

Frequency and Subcarrier Reuse Partitioning for FH-OFDMA Cellular Systems

Yeonwoo Lee[†], Kyung-Ho Kim[†]

ABSTRACT

One of the most serious factors constraining the next generation cellular mobile consumer communication systems will be the severe co-channel interference experienced at the cell edge. Such a capacity-degrading impairment combined with the limited available spectrum resource makes it essential to develop more spectrally efficient solutions to enhance the system performance and enrich the mobile user's application services. This paper proposes a unique hybrid method of frequency hopping (FH) and subcarrier-reuse-partitioning that can maximize the system capacity by efficiently utilizing the available spectrum while at the same time reduce the co-channel interference effect. The main feature of the proposed method is that it applies an optimal combination of different frequency reuse factors (FRF) and FH-subcarrier allocation patterns into the partitioned cell regions. From the simulation results, it is shown that the proposed method can achieve the optimum number of subcarrier subsets according to the frequency-reuse distance and results in better performance than the fixed FRF methods, for a given partitioning arrangement. The results are presented in the context of both blocking probability and BER performances. It will also be shown how the proposed scheme is well suited to FH-OFDMA based cellular systems aiming at low co-channel interference performance and optimized number of subcarriers

Key words: Reuse partitioning, FH-OFDMA, frequency reuse partitioning, reuse factor, subcarrier

1. INTRODUCTION

Drive towards providing multi-media services over wireless links has accelerated in recent years as a result of the rapid growth in the high data rate and high quality packet data transmission systems such as the wireless metropolitan area network (WMAN), mobile broadband wireless ac-

cess (MBWA) and 4G mobile networks [1]. The ability of these systems to support the increasing demands on packet data services for ubiquitous Internet access relies heavily on the choice of a robust and flexible air-interface technique. Orthogonal frequency division multiplexing (OFDM) is largely viewed as a promising air-interface technique that can meet such requirements due to its inherent properties that are well suited to broadband transmission [2]. The feasibility and suitability of OFDM for high data rate transmission has been verified with successful development and commercialization of several wireless systems including digital video and audio broadcasting (DVB/DAB) as well as wireless local area networks (WLANs). Such success has made OFDM a strong candidate as the technique of choice for the next generation of WLANs including the IEEE 802.16 based WMAN and IEEE 802.20 based MBWA [3].

Among the hybrid multiple access schemes

※ Corresponding Author: Yeonwoo Lee, Address: (534-729) Mokpo National Univ. Dept. of Inform. & Comm. Eng., 61, Dorim-Ri, Chunggye-Myon, Mjeon-Gun, Chonnam, TEL: +82-61-450-2745, FAX: +82-61-450-6470, E-mail: ylee@mokpo.ac.kr

Receipt date: Feb. 27, 2013, Revision date: Mar. 15, 2013
Approval date: Mar. 15, 2013

[†] Dept. of Information & Communication Engineering, Mokpo National University

(E-mail: ylee@mokpo.ac.kr, khkim@mokpo.ac.kr)

※ This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education, Science and Technology (Grant No.:KRF-2008-313-D00648).

based on OFDM, frequency-hopping orthogonal frequency division multiple access (FH-OFDMA) combines the advantages of resilience to multipath distortion, full exploitation of the available frequency diversity and flexible resource granularity [4,5]. The frequency hopping part of FH-OFDMA based systems makes it possible to achieve frequency diversity and interference averaging through the dynamic allocation of subcarrier subsets to the different users in a random manner. Such a technique can average the interference during several time-slots as well as reduce the probability that a specific user takes the full impact of a deep fade. Frequency reuse partitioning (FRP) has originally been proposed in [6] as a means to further enhance the spectral efficiency of cellular systems. Such a technique was shown to increase the system capacity and reduce the higher interference levels experienced at the cell's boundary. The FRP technique applies different frequency reuse factors into split smaller cell-areas. In contrast to the fixed channel allocation schemes, the FRP strategy was devised for enhancing poor spectrum utilization in a dynamic fashion. Using this technique, the system is able to allocate the available channels to the mobile users more efficiently and reduces the probability of experiencing higher interference levels by mobile users at the cell's boundary. For a 3G LTE-advanced cellular system adopting OFDMA without FH method, frequency reuse techniques are proposed in previous works [7,8].

