Spectral Efficient Frequency Allocation Scheme in Multihop Cellular Network

Lei Guan, Jianhua Zhang, *Member, IEEE*, Jianing Li, Guangyi Liu, Ping Zhang, *Member, IEEE*
Beijing University of Posts and Telecommunications
Key Laboratory of Universal Wireless Communication, Ministry of Education, China

***Abstract*— Radio frequency allocation is of great importance in the multihop cellular network, because some extra resources (frequency or time slot) seem to be allocated to the relay station. Generally, the tradeoff must be made between the frequency reuse factor and the inter-cell interferences during establishing frequency allocation scheme. A "pre-configured and fixed (PreF)" frequency allocation scheme has been proposed in [1]. In this paper, the concept of "soft frequency reuse (SFR)" in [2] is first borrowed, and applied to the multihop cellular network. After that, the improvement is made to the SFR scheme, and a more efficient "modified SFR (MSFR)" frequency allocation scheme is proposed. Through the simulations, it is demonstrated that, almost the same cell throughput can be achieved in the PreF and SFR schemes for the uniform traffic distribution, and the MSFR scheme can provide nearly twice cell throughput as large as that in the aforementioned two schemes. Moreover, the SFR and MSFR schemes both outperform the PreF scheme for the non-uniform traffic distribution because of the support to dynamic frequency resource allocation in the proposed schemes.**

keywords—frequency allocation scheme; the MSFR scheme; multihop cellular network; SINR

I. Introduction

A large amount of attentions have been plunged into the study of the 4G communication system, which is confronted with the objectives for high data rates [3], high spectral efficiency and ubiquitous coverage [4]. This will introduce extreme challenges to the conventional cellular network. To resolve these problems, major modifications in the wireless network architecture need to be carried out. As a result, a promising cooperative transmission technology based on multihop cellular network emerges [5], such as the standardization work in the 802.16j and the WINNER project, which can provide with system capacity enhancement and cell coverage expansion in a cost-efficient way.

Orthogonal frequency division multiplex access (OFDMA) has been proposed as the most promising physical layer technology for future broadband wireless system, but inherently it can't achieve interference mitigation as what code division multiple access (CDMA) can do. So radio frequency allocation is of great importance in system planning. Furthermore, it is even more serious in OFDMA-based multihop cellular network because some extra resources seem to be allocated to the relay station. Generally, tradeoff must be made between the frequency reuse factor and the inter-cell interferences during establishing frequency allocation scheme. H. Hu has proposed a "pre-configured and fixed (PreF)" frequency allocation scheme in [1], which can achieve range extension without any capacity penalty. But a bit large frequency reuse factor of four and pure application to uniform traffic distribution become its obvious limitations. A "reuse partitioning" scheme in [6][7] divides the whole frequency resources into three subsets which cannot overlap, and each subset corresponds to each link among the base station (BS), relay station (RS) and mobile station (MS). This scheme can be applicable to non-uniform traffic distribution by adjusting the proportion of the three subsets. But it is wasteful to use different frequency bands between the BS-RS and RS-MS link.

In this paper, OFDMA is considered as the multiple access mode, which is prone to frequency resource scheduling. Based on this, the concept of "soft frequency reuse (SFR)" in [2] is first borrowed, and applied to the multihop cellular network. The SFR scheme can efficiently improve cell edge performance, which can obtain frequency reuse factor between one and three. Thereafter, the improvement is made to the SFR scheme, and a "modified soft frequency reuse (MSFR)" scheme is proposed, which is a better tradeoff between the frequency reuse factor and the inter-cell interferences.

In the simulations, the same total frequency bands is assumed, and it is observed that, almost the same cell throughput can be achieved in the PreF and SFR schemes for the uniform traffic distribution, and the MSFR scheme can provide nearly twice cell throughput as large as that in the aforementioned two schemes. Moreover, the SFR and MSFR schemes both outperform the PreF scheme for the non-uniform traffic distribution because of the support to dynamic frequency resource allocation in the proposed schemes.

The remainder of this paper is organized as follows. Section II briefly introduces the system model and frequency allocation schemes. Simplified interference analysis is presented in Section III. Simulations and discussions will be exhibited in Section IV. Finally we conclude in Section V.

II. System Model and Frequency Allocation Scheme

A. System model

The downlink of an OFDMA-based multihop cellular system is considered. In each cell, as shown in Fig. 1, a BS and

The research is funded by PRC National 863 Project: Cooperative techniques research in cellular network (No.2006AA01Z258).

