $m$ , the total inter-cell interference power at all the other BS's from MS  $m$  and RS  $r$  is expressed as follows:

$$\frac{P'_{Rr}}{g_{Rr}} + \frac{P'_{Mm}}{g_{Mm}}. \quad (13)$$

Since intra-cell interference is increased by  $P'_{Mm}$  as shown in Sect. 2.2, the total interference power at all the other BS's is expressed as follows:

$$\frac{P'_{Rr}}{g_{Rr}} + P'_{Mm} \left( 1 + \frac{1}{g_{Mm}} \right). \quad (14)$$

Consequently, the condition for the interference to be reduced can be expressed as follows:

$$\frac{P_{Mm}}{g_{Mm}} > \frac{P'_{Rr}}{g_{Rr}} + P'_{Mm} \left( 1 + \frac{1}{g_{Mm}} \right). \quad (15)$$

Therefore, in case an MS transmits via such an RS that satisfies the condition of (15), the total interference power at BS's is decreased compared to the case of using a single-hop transmission.

## 3. System Model

In this section, we describe features of two-hop cellular systems. First, in order to realize the assumptions in Sect. 2.1, frequency division is used. Next, a call admission control, which plays a very important role to guarantee a certain level of the QoS, is described. Next, on the basis of the above-mentioned analyses, a new route selection criterion is proposed to decrease interference. Finally, by using the call admission control and the proposed route selection criterion, a new routing algorithm with the aim of enhancing the capacity is proposed.

### 3.1 Frequency Division Relaying

In case the RS receives a signal from an MS and relays it to the BS at the same time by using the same frequency band, a part of the radio wave radiated from the transmitting antenna of the RS might be fed back to the antenna receiving the MS's signal. This might cause signal degradation. One of the solutions of this problem is to introduce an interference canceller in a portable radio station. However, it is difficult to realize it with a small-sized radio equipment. For this reason, to avoid the interference between first-hop (from MS to RS) transmission and second-hop (from RS to BS) transmission, a pair of frequency bands is assumed to

be used for the reverse link transmission.

In this case, a frequency band assigned to the first-hop transmission should be different from that assigned to the second-hop transmission. However, when one frequency band is always assigned to the first-hop transmissions and the other frequency band is always assigned to the second-hop transmissions, the interference may be concentrated on the latter frequency band. To solve this problem, upon each new admission request, the frequency whose co-channel interference level at the BS is smaller than the other frequency is assigned to the single-hop or the second-hop transmission and the other frequency band is assigned to the first-hop transmission. RS is assumed to be able to transmit and receive signals simultaneously. In this case, the same end-to-end throughput is achieved for both single-hop and two-hop transmission.

### 3.2 Call Admission Control

The user capacity of CDMA is essentially limited by the total level of co-channel interference arising from the simultaneous utilization of the radio channel by several users. A call admission control thus plays a very important role in CDMA systems to guarantee a certain level of the QoS because it directly controls the number of active users. In this scheme, a new call is accepted so long as the total interference observed by the BS does not exceed a preset interference threshold,  $\eta$ , where  $\eta$  is defined as  $\eta = I_{0,\text{req}}/N_0$ , and  $I_{0,\text{req}}$  is the maximum total acceptable interference density [9], [10].

### 3.3 Route Selection Criterion

Most of the routing protocols for the multihop cellular systems consider the shortest-path with the minimum total path loss [4] or the minimum total transmit power [7] as a route selection criterion. These route selection criteria are not necessarily appropriate for capacity enhancement because the interference at the BS's, which limits the user capacity, is not taken into consideration. In order to enhance the capacity, we propose to use the route with the maximum amount of total interference reduction at the other BS's as a route selection criterion.