To our knowledge there is no information available in the open literature on applying the FRP technique to FH-OFDMA systems and no attempts have been made to provide an insight into the physical characteristics of the OFDM orthogonal subcarrier-subset reuse partitioning. Therefore, in this paper we consider the application of subcarrier-subsets reuse partitioning in combination with a suitable frequency-reuse scheme for FH-OFDMA-based cellular systems. We aim to ana-

lyze the proposed scheme's spectral efficiency and ability to reduce the higher co-channel interference (CCI) level normally incurred at the cell's boundary. In this study, we partition the cell into a number of regions where different FRFs are applied to the different regions of the cell to alleviate the excessive interference at the cell's boundaries. Specifically, to reduce the interference effect to users close to the cell's boundary large FRF values are assigned to the FH-bands that are occupied by those users. On the other hand, relatively smaller FRF values are assigned to FH-bands used by users in the inner regions of the cell closest to the serving base-station. The optimum number of subcarriers corresponding to each FRF value is selected on the basis of improving the error performance and blocking probability of the entire system.

The rest of this paper is organized as follows. The FH-OFDMA system model interference analysis with random frequency hopping pattern is described in the next section. In Section III a detailed discussion of the proposed hybrid frequency reuse and subcarrier reuse partitioning method with the optimized number of carriers is presented. In Section IV the blocking probability and BER error performance are demonstrated by simulation results. Finally, concluding remarks are presented in Section V.

2. FH-OFDMA SYSTEM MODEL WITH RANDOM FREQUENCY HOPPING

2.1 System Model

The block diagram of the modulator and demodulator for this system considered in this paper is depicted in Fig. 1. As can be seen from this figure, the encoded user's signals are passed through serial-to-parallel (S/P) conversion to produce low bit rate data streams. Each of these streams is then passed to a random FH mapper in which the frequency-hopped subcarriers N_{FH} are determined and assigned to their corresponding user for a finite

time-slot. In order to avoid the intra-cell interference, the assigned frequency hopped subcarriers of each of the intra-cell users must be orthogonal to each other. The hopped subcarriers are baseband modulated by the inverse fast Fourier transform (IFFT) and converted back into serial data by a parallel-to-serial (P/S) converter. Prior to RF transmission, each symbol is appended with a cyclic-prefix guard interval (GI) in order to prevent inter-symbol interference (ISI) and preserve the OFDM orthogonality. At the demodulator, these functional blocks are repeated in a reverse order. The demodulator also includes the frequency domain equalizer (FDE) to compensate for independent frequency selective fading that each subcarrier may experience. The FDE stage can coherently combine the energy of the received signal scattered in the frequency domain and undo any phase distortion imposed by the radio channel.

2.2 Signal-to-Interference Ratio (SIR)

In a multiple cellular system scenario, if we assume that the total transmitted power from each cell's base station (BS) using all the subcarriers

is set to P , then each BS sends P/N_{\max} transmission power to each mobile station (MS), where N_{\max} is the maximum number of MS which the system can support. The path-loss can be defined as a function of the distance between the MS and its supporting BS, e.g. the k th BS, $\Gamma(d_k)$. Assuming that the cell has N_u active MS users, then the cell load (CL) factor can be defined by:

$$CL = \Omega = \frac{N_u}{N_{\max}} \quad (1)$$

Without loss of generality and for simplicity of analysis, the CL factor is considered the same in every cell. In order to calculate the hit probability of the used subcarriers, let us begin with the calculation of the occupied subcarriers by the BS of interest (BS0). The number of subcarriers being used for FH can be given by $N\Omega$ according to the cell loading factor and total number of subcarriers (N). Thus, the number of available, or unused, subcarriers can be shown to be $N(1-\Omega)$.