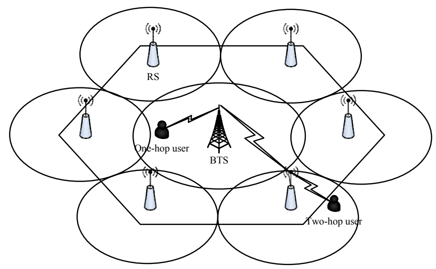

Fig. 1. Cell layout of the considered multihop cellular network

six RSs are respectively located at the cell center and edge, and each RS is on the line that connects BS and cell vertices. Users can be served directly by the BS through a one-hop link, or alternatively, establish a two-hop link from a RS, which can be decided by a SINR-based selection algorithm, and refer to [8] for other route selection algorithms. In addition, all transceivers in the system are assumed to be equipped with omni-directional antennas.

UL:MS->BS	Gp	DL:BS->MS

(a) one-hop user

UL:MS->RS	UL:RS->BS	Gp	DL:BS->RS	DL:RS->MS

(b) two-hop user

Fig. 2. Simplified time slot structure of the considered system

In this paper, the duplex mode is selected to be time division duplex (TDD), and Fig. 2 exhibits the simplified time slot structure of the considered system. Especially for the two-hop transmission, an original time slot is split into two equal parts. That is to say, the BS-RS and RS-MS link during one two-hop transmission are allocated in the same frequency band, but different in time slots, which can save the precious frequency resources and increase the spectral efficiency.

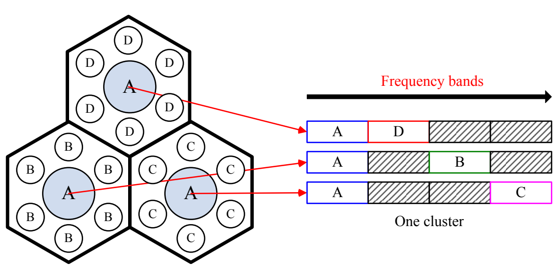

Fig. 3. The SFR frequency allocation scheme

B. The SFR Frequency Allocation Scheme

The concept of “SFR” is first derived from [2], for the purpose that this scheme can efficiently improve cell edge data rates and adapt to the non-uniform traffic distribution. In the SFR scheme, the whole cell is divided into the inner zone and outer zone, in which non-overlapped frequency bands are respectively employed. The frequency reuse factor is between one and three, which means that, the inner zone frequency bands can be reused in each cell, but the outer zone frequency bands in neighboring cells must be orthogonal.

The borrowed SFR scheme is applied to the considered system, as shown in Fig. 3, in which three cells are included in one cluster, and the whole frequency bands are divided into four portions marked by A, B, C and D. The inner zone frequency bands A, which can be reused in each cell, are only employed for BS-MS link, and the outer zone orthogonal frequency bands B, C and D are used for BS-RS and RS-MS link. Of course, the BS-RS and RS-MS link during one two-hop transmission are allocated in the same frequency band, but different in time slots, which can increase the spectral efficiency. In each cell, frequency bands are allocated between the inner zone and outer zone according to the traffic distribution because of the facility for frequency resource scheduling in OFDMA-based system, furthermore, the outer zone frequency bands are also dynamic allocated between the six relay stations. The drawback of the SFR scheme is that, the outer zone frequency reuse factor is still a bit large, so we make some improvement and propose a new frequency allocation scheme in the following.

C. The Modified SFR Frequency Allocation Scheme

In the SFR scheme, although the inner zone spectral efficiency is high, the frequency reuse factor of the outer zone is still not small enough. To further increase the system spectral efficiency, a modified version of the SFR scheme is proposed, as shown in Fig. 4, in which the frequency reuse factor of one can be achieved both in the inner and outer zone.