If MS  $m$  transmits a signal via RS  $r$ , the amount of interference reduction can be written as:

$$\Delta I = \frac{P_{Mm}}{g_{Mm}} - \left[ \frac{P'_{Rr}}{g_{Rr}} + P'_{Mm} \left( 1 + \frac{1}{g_{Mm}} \right) \right]. \quad (16)$$

As a result of power control, the received power at BS  $i$  from RS  $r$  is almost the same as that from MS  $m$  in single-hop systems. This relationship can be written as:  $P_{Mm} = P'_{Rr} = S$ . In this case, Eq. (16) can be written as:

$$\begin{aligned} \frac{\Delta I}{S} &= \frac{1}{g_{Mm}} - \left[ \frac{1}{g_{Rr}} + \frac{P'_{Mm}}{P_{Mm}} \left( 1 + \frac{1}{g_{Mm}} \right) \right] \\ &= \frac{1}{g_{Mm}} - \left[ \frac{1}{g_{Rr}} + \frac{T'_{Mm}}{T_{Mm}} \left( 1 + \frac{1}{g_{Mm}} \right) \right] \end{aligned} \quad (17)$$

where  $T'_{Mm}$  is the required transmit power of MS  $m$  in a two-hop case. In order that BS can centrally evaluate the amount of interference reduction to select a route, each MS sends its geometry in addition to its transmit power to the BS to which the MS belongs.

### 3.4 Routing Algorithm

Under light traffic load conditions, it is not necessary to decrease interference at the sacrifice of consuming the power of RS's. Therefore, at the start of the transmission, a single-hop connection is used. When the traffic increases and, consequently, a new call request is blocked as a result of the admission control, the BS informs BS's in the adjacent cells of the call blocking. Then, in order to decrease interference, each BS independently searches for a pair of one MS whose call is in progress and another MS that is neither transmitting nor relaying, and thus is able to play a role of an RS by finding such a pair maximizing Eq. (17). By this scheme, interference power at BS's may be decreased and more calls can be admitted.

In case all call requests can be admitted, the BS informs BS's of the adjacent cells of no further necessity of two-hop relaying. Until the reception of this information, BS's repeat asking MS's to switch from single-hop to two-hop transmissions. An MS is assumed to be able to serve as an RS for only one MS and BS removes such an MS that is transmitting or relaying from the candidates of an RS. When an RS originates a new call, the two-hop transmission is returned to a single-hop transmission.

The interference power at nearby BS's can be decreased by this route selection criterion. However, in case frequency assignment described in Sect. 3.1 is adopted, MS's and RS's that share the same frequency channels interfere with each other. Particularly, when a new transmission severely interferes with the RS, the transmit power of the MS increases as a result of power control. This might cause serious interference to BS's. In order to avoid serious interference to BS's, when the amount of interference reduction expressed by Eq. (17) turns to negative, the MS selects the single-hop connection to prevent excessive interference at BS's.

## 4. Computer Simulations

### 4.1 Simulation Parameters

The performances of the proposed route selection criterion and routing algorithm are evaluated using computer simulations assuming 7 hexagonal cells layout. Each cell is split into six sectors. The parameters assumed in computer simulations are listed in Table 1. BS's are arranged at the center of each cell and assumed to be equipped with sectorized directional antennas. MS's are assumed to be uniformly distributed in the cell and to be stationary throughout the simulation. Omnidirectional antennas are used for MS's. Interference is assumed to be equivalent to Gaussian noise over

**Table 1** Parameters assumed in computer simulations.

Parameters	Values
Number of cells	7
Cell radius	1000 m
Number of MS's	200/cell
BS total Tx power	30 dBm
MS max Tx power	20 dBm
Antenna gain	16 dBi (BS), 0 dBi (MS)
Thermal noise density	-174 dBm/Hz
Noise figure	5 dB
Path loss (BS-MS)	Walfisch-Ikegami model [11]
(MS-MS)	Street cell LOS model [12]
Shadowing	Log-normal distribution ( $\sigma = 8$ dB)
Packet length	80 bits
Carrier frequency	2 GHz
Bandwidth	3.84 MHz $\times$ 2
Spreading factor	32
Required $E_b/I_0$	5 dB
Interference margin $\eta$	6 dB