The interference incurred by the n th subcarrier in the k th BS (BS k) is $PT(d_k)/N$ if the k th BS is using the same subcarrier, otherwise the interference is zero. For the calculation of the averaged

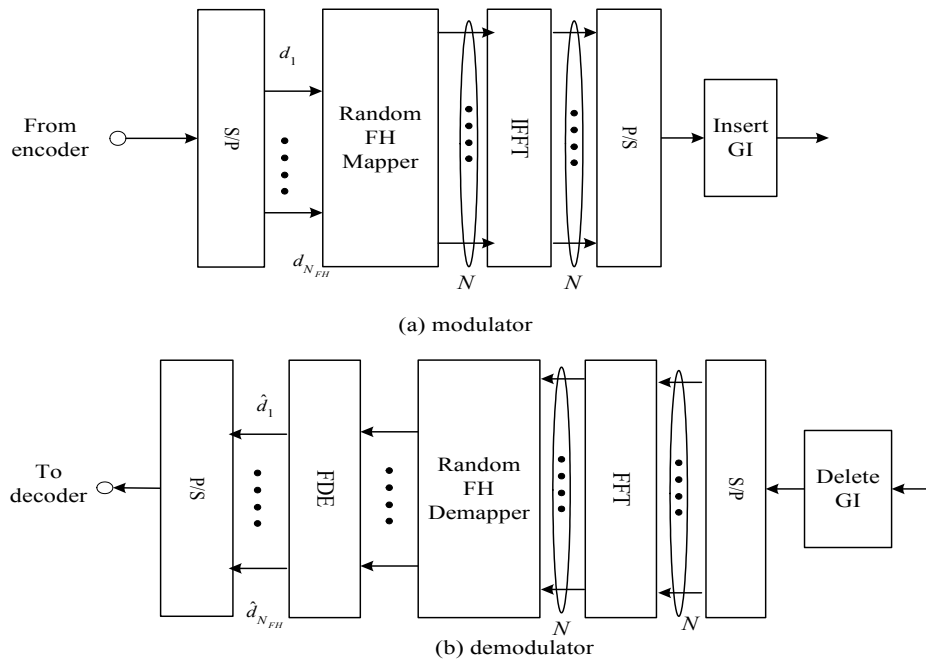


Fig. 1 A simplified block diagram of the modulator and demodulator of the FH-OFDMA system.

hit probability and the SIR value, we need to average out the number of hit (overlapped) subcarriers between the allocated subcarriers in BS0 and BSk. If two BSs perform independent random FH, then the hit probability of the n th subcarrier is defined by:

$$p(i=n) = \binom{N-N\Omega}{N\Omega} \times \binom{N\Omega}{n} \bigg/ \binom{N}{N\Omega}, \quad i=0,1,2,\dots,N\Omega \quad (2)$$

where $\binom{j}{k} = 0$ if $j < k$. With this hit probability in Eq.(2), now we can derive the average number of overlapped subcarriers as follows:

$$E\{i\} = N\Omega^2 \quad (3)$$

Thus, the average number of subcarriers being used for active MS users N_u can be rewritten by

$$E\{i\} = N\Omega^2 / N_u \quad (4)$$

Assuming the transmitted power to each subcarrier from BSk is P/N and using (1) and (4), the average interference caused by the k th BS to BS0 can be derived as

$$E\left\{\frac{P}{N} \frac{i}{N_u} \Gamma(d_k)\right\} = \frac{P\Gamma(d_k)\Omega^2}{N_u} = \frac{P\Gamma(d_k)N_u}{N_{\max}^2} \quad (5)$$

Now, we can get the SIR as the desired signal to the total sum of interference from Kother-cells. This is:

$$SIR = \frac{\frac{P}{N_{\max}} \Gamma(d_0)}{\frac{PN_u}{N_{\max}^2} \sum_k^K \Gamma(d_k)} = \frac{\Gamma(d_0)}{\Omega \sum_k^K \Gamma(d_k)} \quad (6)$$