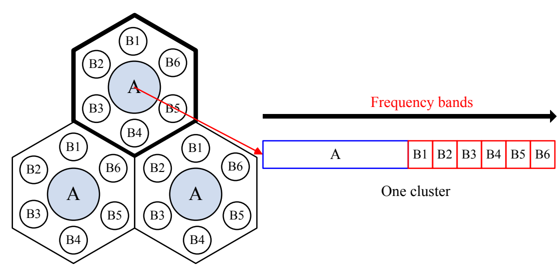

Fig. 4. The MSFR frequency allocation scheme

In the MSFR scheme, the whole frequency bands are divided into two portions, one of which is used in inner zone marked by A, the same as the SFR scheme, and the other portion of the frequency bands in outer zone are further divided into six small equal parts marked by B1 to B6, and they can be reused in neighboring cells. In this way, the inter-cell interferences of outer zone is a bit larger than that in the SFR scheme, but instead, the system spectral efficiency can be greatly increased. In another word, under the assumption that the total frequency bands is a constant, the cell throughput of the MSFR scheme is much larger than that of the SFR scheme because the allocated frequency bands per cell in the MSFR scheme is twice as many as that in the SFR scheme. Furthermore, in each cell, frequency bands are allocated between the inner zone and outer zone according to the traffic distribution, the same as that in the SFR scheme, and the subsequent simulations also demonstrate that, more benefits can be obtained by the aforementioned two proposed schemes under the non-uniform traffic distribution in comparison with the PreF scheme, in which the frequency resources are allocated in a fixed way.

III. Simplified Interference Analysis

In the considered system, the signal-to-interference and noise power ratio (SINR) of users is of great importance in evaluating the system performance. In this section, simplified user SINR analysis is provided with the aforementioned two proposed frequency allocation schemes, as well as the PreF scheme in [1]. First of all, several assumptions are made as follows:

- The system is fully loaded.
- MS follows the same distribution in all cells.
- The effect of the small-scale fading is omitted.
- The path-loss model for any link with transmitter-receiver distance d is:

$$PL(d) = \left(\frac{4\pi d_0}{\lambda}\right)^2 \cdot \left(\frac{d}{d_0}\right)^\gamma \tag{1}$$

where, wave length $\lambda = f_c/c_0$, carrier frequency $f_c = 2$GHz, speed of light $c_0 = 3 \cdot 10^8$m/s, reference distance $d_0 = 10$m, and $\gamma = 3.76$ is the path-loss exponent.

The users in the central cell are considered, which can be a direct transmission with the BS or a two-hop transmission through a RS. Denote P_B as the transmit power of BS, P_R as that of RS, L_b, L_r, L_B, L_R as the distance between the considered users and their served BS, RS, and r_{ij}, D_i, d_{ij} as the distance between the considered users and the dominant interfering BS, RS.

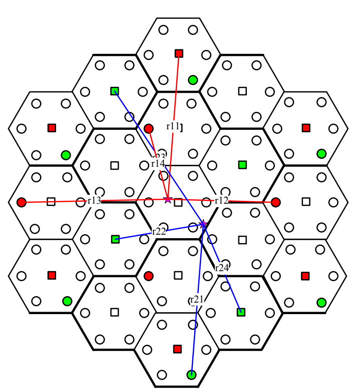

Fig. 5. Interference case for PreF frequency allocatoin scheme

For the PreF scheme, in which a RS reuses the frequency bands of its neighboring cell BS, the interference case is as shown in Fig. 5 (the repetitious distances are omitted), where the one-hop user served by the BS is interfered by the surrounding six BSs and four RSs (red points), while the interferences of the two-hop user come from six RS interfering sources and four BS interfering sources (green points). Then, the user SINR is expressed as follows, and refer to [9] for details of interference analysis for the PreF scheme.

$$\Gamma^{bs}(L_b, r_{1i}) = \frac{L_b^{-\gamma}}{6r_{11}^{-\gamma} + (r_{12}^{-\gamma} + r_{13}^{-\gamma} + 2r_{14}^{-\gamma}) \cdot P_R/P_B} \tag{2}$$

$$\Gamma^{rs}(L_r, r_{2j}) = \frac{L_r^{-\gamma}}{6r_{21}^{-\gamma} + (2r_{22}^{-\gamma} + r_{23}^{-\gamma} + r_{24}^{-\gamma}) \cdot P_B/P_R} \tag{3}$$

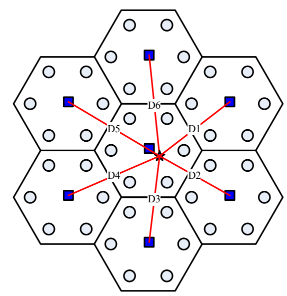

Fig. 6. Interference case for inner zone users

Now we come to the interference analysis of the two our proposed frequency allocation schemes. First the inner zone one-hop user is considered, as shown in Fig. 6, and the interference case of users in inner zone is almost the same for the SFR and MSFR schemes. Then, the SINR of inner zone users can be expressed as follows, where the most dominant six interfering BS in the inside track cells are considered only.

