Downlink Performance Improvement of TDD CDMA Cellular Networks with Time Slot and Fixed Hopping Station Allocations

Rui Zhou, Hoang Nam Nguyen, and Iwao Sasase

Abstract: **In this paper, downlink capacity of time duplex division (TDD) based cellular wireless networks utilizing fixed hopping stations is investigated. In the network, a number of fixed subscriber stations act as hopping transmission stations between base stations and far away subscribers, forming a cellular and ad hoc mobile network model. At the radio layer, TDD code division multiple access (CDMA) is selected as the radio interface due to high efficiency of frequency usage. In order to improve the system performance in terms of downlink capacity, we propose different time slot allocation schemes with the usage of fixed hopping stations, which can be selected by either random or distanced dependent schemes. Performance results obtained by computer simulation demonstrate the effectiveness of the proposed network to improve downlink system capacity.**

Index Terms: **Cellular network, fixed hopping station, time duplex division code division multiple access (TDD CDMA), time slot allocation.**

I. INTRODUCTION

The wireless communication industry has rapidly evolved in the past decade to provide high transmission rate wireless communications in the form of mobile cellular and wireless local area networks. Current mobile communication networks are based on a single-hop network architecture, where every user connects to base stations (BS) directly. Therefore, cell coverage and system throughput are limited by B's transmission capability. In order to provide high speed access, high user's signal to interference ratio (SIR) is required. Increasing the transmission power of BSs can extend their coverage. However, in interference limited systems such as code division multiple access (CDMA) systems, increasing signal power allocated to a user also increases the interference to other users. Another solution is to increase BS density and reduce individual BS's coverage size resulting in higher infrastructure cost. To solve such problems, there has been an upsurge of interest in multihop networks [1]. Examples are cellular ad hoc networks, mesh networks in IEEE 802.16, and the coverage extension of HyperLAN/2. A concept and related performance evaluation for a wireless broadband system based on fixed relay stations acting as wireless bridges are presented in [2].

Many researches have demonstrated the ability of ad hoc communication to extend wireless coverage. However, pure ad hoc networks suffer from low throughput due to inefficient routing and power limitation. A hybrid model with both mobile and fixed users, which is proposed in [3], is also inefficient due to the same reason, although the usage of BSs yields high throughput.

Multihop CDMA cellular networks have been proposed recently where the cell coverage and system throughput are improved by using independent wired or wireless stations for relaying signals to users who might have insufficient SIR when connecting directly to a BS. Lin and Hsu propose a practical multi-hop wireless connection scheme for cellular networks by forwarding data packets from one user to another [4]. Zhao and Terence consider a cellular CDMA system with out-of-band ad hoc traffic relaying, the dual-mode mobile stations can choose available relay to improve cellular capacity [5]. The approaches for relay node placement in cellular space could extend B's coverage by planning of an ad hoc relay network [6]. However, there is a tradeoff between the ad hoc network and cellular systems. Data may be forwarded in a multi-hop fashion to increase coverage of BS, but it provides only a slight advantage in system capacity because of the low performance of the mobile terminal [7].

On the other hand, using time duplex division (TDD) CDMA [8] techniques for mobile users can provide higher frequency usage efficiency because of the flexibility in time slot allocation. Single hop TDD CDMA cellular networks have been widely investigated, where both mobile stations and fixed stations can directly connect to the BS. For a combination of multihop cellular and TDD CDMA networks, the congestion-based routing algorithm is proposed in [9] to minimize the overall power in the multihop TDD CDMA. However, the network capacity is still required for improvement. It is expected that the system capacity can be increased by combining time slot management and relay station selection properly.