We can observe from equation (6) that the CL factor has an important impact on deciding the achievable SIR value. Specifically, the larger is the CL factor the lower will be the SIR value that can be achieved. Moreover, equation (6) can be regarded as SIR when using FRF=1 since all the surrounding other-cells are considered. On the contrary to FRF=3, the amount of total interference caused by other-cells is three times lower than that given by (6) for a given spectrum, which results in higher SIR. However, the available spectrum (or sub-

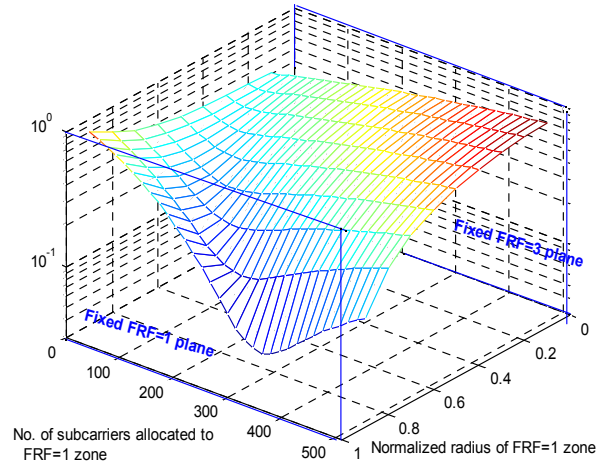


Fig. 2. Average blocking probability as a function of the number of subcarriers allocated to FRF=1 region and the normalized radius of FRF=1 zone with the offered 50 % SL.

carriers) is also reduced down to three times smaller than that of FRF=1. This suggests to us the very interesting point of how to allocate an appropriate number of subcarriers and FRF values in order to achieve higher SIR as well as better throughput performance. In the next section we describe a unique frequency and subcarrier reuse partitioning method that is designed to achieve better control of the CL factor and improve the system efficiency by optimizing the number of subcarriers assigned to each frequency reuse factor as shown in Fig. 2.

3. HYBRID FREQUENCY AND SUB-CARRIER REUSE AND SUB-PARTITIONING DESIGN

3.1 Frequency and Subcarrier Reuse Partitioning Design

In the proposed FH-OFDMA system the subcarriers are grouped into several subsets which are then assigned different FRF values. The subset with a small FRF value is then allocated to the inner region of each cell while the subsets assigned larger FRF values are allocated to the outer regions. The number of subcarriers allocated to

each cell region is optimally chosen on the basis of minimizing the blocking probability. In order to maximize the total system spectral efficiency, the central regions with radius r_{in} utilize an FRF=1. This is feasible to achieve because the amount of co-channel-interference (CCI) from the neighbouring base stations is relatively small in this region. On the other hand, in the boundary regions with radius r_{out} , the proposed scheme applies an FRF=3 to reduce the CCI effect. By partitioning each cell into only two zones, it is possible to maintain sufficient trunk efficiency. It is important to note that the larger the number of partitioned regions per cell the less the available number of channels per zone and therefore the lower will be the trunk efficiency. To further enhance the frequency and interference diversity effect, the subcarriers within a frequency guard (FG) band should be separated in the frequency domain rather than using contiguous subcarrier subsets. The more number of FH bands can be increased however the larger the number of partitioned zones can be expanded and the better the control of the CCI effect will be. In such cases the total spectrum is divided into K-subcarrier subsets and a corresponding set of FRP zones r_1, r_2, \dots, r_k , with each one having a different FRF value, e.g. 1, 3, 4, 7, \dots etc.

In the proposed scheme, the subcarrier subsets with FRF equal to 1 are used in the inner region marked as A (FRF=1 zone) with radius r_{in} and the subsets with FRF equal to 3 are used in the outer regions marked B1, B2, and B3 (FRF=3 zones) with radius r_{out} . When the inner zone is expanded above a normalized reuse distance (r_{in} / r_{out}) of 0.5, there exists a trade-off between the subcarrier subsets allocation and the reuse distance. As a consequence of this, if more than 50% of the channels (or subcarrier subsets) satisfying the required SIR level are allocated to the FRF=1 zone, then the FRF=3 zone must use less than 50% of the channels of a given spectral bandwidth. Note that the FRF=3

zone plays an important role for guaranteeing the suppression of CCI by proper usage of the subcarrier subsets with FRF=3. The proposed scheme in this paper is designed to provide an optimal solution for this trade-off with the optimized FH-subcarrier subsets allocation with respect to the normalized radii of the FRF=1 zone. This results in maximizing the resource utilization and enhances the frequency reuse partitioning.