$$\Gamma^{BS}(L_B, D_i) = \frac{P_B/PL(L_B)}{\sum_{i=1}^{6} P_B/PL(D_i)} = \frac{L_B^{-\gamma}}{\sum_{i=1}^{6} D_i^{-\gamma}} \tag{4}$$

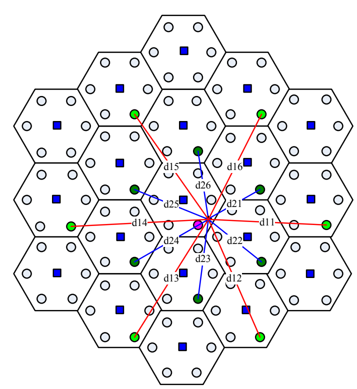

Fig. 7. Interference case for outer zone users

Next, the interference case of the outer zone two-hop users for the two proposed schemes is enormously different, as shown in Fig. 7. For the SFR scheme, the frequency reuse factor of outer zone users is three, which means that the considered user (beside the pink point in Fig. 7) is interfered by the RS in the non-neighboring cells (the light green points).

But for the MSFR scheme, outer zone frequency reuse factor is one, so the most dominant six interfering RS is in the neighboring cells (the heavy green points). Now the SINR of outer zone user for the two frequency allocation schemes $\Gamma^{RS}(L_R, d_{1j})$ and $\Gamma^{RS}(L_R, d_{2j})$ can be expressed as follows:

$$\Gamma^{RS}(L_R, d_{1j}) = \frac{P_R/PL(L_R)}{\sum_{j=1}^{6} P_R/PL(d_{1j})} = \frac{L_R^{-\gamma}}{\sum_{j=1}^{6} d_{1j}^{-\gamma}} \qquad (5)$$

$$\Gamma^{RS}(L_R, d_{2j}) = \frac{P_R/PL(L_R)}{\sum_{j=1}^{6} P_R/PL(d_{2j})} = \frac{L_R^{-\gamma}}{\sum_{j=1}^{6} d_{2j}^{-\gamma}} \qquad (6)$$

Provided the SINR of the user is got, the throughput can be calculated by the following formula:

$$T = B \cdot log_2(1 + \beta \cdot \Gamma) \; bps \qquad (7)$$

where, B is the frequency bandwidth of the user, and β is a constant for the user's $BLER$ requirement $BLER_{threshold}$, which is specified as [10]:

$$\beta = \frac{1.5}{-ln(5 \cdot BLER_{threshold})} \qquad (8)$$

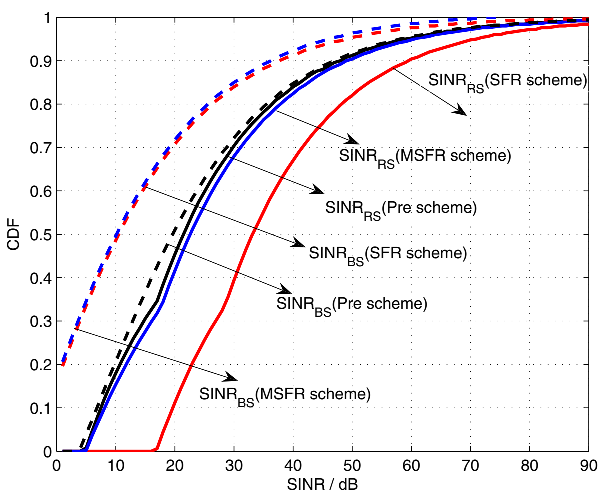

Fig. 8. SINR CDFs under the cell radius of 500m

In order to compare the three frequency allocation schemes, their SINR CDFs are plotted in Fig. 8, in which the cell radius is 500m. It is observed that, for the one-hop user, the SINR performance of the PreF scheme obviously outperform the other two schemes, because the inner zone frequency reuse factor is one both in the SFR and MSFR schemes which can induce higher inner zone interferences. And for the two-hop user, the SFR scheme has visible superiority due to its orthogonal outer zone frequency allocation. To sum up, the PreF and SFR scheme have almost the same SINR performance, while the MSFR scheme introduces more interferences to the system, instead, it can reduce the frequency reuse factor so as to enhance the system spectral efficiency. Subsequent simulations also demonstrate that, under the same total frequency bands, almost the same cell throughput can be achieved in the PreF and SFR schemes for the uniform traffic distribution, and the MSFR scheme can provide nearly twice cell throughput as large as that in the other two schemes.