In this paper, we consider a TDD CDMA cellular network with fixed hopping stations, which includes both fixed users and mobile users. Some of fixed users (FUs) act not only as end users but also as subscriber hopping stations (SHSs). It is known in [9] that more hops by mobile users do not benefit cellular system on capacity so much, since more hops increase interference and packet delay. Therefore, for practice and simplicity, it is assumed that the maximum hop is limited to 2 hops, where users can connect to BS directly or via an SHS with 2 hops. In order to improve the system capacity, we consider a combination of time slot allocation and usage of hopping stations. Since the hopping

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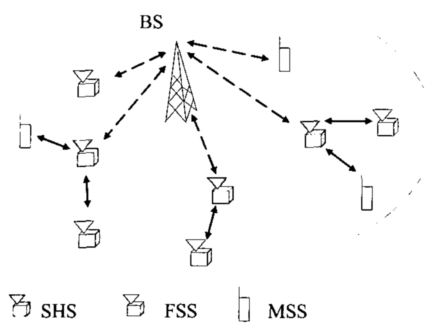

Fig. 1. TDD CDMA cellular architecture.

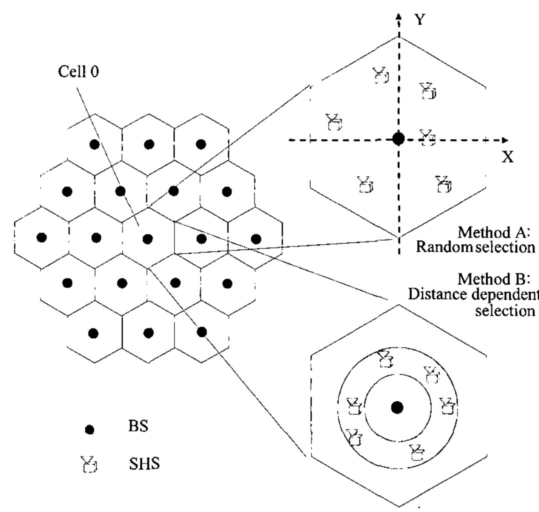

Fig. 2. SHS selection schemes.

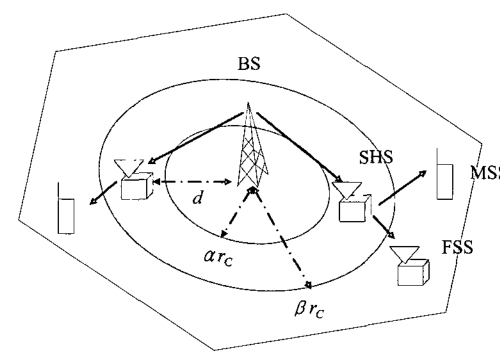

Fig. 3. Distance dependent SHS selection scheme.

station selection would impact the capacity by relay reusing, we investigate two hopping station selection schemes in which the hopping station would be allocated randomly or distance dependently. Computer simulations show that the proposed scheme improves the system capacity by relaying while the distance dependent SHS selection scheme achieves better performance.

This paper is organized as follows. The system model is described in the next section. Section III shows the system analysis. The performance of the proposed system is presented in Section IV. Conclusion remarks are given in the last section.

II. SYSTEM MODEL

The system model of the TDD CDMA cellular network with fixed hopping stations is shown in Fig. 1. It is assumed that a subset of FUs is selected as SHSs relaying signals from BSs. We denote the rest fixed users as fixed subscriber stations (FSSs), mobile users as mobile subscriber stations (MSSs). FSSs and MSSs can connect to BSs or SHSs, where all the stations (BSs, SHSs, FSSs, and MSSs) are equipped with the omni antennas. X and Y are denoted as the two coordinates of the user as shown in Fig. 2, respectively. Two uniform distributed random generators are used to allocate X coordinate and Y coordinate of user within hexagon cells in the multi cell model. When using uniform distribution for two directions, there might be users allocated outside the cell. In this case, the random generators allocate these users again until positions of all users are in the cell, which make sure that probability density is equal in area.

A. SHS Selection Scheme

Two methods of SHS selection are introduced. The first method is a random SHS selection scheme. Each FU can be selected to be SHS by using random variable, which is shown as Method A in Fig. 2, therefore, the SHS can be allocated in the whole cell. By considering a general case where the users could not be predicted, selection of SHS depends on the value of a random generator with uniform distribution of range [0, 1] for FU, γ, which is the ratio of the number of SHSs to the total number of FUs. If the random number of FU is less than or equal to γ, the FU would be selected as a SHS. The second method is a distance dependent selection scheme shown in Fig. 3, which selects SHSs in particular range of the cell. For description, the following notation is used:

- r_C is the radius of a radio cell.
- α and β are the allocation variables of SHS shown in Fig. 3, $0 < \alpha < \beta < 1$. Here, it is assumed that SHSs are fixed, while all FUs are the candidates for SHSs.
- The number of FUs is n_{FU}, and the number of SHSs is n_{SHS}. γ is used to express the number ratio of SHSs to total fixed stations, $n_{SHS} = \gamma n_{FU}$, and $0 < \gamma < 1$.