If we divide the CL factor into two regions such as Ω_A and Ω_B which are respectively defined by $N_{u,A}/N_{max}$ and $N_{u,B}/N_{max}$ where $N_u = N_{u,A} + N_{u,B}$, then we can define the SIR of the proposed scheme $SIR_{FRF=(1,3)}$ as:

$$SIR_{FRF=(1,3)} = \frac{\Gamma(d_0)}{\Omega_A \sum_k^K \Gamma(d_k) + \Omega_B \sum_j^J \Gamma(d_j)} \quad (7)$$

where the first term in the denominator is the contribution of the A-region from K other-cells and the second term is from the same B-regions (B1, B2, or B3, i.e. FRF=3 zone), and J is approximately equal to K/3 other-cells in(6). It is noticeable that SIR can be controlled by appropriately allocating the active MS users, i.e. assigning the number of subcarriers according to each FRF zone. As mentioned before, there exists a trade-off between the optimized number of subcarriers (i.e. resource channel) and the FRF zone. The insight on blocking probability and BER are discussed and compared by introducing a new cost function (7) and using the simulation study in the following sections.

3.2 Optimization of the Number of Subcarriers

Assuming that the same number of active MSs are uniformly distributed in each cell and that they arrive according to a Poisson process with an arrival rate, λ (call/cell), the offered traffic load at each zone can be defined by $\rho_A = \lambda_A / \mu$ and $\rho_B = \lambda_B / \mu$ where μ is the mean call duration and the new call arrival rates in each zone are $\lambda_A = \lambda(r_{in}^2 / r_{out}^2)$ and $\lambda_B = \lambda - \lambda_A$, respectively. Let C_A and C_B be the

number of channels allocated to the A and B regions respectively; then, we have the constraint $C_A + 3C_B \leq M$ where M is the total available channels in a cellular system, given by: the total number of subcarriers / number subcarriers per user. Thus, the cost function can be given in terms of an average blocking probability [9] as:

$$\min \left\{ \frac{\lambda_A}{\lambda} \left(\frac{(\rho_A)^{C_A} / C_A!}{\sum_{k=0}^{C_A} \rho_A^k / k!} \right) + \frac{\lambda_B}{\lambda} \left(\frac{(\rho_B)^{C_B} / C_B!}{\sum_{k=0}^{C_B} \rho_B^k / k!} \right) \right\} \quad (7)$$

To obtain an optimized FRF value and the corresponding optimized number of subcarriers to allocate to each region, we need to find C_A and C_B that minimize the cost function in (7). However, the cost function in (7) is highly nonlinear and therefore we determine C_A and C_B by relying on a numerical method. For the numerical analysis of (7), we assume that each cell has a 300 m radius, with a total of 512 subcarriers allocated to the system, and each FH consists of 16 subcarriers N_{FH} (i.e. $M=512/16 = 32$). The loading for all base stations is the same on average. Let the system load (SL) be the total number of subcarriers used by the active users per cell over the total available subcarriers per system:

$$SL = (C_A + C_B) / M \quad (8)$$

where the SL factor is half of the CL factor since the later considers the total spectrum of the system, whereas the former takes only the allocated spectrum of the cell into account. For the proposed FRF=(1, 3) system, only half of the total spectrum is used in each region. Based on these parameters for the 50% offered SL (thus, 100% offered CL), the average blocking probability of the proposed scheme as a function of the number of subcarriers allocated to FRF=1 zone and normalized radius of FRF=1 zone is shown in Fig. 2.