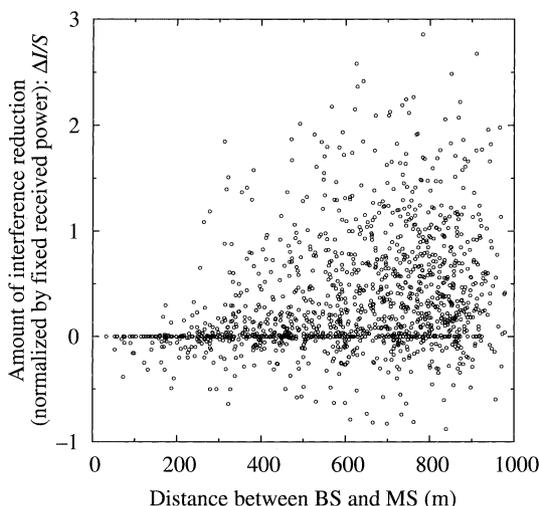
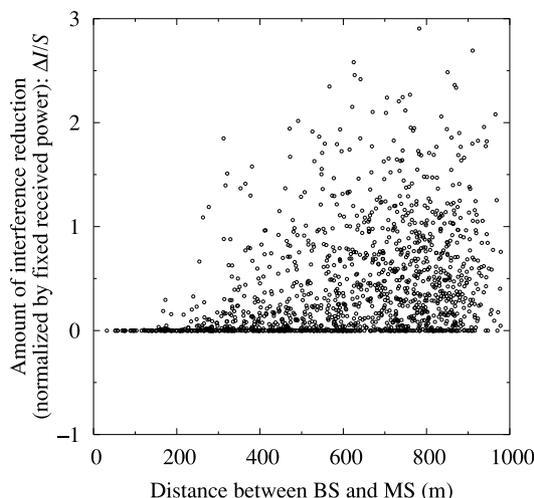
the signal bandwidth. Thermal noise is also considered at the receiver, which has a noise figure of 5 dB. The routing is assumed to be completed in advance of a transmission.

In order to implement frequency division relaying described in Sect. 3.1, two frequency bands are necessary. To make a fair comparison, two frequency bands are used for both the single-hop system and the two-hop system, and throughput of these systems are compared in terms of spectral efficiency (bit/sec/Hz).

The data are assumed to be generated according to an exponential distribution for interarrival-time and a log-normal distribution for data size, and divided into packets. The average data size is set to 4,400 bytes and the average interarrival-time is used to change the system load. The packet length is fixed to 80 bits.

In CDMA systems, tight transmit power control is inevitable to keep all MS's signals at the same level at the BS receiver because of the well-known near-far problem. In addition to this, by reducing transmit power from an MS to an RS while maintaining the  $E_b/I_0$  requirements at the BS, the interference at the BS can be further reduced, where  $E_b/I_0$  is signal energy per bit-to-interference and noise power spectral density ratio. Therefore, transmit power control is applied to all the packets to satisfy the  $E_b/I_0$  target at the start of each packet transmission. Receiving a packet will fail if the received power is below the required  $E_b/I_0$ . In this case, the lost packet is retransmitted after the power is controlled unless the amount of interference reduction  $\Delta I$  becomes negative.

Wireless communication links are severely influenced by various radio propagation effects. Therefore, prediction of radio signal propagation in each of the specific radio environments is essential to design the system. Propagation between BS and MS is assumed to be modeled by Walfisch-Ikegami model [11]. Propagation between RS and MS is

**Fig. 5** The amount of interference reduction by using the minimum power criterion.**Fig. 6** The amount of interference reduction by using the proposed interference reduction criterion.

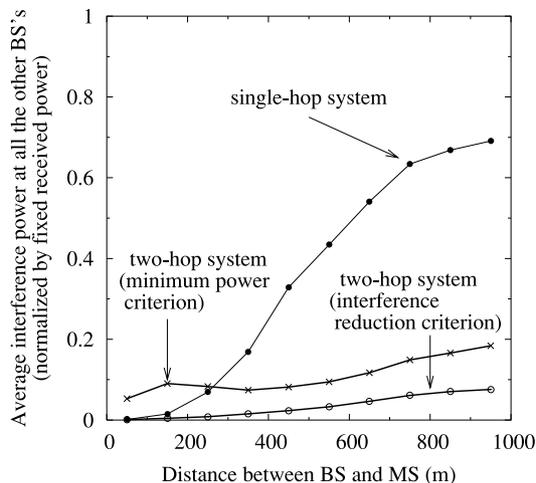
assumed to be modeled by a two-ray model, which consists of a direct path and single ground bounce [12]. The MS is connected at all times to the best BS, i.e. the one that gives the least attenuation due to propagation loss.