In this case, the distance d, from SHS to BS should satisfy: $\alpha r_C < d < \beta r_C$, which is shown as Method B in Fig. 2 and described in Fig. 3, where the SHS should be allocated in the shadowing area. The difference of SHS selection scheme in Method B compared with the scheme Method A is that choices of SHS are limited by not only γ but also the distance from BS which selects SHSs from FUs in the area dependent on α and β in Method B.

A user, which can be either FSS or MSS selects BS or SHS for connection by monitoring pilot signals broadcasted periodically. When FSSs or MSSs connect to the network, they measure received power of pilot signals from BS and SHSs to select the connection to the appropriate BS/SHS which has the strongest pilot power. BS and SHSs can update the information for routing packets to destination stations. Therefore, the users can change the connected BS/SHS if the received pi-

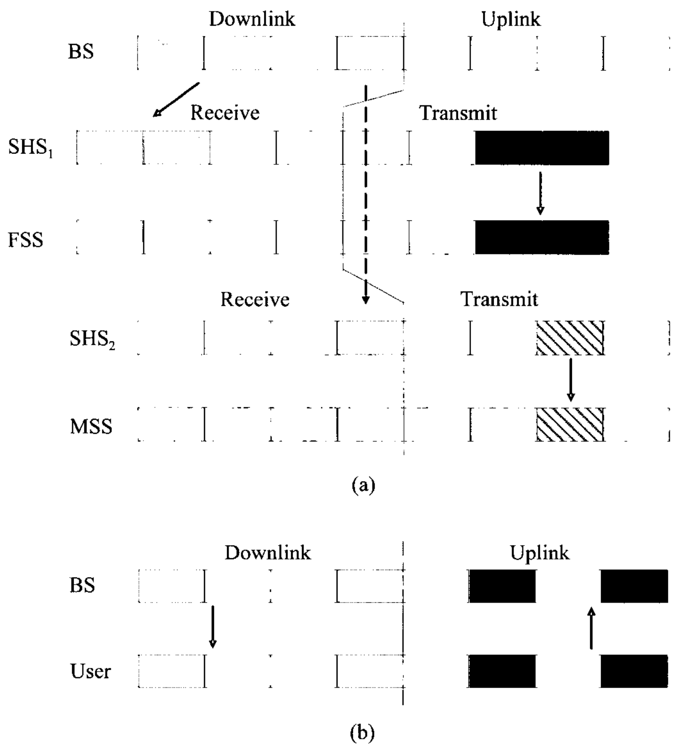

Fig. 4. Comparison of time slot allocation schemes; (a) proposed TDD CDMA multihop network, (b) conventional single hop network.

lot power becomes weaker than other broadcasted pilot power. Note that, less pilot transmission would keep the connection of users longer, while traffic would not be sent to different SHSs. On the other hand, frequent pilot transmission would give more diversity in the time varying channel. However, it would cause two much pilot traffic and waste of transmission power. In this paper, we consider a practical system, in which BS and SHSs would send their pilot signals every time frame. Channel condition is assumed to keep stable in one time frame which includes half uplink time slots and half downlink time slots.

B. Time Slot Allocation

Fig. 4 shows the proposed time slot allocation scheme with the usage of fixed hopping stations compared to the conventional single hop TDD CDMA network. For the conventional system, time slots are divided into two parts: Uplink time slots and downlink time slots from the BS. In each uplink time slot, the BS receives if there is a data packet from the user. In each downlink time slot, the BS serves the data packet if there is packet in the data queue.