IV. Simulations and Discussions

In the simulations, the downlink of a OFDMA based multihop cellular system is considered, which consists of 19 omni hexagonal cells. In each cell, a BS and six RSs are respectively located at the cell center and edge, and each RS is on the line that connects BS and cell vertices, and 2/3 away from the BS. The total system frequency bands are assumed to be 40MHz, which means that, for the PreF and SFR schemes, the frequency bands per cell is 20 MHz, while the MSFR scheme has the cell frequency bands of 40MHz duo to its efficient frequency reuse factor. The system is assumed to be fully loaded with 40 users per cell. The transmit power of BS and RS are assumed to be 20w and 1w, respectively. The passloss model is expressed in formula (1), and a lognormal random variable with a standard deviation of 8dB is for shadowing effects capture. Finally, the noise power spectral density is expressed in $N_0 = K_0 \cdot T$, where K_0 is a constant of $1.38 \cdot 10^{-23} J/K$, and $T = 300K$ is the environment temperature.

To further increase the system throughput and to extend the high data rate coverage, the adaptive modulation and coding (AMC) is introduced into the considered system. The combinations of three modulation schemes (QPSK, 16-QAM, 64-QAM) and several code rates are considered, which are "QPSK, rates 1/3 1/2 2/3", "16-QAM, rates 1/2 2/3 3/4", "64-QAM, rates 2/3 3/4 6/7". In this paper, the users' BLER requirement is considered as 0.1, which corresponds to the SINR thresholds as $\Gamma_{SINR} = [3.5, 5, 8, 11, 13.5, 15, 19, 21, 24]$ dB.

The non-uniform traffic situation is also considered, and a traffic load factor α is introduced, which is defined as the number of inner zone users divided by the outer zone user number. For example, "$\alpha = 1$" means the uniform traffic distribution, and "$\alpha = 4$" means 32 users locate in the outer zone, while 4 users in the inner zone.

A. Cell throughput under uniform traffic distribution

Cell throughput is a significant guideline to the system level simulation, and Fig. 9 gives the cell throughput vs. different cell radius for the uniform traffic distribution. As can be observed that, a slight superiority can be achieved by the PreF scheme in comparison with the SFR scheme under the small cell radius because of a bit larger inner zone interferences induced by the SFR scheme, but both have almost the same performance when the cell radius becomes large, because at this situation the interferences reduce to the noise level which can be neglected. Another attractive thing is that, the MSFR scheme provides nearly twice cell throughput as large as that in the other two schemes even though it introduces larger interferences into the system, because under the same total frequency bands, the per cell frequency bands allocated in the MSFR scheme can be twice more than that in the other two schemes in virtue of its highly efficient frequency reuse factor.