Here, the costfunction is demonstrated as a function of the number of subcarriers allocated to FRF=1 zone ($C_A N_{FH}$), while $(M - C_A) N_{FH} / 3$ subcarriers are allocated to the FRF=3 zone. The fixed FRF=3 plane as shown in Fig. 3 with the normal-

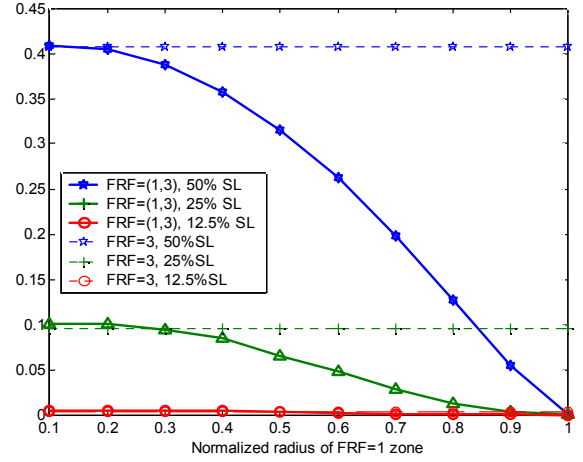


Fig. 3. Average blocking probability comparison of the fixed FRF=3 and the proposed FRF=(1, 3) with the optimized number of subcarriers as a function of the normalized radius of FRF=1 zone (r_{in}/r_{out}) for various offered SL.

ized reuse distance (r_{in}/r_{out}) set to 0 indicates the conventional fixed FRF=3 scheme since there is no FRF=1 region. On the other hand, $r_{in}/r_{out} = 1$ stands for the conventional fixed FRF=1 scheme (i.e. fixed FRF=1 plane as shown in Fig. 3). In terms of blocking probability versus number of allocated subcarriers, it is observed that the fixed FRF=3 is less sensitive to the allocated number of subcarriers, whereas the fixed FRF=1 has global minimum point. This leads us to an optimization problem as to how many number of allocated subcarriers is needed to both FRF=1 zone and FRF=3 zone in the proposed FRF=(1, 3) scheme.

Fig. 2 shows that with the optimized number of subcarriers based on minimizing the costfunction (i.e. the minimum points) of the proposed scheme can outperform the fixed FRF cases and guarantee the lowest blocking probability throughout the entire cell area. This is done by allocating the number of subcarriers used at different FRF zones and adjusting the maximum radius of the FRF=1 zone (i.e. frequency reuse distance) according to the traffic variation. To help more understand this, Fig. 4 shows the average blocking probabilities of the fixed FRF=3 with the maximum number of sub-

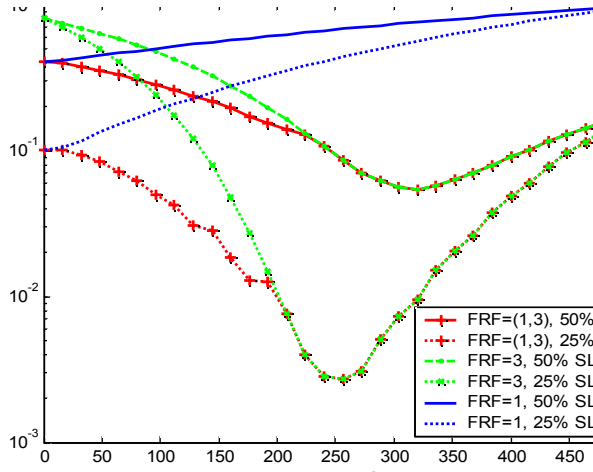


Fig. 4. Average blocking probability comparison of the proposed FRF=(1,3) and others as a function of the number of allocated subcarriers to FRF=1 zone.

carriers ($MN_{FH}/3$), when $C_A=0$ compared to the proposed FRF=(1,3) design scheme with the optimized number of subcarriers, as a function of the normalized radius of FRF=1 zone (r_{in}/r_{out}) for various offered SL values. The solid lines of Fig. 3 show the minimum cost function when using the optimized number of subcarriers according to the normalized radius of FRF=1 zone for the 50% offered SL. As shown in Fig. 3, the proposed FRF=(1,3) design scheme can guarantee lower average blocking probability than that of the fixed FRF=3 for every offered load condition and various normalized radius of FRF=1 zone. It is noticed that when the FRF=1 zone expands, the plentiful subcarrier resource available in the FRF=1 zone can ensure the lowest blocking probability of the overall system.