In contrast to the conventional system, time slot allocation is performed by BS for SHSs and the FSSs/MSSs which connect directly with the BS in the proposed system. SHSs allocate time slots for the users which are connected with the SHSs. Assume all cells are frame synchronized, a station can only transmit or receive in one time slot. One time frame is divided into two parts for downlink and uplink transmission. In SHSs' receiving time slots, BS, FSSs, and MSSs connected to SHSs can transmit. In SHS's transmitting time slots, only SHSs, FSSs, and MSSs connected to BS can transmit. As shown in the part (a) of Fig. 4,

Table 1. Propagation parameters.

Carrier frequency	5 GHz
Rooftop level	12 m
Distance between the rows of buildings	80 m
Street width	30 m

Table 2. Margin specifications.

	Gain (dBi)	Antenna height (m)
BS	10	30
SHS	5	15
FSS	5	15
MSS	0	1.5

we take one FSS and one MSS connecting to two SHSs for example. Spreading codes are assigned for stations to decrease the interference in the same time slot. In one time slot each code is used for only one station. By receiving the time slot allocation information from BS, SHSs, FSSs, and MSSs can share all the spreading codes.

III. SYSTEM PERFORMANCE ANALYSIS

A. Propagation Models

$L(R)$ is denoted as the path loss with the distance R (in km). Assume that propagation between BS and SHS/FSS and between SHS and FSS follows a line of sight model where the propagation loss is the free space loss. The propagation model in [10] is used to calculate the path loss between BS and FSS/MSS, SHS, and FSS/MSS.

Total path loss in decibels is expressed as the summation of three independent terms: Free space loss L_{fs}, diffraction loss from rooftop to street L_{rts}, and reduction due to plane wave multiple diffraction past rows of buildings L_{md}. The following equation is used for calculation of path loss.

$$L(R) = L_{fs} + L_{rts} + L_{md} \tag{1}$$

With the parameters of propagation model and antenna shown in Tables 1 and 2, propagation losses are calculated as following: The propagation loss between BS and FSS is expressed as

$$L(R) = 91.4 + 20 \log R. \tag{2}$$

The propagation loss between BS and MSS is

$$L(R) = 126.6 + 38 \log R. \tag{3}$$

The propagation loss between SHS and FSS is

$$L(R) = 96.4 + 20 \log R. \tag{4}$$

And the propagation loss between SHS and MSS is

$$L(R) = 145.6 + 40 \log R. \tag{5}$$

B. Interference Analysis

A 19-cell model is considered as shown in Fig. 2. The central cell is denoted as cell 0. Because the time slot allocation divides time frame into uplink and downlink, it is assumed that other cells use the same uplink and downlink time frame to reduce the inter cell interference. The received signal power P_r can be expressed as,

$$P_r = P_t 10^{-L(R,f,G)/10} 10^{\eta/10} \tag{6}$$

where P_t is the transmission signal power, $L(R,f,G)$ is the function that stands for propagation path loss depending on distance R, carrier frequency f, and antenna gain G. η is a normally distributed random variable with a mean of 0. The two parts behind the transmission power represent distance attenuation and shadowing, respectively.

Since one time frame is divided into uplink and downlink for BS and FSSs/MSSs, it is necessary to consider the SIR of in both transmitting and receiving time slots for SHSs. In BS uplink time slots, only SHSs and FSSs/MSSs directly connecting to BSs can transmit. FSSs and MSSs connecting to BS and SHS are denoted as subscriber stations (SSs) connected to BS and SHS (SS^B and SS^H, respectively). Since CDMA is interference limited system, interferences from BSs, SHSs and transmitting users are considered. Signal power of $SS^H_{0,i}$ in cell 0 received from $SHS_{0,j}$ in cell 0 is expressed as

$$\begin{aligned} S^H_{0,i} &= P(SS^H_{0,i}, SHS_{0,j}) \\ &= P(SHS_{0,j}) 10^{-L[R(SS^H_{0,i}, SHS_{0,j}), f, G]/10} 10^{\eta/10}. \end{aligned} \tag{7}$$