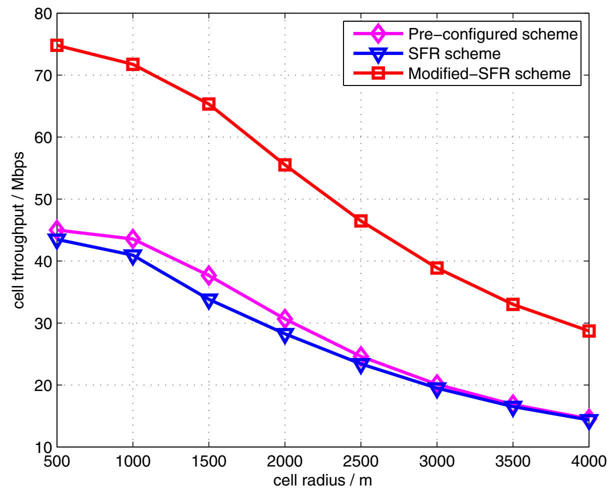

Fig. 9. Cell throughput for uniform traffic distribution

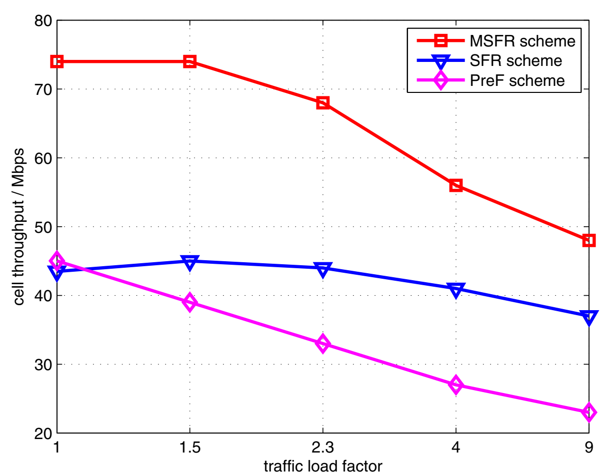

Fig. 10. Cell throughput vs. different traffic load factor

B. Cell throughput under non-uniform traffic distribution

In most cases, the cell with non-uniform traffic distribution is more realistic, and a traffic load factor α is introduced to reflect this situation. Figure. 10 shows the cell throughput vs. different traffic load factor α under the cell radius of 500m. It can be observed that, when the traffic load factor is more than one ("$\alpha = 1$" corresponds to the uniform traffic distribution which is expressed in Fig. 9), the cell throughput of the SFR and MSFR schemes outperforms the PreF scheme all the while because of the support to dynamic frequency resource allocation in our proposed schemes. And as the traffic load factor increases, the cell throughput of the PreF and MSFR schemes decrease obviously, the reasons of which can be explained, respectively, the fixed way to allocate frequency resources in the PreF scheme and larger outer zone interferences in the MSFR scheme. Moreover, the SFR scheme is not sensitive to the different traffic load factor.

V. Conclusions

Two spectral efficient frequency allocation schemes for the multihop network are proposed in this paper. The concept of "soft frequency reuse" in [2] is first borrowed, and applied to the multihop cellular network. Then, the improvement is made to the SFR scheme, and a modified SFR frequency allocation scheme is proposed, which is a better tradeoff between the frequency reuse factor and the inter-cell interferences. Although the MSFR scheme brings a bit more interferences into the system, it can highly improve the system spectral efficiency. Through our simulations, it is demonstrated that, almost the same cell throughput can be achieved in the PreF and SFR schemes for the uniform traffic distribution, and the MSFR scheme can provide nearly twice cell throughput as large as that in the other two schemes. Moreover, the SFR and MSFR schemes both outperform the PreF scheme for the non-uniform traffic distribution because of the support to dynamic frequency resource allocation in the proposed schemes.

Acknowledgment

The author would thank Ding Xu, Yu Zhang and Yang Lu for their helpful discussions and suggestions. Their support is gratefully acknowledged.

References

[1] H. Hu and H. Yanikomeroglu, "Range Extension without Capacity Penalty in Cellular Networks with Digital Fixed Relays", *IEEE Globecom 2004*, pp.3053-3057

[2] R1-050507, "Soft Frequency Reuse Scheme for UTRAN LTE", Huawei

[3] H. Yanikomeroglu, D. D. Falconer, and V. Sreng, "Coverage enhancement through two-hop peer-to-peer relaying in cellular radio networks", *World Wireless Research Forum* meeting no.7, 3-4 December 2002, Eindhoven, the Netherlands

[4] R. Pabst, "Relay-based Deployment Concepts for Wireless and Mobile Broadband Radio", *IEEE Communications Magazine*, vol.42, no.9, Sep.2004, pp.80-89

[5] H. Yanikomeroglu, "Fixed and Mobile Relaying Technologies for Cellular Networks", *2nd Wksp. Apps and Svcs. in Wireless Networks*, Paris, France, 3-5 July 2002, pp.75-81

[6] Tao Liu, Ping Li, "Radio Resource Allocation in Two-hop Cellular Relaying Network", *VTC 2006-Spring*. IEEE 63rd vol 1, 2006 Page 91-95

[7] Tao Liu, Mengtian Rong, et, "Reuse Partitioning in Fixed Two-hop Cellular Relaying Network", *IEEE WCNC 2006*, vol.1, April.2006, pp.177-182

[8] V. Sreng, H. Yanikomeroglu and D. D. Falconer, "Relayer Selection Strategies in Cellular Networks with Peer-to-Peer Relaying", *IEEE VTC'2003*, vol.3, Oct.2003, pp.1949-1953

[9] Ping Li, Mengtian Rong, Tao Liu, Dan Yu, "Interference Modeling and Analysis in Two-hop Cellular Network with Fixed Relays in FDD Mode", *International Conference on Wireless Communications*, Networking and Mobile Computing 2005, 24-25 September, pp. 427-431

[10] A. J. Goldsmith, S. G. Chua, "Variable-Rate Variable-Power MQAM for Fading Channels", *IEEE Trans. Commun*. Vol.45, NO.10, pp.1218-1230, Oct.1997