## 4.2 Simulation Results

### 4.2.1 Interference Reduction under Low Traffic Load Conditions

In this section, we evaluate the interference reduction ability of the minimum total transmit power criterion (hereinafter referred to as "minimum power criterion") and the proposed interference reduction criterion. For the ease of analysis, only one MS is assumed to be transmitting, i.e., there is no co-channel interference.

Figures 5 and 6 show the amount of interference reduction  $\Delta I/S$  of each MS versus the distance between BS and



**Fig. 7** Average interference of two route selection criteria as a function of the distance.

MS using the minimum power criterion and the proposed interference reduction criterion, respectively. Figure 5 shows that some MS's have negative  $\Delta I/S$ , and it means that these MS's increase interference though the total radiated power is decreased by changing a single-hop connection to a two-hop connection. Therefore, the minimum power criterion does not always lead to interference reduction. On the other hand, Fig. 6 shows that no MS has negative  $\Delta I/S$  according to the proposed criterion.

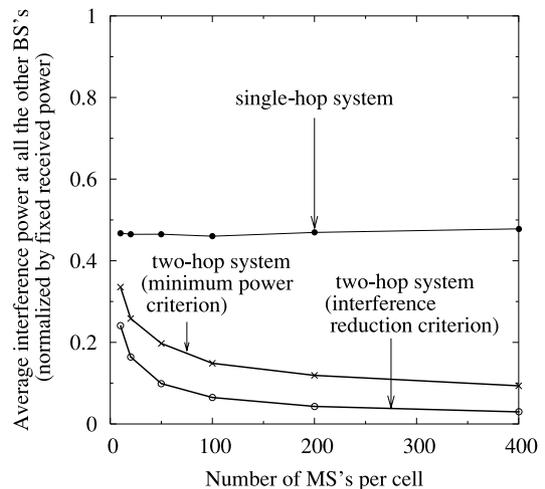
Figure 7 shows the average interference power at the other BS's versus the distance between BS and MS for the two route selection criteria. The interference power at the other BS's of the single-hop transmission and the two-hop transmission are described in Eqs. (12) and (14), respectively. In case that MS is located near BS, the minimum power criterion increases interference despite of using a two-hop connection. This is because of the additional intra-cell interference due to relay operation described in Sect. 2.2 since these MS's are far from the other BS's.

Increase of interference by the minimum power criterion can be explained by Eq. (16) as follows. One case is that an MS is located near the BS, and such an RS that is located also near the BS will be selected. It means that geometry of both the MS and the RS is large. In this case, Eq. (16) can be written as:

$$\lim_{g_{Mm}, g_{Rr} \rightarrow \infty} \Delta I = -P'_{Mm} < 0. \quad (18)$$

Therefore, interference is increased by two-hop relaying. However, since the MS that increases interference exists throughout a cell as shown in Fig. 5, the reason why interference increases is not unique. In order to explore another reason, the case that the MS is located on the fringe of its cell is considered. In this case, large transmit power reduction might be achieved according to the minimum power criterion, i.e.  $T'_{Mm}/T_{Mm} \ll 1$ , and Eq. (17) can be written as:

$$\lim_{T'_{Mm}/T_{Mm} \rightarrow 0} \Delta I/S = \frac{1}{g_{Mm}} - \frac{1}{g_{Rr}}. \quad (19)$$



**Fig. 8** Average interference of two route selection criteria as a function of the number of MS's.

Therefore, selecting an RS whose geometry is smaller than that of the MS increases interference.