Interference power received by $SS^H_{0,i}$ in the central cell is expressed as

$$I_{SS} = \sum_{k=0}^{19} \Big(\sum_{p=1}^{N_{SHS}} P(SS^H_{0,i}, SHS_{k,p}) + \sum_{q=1}^{N^B_{SS}} P(SS^H_{0,i}, SS^B_{k,q}) \Big) \quad \text{if} \quad k=0, \quad p \neq j. \tag{8}$$

where N_{SHS} denotes the number of SHSs in the cell, N^B_{SS} denotes the SSs connecting to BS. Since FUs are allocated in the cell with a uniform distribution, the number of FUs allocated in the area for selection of SHSs can be calculated with the value of α and β. On the other hand, the parameter γ which is denoted as the ratio for number of SHSs over number of FUs also limits the number of SHSs. There would be optimized value for α, β and γ for the system. However, it is complicated to calculate for three variables to get the optimization. Thus, we fix the value of γ by changing the values of α and β to get relationships between N_{SHS} and these values. With fixed value of γ the maximum number of SHSs is expressed as

$$N^{\gamma}_{SHS} = \gamma N_{FU} \tag{9}$$

where N_{FU} is denoted as total number of FUs allocated in the cell. Because the FU is uniformly distributed in the cell, by considering the values of α and β, we can get another maximum number of SHSs which is denoted as

$$N^{\alpha,\beta}_{SHS} = (\beta^2 - \alpha^2) N_{FU}. \tag{10}$$

Therefore, we have the N_{SHS} calculated as

$$N_{SHS} = \min\{N^{\gamma}_{SHS}, N^{\alpha,\beta}_{SHS}\}. \tag{11}$$

Thus, the received SIR is calculated as

$$\begin{aligned} SIR_{SS} &= \frac{S^H_{0,i}}{I_{SS}} \\ &= \frac{P(SS^H_{0,i}, SHS_{0,j})}{\sum_{k=0}^{19} \Big(\sum_{p=1}^{N_{SHS}} P(SS^H_{0,i}, SHS_{k,p}) + \sum_{q=1}^{N^B_{SS}} P(SS^H_{0,i}, SS^B_{k,q}) \Big)} \\ &\quad \text{if} \quad k=0, \quad p \neq j. \end{aligned} \tag{12}$$

In the BS downlink time slots, SHSs and FSSs/MSSs directly connecting to BS can receive packets. The calculation of SIR is the same as that for the single hop cellular system. Most of the interference power comes from other BSs. Other interference power comes from the FSSs/MSSs transmitting to their SHSs. All SHSs and FSSs/MSSs need to get there SIR higher than SIR_{req} to satisfy the required signal quality.

IV. PERFORMANCE EVALUATION

A. System Assumptions

Simulation parameters are shown in Table 3. Assume that the conventional network is a single hop TDD CDMA network operating at 5 GHz utilizing fixed time slot allocation (half of the time slots for downlink and the other half for uplink). In order to compare the proposed network to the conventional network, the total transmitting power in each cell is identical. Therefore, the BS power for the conventional network equals to the BS power added with the power of all the SHSs to make sure that power transmitted in each cell is the same.

Assume both conventional and proposed networks have sufficient number of spreading codes. In the proposed network, all cells are assumed to be synchronized and use the same time slot allocation scheme. Therefore, the downlink time slots for FSSs and MSSs are allocated in the BS downlink time slots for the users connecting to BS or in the BS uplink time slots for the users connecting to SHSs. In this case, compared to reverse time slot allocation, the inter cell interference could be reduced.

Shadowing is taken into account only for MSS's propagation model, while the power control is used at BSs. Since the capacity of CDMA networks depends on the total interference, the worst case is considered, where BSs and SHSs transmit at their maximum power. In order to analyze the downlink traffic in the proposed time slot allocation scheme, the downlink traffic occurs for FSSs/MSSs directly connecting to BS in the BS's uplink time slots, while for others connecting to SHSs in the BS's uplink time slots. Therefore, SHSs cause interference when transmitting to their connected users in the BS's uplink time slots. In the BS's downlink time slots, interference is from BSs of other cells. Pilot power of both BS and SHS are assumed to be the same although they have different maximum transmission power. Note that, according to propagation models for FU and MSS (see (2)–(5)), BS still has larger coverage since users

Table 3. System parameters.

	Symbol	Quantity
Carrier frequency	F_C	5 GHz
Number of BSs (cells)	n_{BS}	19
Number of users (FU and MSS) per cell	N_u	Maximum 300
Radius of cells	r_C	1 km
Max number of hopping	Max_H	2
Max power of BS	P_{BS}	10 W
Max power of SHS	P_{SHS}	1.5 W
Allocation variables	α, β	$0 < \alpha < \beta < 1$
SHS ratio (number of SHSs to number of FUs)	γ	0.1, 0.2, 0.3
Required SIR	SIR_{req}	5 dB
Pilot power of BS	P_{BS_Pilot}	0.25 W
Pilot power of SHS	P_{SHS_Pilot}	0.25 W
Spreading factor	SF	128

receive the signal from BS have 5 dB gain more than from SHS. γ is considered as a system input parameter, for practicality the value are assumed as 0.1, 0.2, and 0.3 in the simulation.

B. Performance Results

As the two SHS selection schemes are introduced, the system is simulated with different SHS ratios and values of α, β, and γ for the distance dependent selection scheme. Since the CDMA system is interference limited system, transmission power control (TPC) is adopted. All FSSs and MSSs connected to SHSs receive their traffic from the SHSs. In order to satisfy the required SIR, each user should receive a minimum power which is strong enough from BS or SHS. If a user could not get its required power, the user is considered to be an outage user. Thus, outage probability is expressed as the number ratio of unsuccessful users out of total users.

The selection of SHS is limited by not only γ but also the distance from BS which selects SHSs from FUs in the area dependent on α and β in Method B. Fig. 5 shows the simulation to find a sub-optimized result for Method B by fixing the value of γ when changing the values of α and β, where γ is considered as a system input value indicating the number of SHSs allocated in each cell. α and β are simulated with a step 0.1 for each γ equal to 0.1, 0.2, and 0.3, respectively, where α and β are between 0.1 and 0.8 (since the shape of cell is assumed as a hexagonal, both the values should be less than 0.9). By choosing $\alpha = 0.5$ and $\beta = 0.7$, Method B can perform the best connectivity, when the users near the cell border can connect with SHSs in the BS uplink time slots.

Fig. 6 shows the outage probability of the random SHS selection and distance dependent SHS selection compared to single hop (conventional) system. Number of MSSs is twice as the number of FUs with different values of γ. When the number of user is small, the single hop system is better because SHSs cause interference to their neighbor FSSs/MSSs. However, when there are more users in each cell, the fixed relay network provides better performance. We can observe that the proposed schemes can

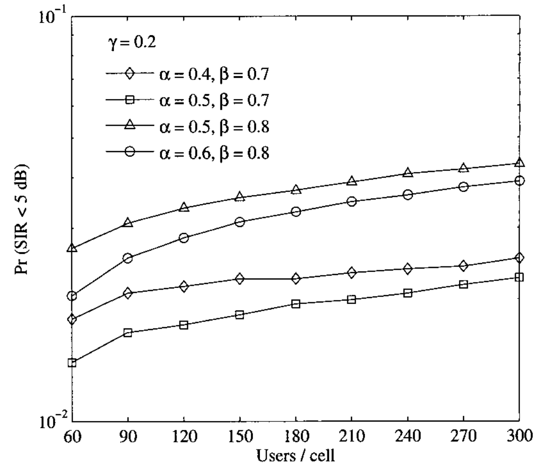

Fig. 5. Optimization for distance dependent SHS selection scheme.

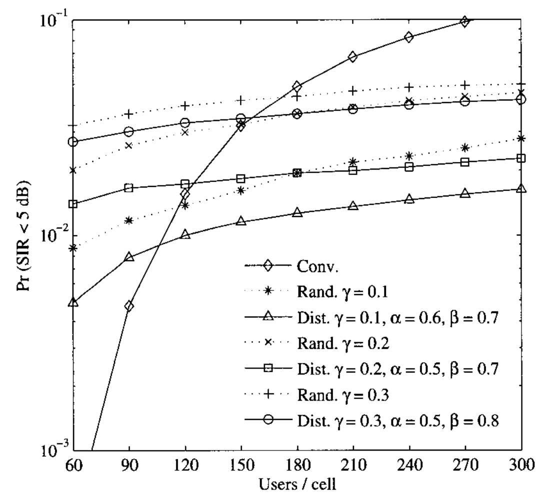

Fig. 6. Outage probability when number of MSSs is twice of FSSs with SHSs with different values of γ.