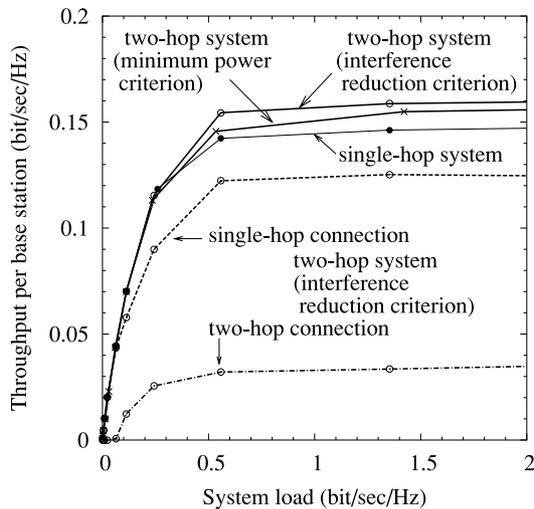
The performances of these two-hop systems can be dependent on the number of MS's. Figure 8 shows the average total interference power at the other BS's versus the number of MS's for the two route selection criteria. When the number of MS's increases, the number of candidates for RS increases, leading to lower interference in two-hop cellular systems. Consequently, it is shown that the proposed interference reduction criterion is more effective than the conventional minimum power criterion in respect of the amount of interference reduction.

#### 4.2.2 Capacity Evaluation of Two-Hop Systems Using the Proposed Routing Algorithm

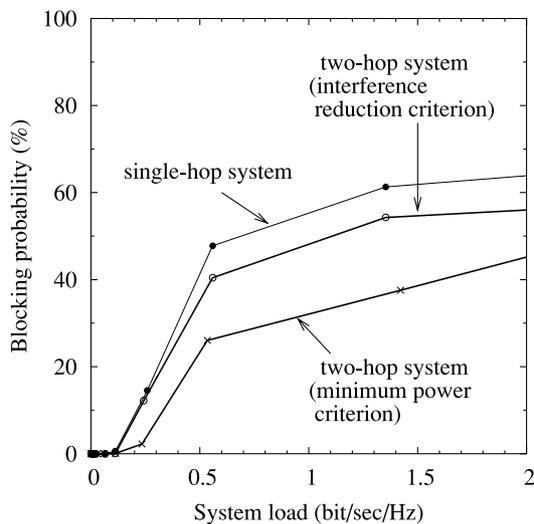
In this section, we evaluate the system capacity of two-hop cellular systems using the proposed routing algorithm. Figure 9 shows the capacity per base station versus the system load for single-hop and two-hop cellular systems. The capacity of single-hop cellular systems is independent of the arrangement of MS's. In contrast to this, the capacity of the two-hop systems with the interference reduction criterion is increased by about 10% constantly owing to the change of network topology.

In spite of allowing two-hop relaying, some MS's transmit signals using single-hop connections. Therefore, the throughput of data transmitted via single-hop connections and that transmitted via two-hop connections are also presented in Fig. 9. Since the end-to-end throughput of single-hop connections and that of two-hop connections are the same, the number of active MS's is expected to be in proportion to the throughput. Therefore, one-third MS's transmit a signal using two-hop connections under heavy traffic load conditions.

Figure 10 shows the blocking probability. Though the blocking probability increases along with the increase of traffic load as a result of the call admission control, two-hop



**Fig. 9** Throughput per base station as a function of system load for single-hop and two-hop cellular systems.



**Fig. 10** Blocking probability as a function of system load for single-hop and two-hop cellular systems.

connections may mitigate blocking owing to interference reduction.

Figures 9 and 10 also show the performance with the minimum power criterion as well as that with the interference reduction criterion. The blocking probability with the minimum power criterion is smaller than that with the interference reduction criterion. On the other hand, throughput with the minimum power criterion is smaller. This is because some MS's increase the interference by using two-hop relaying and, consequently, a failure occurs on packet reception. Therefore, under heavy traffic conditions, the proposed interference reduction criterion is more effective to enhance the capacity.

## 5. Concluding Remarks

In this paper, we showed that the two-hop connection might

not be helpful for capacity enhancement in the single-cell environment. With the aim of evaluating inter-cell interference, the forward link geometry was introduced. Based on these analyses, we then proposed a new route selection criterion that maximizes the amount of interference reduction. Simulation results demonstrate that the proposed criterion outperform the conventional criterion minimizing the total transmit power. In order to enhance the capacity as a result of this interference reduction, we also proposed a new routing algorithm. In this algorithm, when a call request is blocked as a result of the call admission control, BS's in the adjacent cells ask to switch MS's from a single-hop transmission to a two-hop transmission. Simulation results reveal that the capacity of CDMA cellular systems can be increased by 10% owing to the proposed routing algorithm.

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