achieve the outage probabilities less than 0.03 even the number of users reaches 300. By carefully choosing values of α and β with γ equal to 0.1, 0.2, and 0.3, respectively, the distance dependent SHS selection scheme could perform better than random scheme. Since the outage probability can be reduced by connection with FSS/MSS far away from the BS. Further, with high density of users, the distance dependent SHS selection can provide the connection more fairly, especially for the FSSs and MSSs which are far from the BS.

Fig. 7 shows the outage probability with different ratios of MSSs with $\gamma = 0.2$. We denote the ratio for the number of MSSs to the number of fixed stations as η, which changes as 1, 2, and 3, respectively. According to the sub-optimized results we get from Fig. 1, α and β equal to 0.5 and 0.7, respectively. In the BS uplink time slot, SHSs act as relays by transmitting data to the users connected with. As the number of MSS increasing the outage probability is reduced, since less SHSs cause less interference while more MSSs can connect to SHSs successfully instead of BS. Thus, in the BS downlink time slot SHSs and the rest FSSs/MSSs could connect with BS with higher transmission

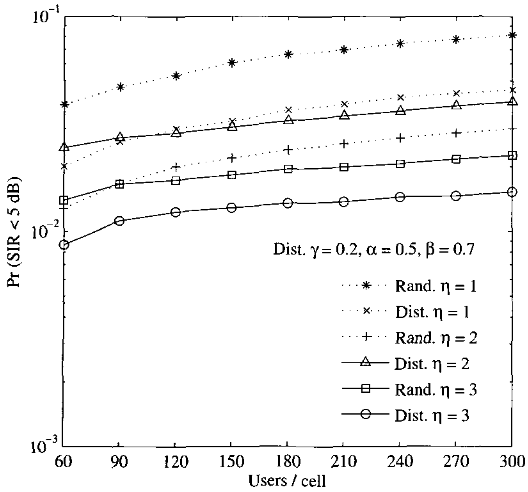

Fig. 7. Outage probability under various ratios of MSSs.

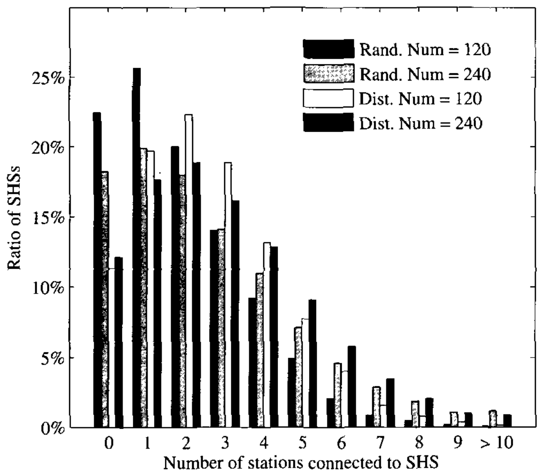

Fig. 8. Ratio of SHSs vs. number of connections for two hopping station selection schemes.

power.

Fig. 8 shows the Ratio of SHSs under different number of connections for comparison of two hopping station selection schemes, where the number of users are 120 and 240, respectively. Note that ratio of SHSs is denoted as the ratio of the number of SHSs whose connection with FSS/MSS equals to 0, 1, 2, 3,$\cdots$ or more than 10 (include 10), respectively. We can find that most of the SHSs allocated by the distance dependent scheme connect 1, 2, or 3 FSSs and MSSs, on the other hand, most of the SHSs allocated by random selection schemes do not connect any user or only connect to 1 user. Thus, more hopping stations are active in the distance dependent hopping station selection scheme and the number of the connection for each hopping station is about 3 or 4 connections. In contrast, some hopping stations connecting with many users or very few in the random hopping station selection scheme. Since TPC is adopted in CDMA system, too many users cause high outage probability due to limitation of SHS transmission power. If locations of SHSs are too near or too far from BS, no FSS or MSS can receive higher SIR from these SHSs compared to BS, whose powers are weaker than that BS can provide. Therefore, the distance dependent SHS selection is more efficient by using hopping stations.

In this section we simulate the different parameters such as α, β, and γ for both random and distance dependent SHS selection schemes by comparing with the conventional single hop system. Considering γ as a system input value, simulation results show that by carefully choose the range of SHS allocation system could get much better performance than random SHS allocation. System designer should also consider the number of FSSs and MSSs to select appropriate allocation values.

V. CONCLUSION

In order to improve system capacity in the TDD CDMA cellular network with hopping station, we propose a time slot allocation scheme which is combined with hopping station selection. By exploiting time slot allocation scheme for different users connecting to BS or hopping stations, the proposed scheme for the system is able to achieve lower outage probability, i.e., more users can connect to the networks with a required SIR. A sub-optimized allocation distance dependent SHS allocation scheme is found by computer simulation. The results show that the proposed networks can achieve lower outage probability compared to the conventional single hop TDD CDMA networks, especially there are more mobile users and high user density. Comparison of two SHS selection schemes shows that the distance dependent selection scheme gains more efficiency than allocating the SHS randomly.

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REFERENCES

[1] R. Pabst, B. H. Walke, D. C. Schults, P. Herhold, H. Yanikomeroglu, S. Mukherjee, H. Viswanathan, M. Lott, W. Zirwas, M. Dohler, H. Aghvami, D. D. Falconer, and G. P. Fettweis, "Relay-based deployment concepts for wireless and mobile broadband radio," *IEEE Commun. Mag.*, vol. 42, no. 4, pp. 80–89, Sept. 2004.

[2] N. Esseling, B. H. Walke, and R. Pabst, "Performance evaluation of a fixed relay concept for next generation wireless systems," in *Proc. IEEE PIMRC 2004*, Barcelona, Spain, Sept. 2004, pp. 744–751.

[3] B. Liu, Z. Liu, and D. Towsley, "On the capacity of hybrid wireless networks," in *Proc. IEEE INFOCOM 2003*, San Francisco, USA, Apr. 2003, pp. 1543–1552.

[4] Y.-D. Lin and Y.-C. Hsu, "Multihop cellular: A new architecture for wireless communications," in *Proc. IEEE INFOCOM 2000*, Tel Aviv, Israel, Mar. 2000, pp. 1273–1282.

[5] D. Zhao and T. D. Todd, "Cellular CDMA capacity improvement using ad hoc relaying," in *Proc. IEEE PIMRC 2004*, Barcelona, Spain, Sept. 2004, pp. 719–723.

[6] H.-Y. Wei, S. Ganguly, and R. Izmailov, "Ad hoc relay network planning for improving cellular data coverage," in *Proc. IEEE PIMRC 2004*, Barcelona, Spain, Sept. 2004, pp. 769–773.

[7] A. Fujiwara, S. Takeda, H. Yoshino, and N. Umeda, "Evaluation of cell coverage and throughput in the multihop CDMA cellular network," in *Proc. IEEE VTC 2004*, Milan, Italy, May 2004, pp. 2375–2378.

[8] R. Esmailzadeh, M. Nakagawa, and A. Jones, "TDD-CDMA for the 4th generation of wireless communications," *IEEE Wireless Commun.*, vol. 10, no. 4, pp. 8–15, Aug. 2003.
[9] T. Rouse, S. McLaughlin, and I. Band, "Congestion-based routing strategies in multihop TDD-CDMA networks," *IEEE J. Sel. Areas Commun.*, vol. 23, no. 3, pp. 668–681, Mar. 2005.
[10] H. H. Xia, "A simplified analytical model for predicting path loss in urban and suburban environments," *IEEE Trans. Veh. Technol.*, vol. 46, no. 4, pp. 1040–1046, Nov. 1997.

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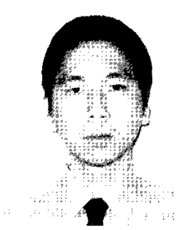

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