The impact of the number of subcarriers allocated to FRF=1 zone on the average blocking probability performance for each design scheme is shown in Fig. 5. Note that for the fixed FRF=3 design, the actual number of allocated subcarriers is given by the total 512 subcarriers - number of allocated subcarriers to the FRF=1 zone. We can see that the larger number of allocated subcarriers to the FRF=1 zone (thus, the smaller number of sub-

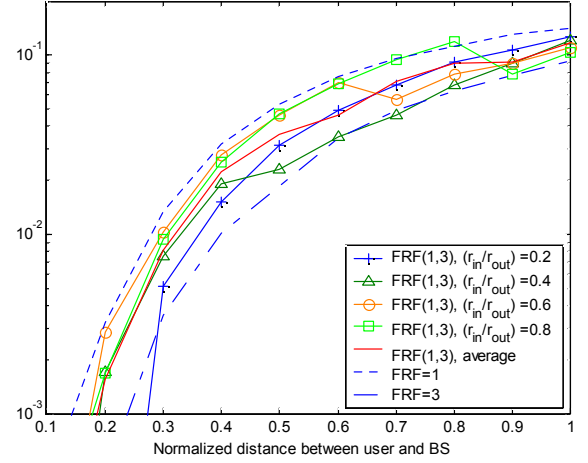


Fig. 5. Bit error rate of the proposed scheme, FRF=(1, 3), as a function of the normalized distance between the users and BS (d_{MB}) for different normalized radii of FRF=1 zone (r_{in}/r_{out}) and the fixed FRF.

carriers to FRF=3), the higher average blocking probability. This means that not enough subcarriers allocation to the users causes more frequent call blocks in the outer zone. On the other hand, for the fixed FRF=1, the minimum blocking probability performance is achieved at a specific number of allocated subcarriers. It is shown that the proposed FRF design scheme can guarantee the lowest blocking probability. This implies that the combination of a well designed subcarrier allocation scheme, which considers the traffic load, and the appropriate frequency reuse partitioning and its corresponding zone decision can accomplish the best blocking performance.

As stated before, the proposed design delivers the global minimum points at every allocated subcarrier and offered load conditions. For the traffic aware system, the mapping table function of the optimized number of subcarriers and FRF=1 zone radius should be built up for all varying traffic situations. Note that these numerical results show that the proposed scheme can deliver the lowest blocking probability, but the CCI effect at the cell boundary on the system performance is not taken into account. Therefore, there still exists a trade-off between the blocking probability and the

practical bit error rate (BER) performance. This impact is taken into account by carrying out physical-layer simulation study which will be discussed in the following section.

4. PHYSICAL LEVEL SIMULATION RESULT

In this section we assess the efficiency of the proposed method in terms of the bit error performance of the OFDMA system illustrated in Fig. 1. The subcarriers allocated to each FH group are randomly chosen within those having the same FRF assignment in every symbol time. In other words, the OFDMA system considered employs fast FH with random hopping sequences. The OFDMA system employs QPSK modulation at each subcarrier with 1/2 rate convolutional coding. The assumed total system bandwidth is 20MHz and the noise spectral density is -174dBm/Hz with 8dB noise figure. The transmitting power from the BS is set to 33dBm with 18dBi antenna gain. The pathloss is considered to have a Log-distance model with the pathloss exponent=4 and a Lognormal fading variance of 8dB. In addition, a 3-tap delay-line pedestrian channel model [10] is used to simulate the frequency selective fading.

The BER evaluation of the proposed scheme is shown in Fig. 5 as a function of the normalized distance between the users and the BS d_{MB} for different normalized radii of the FRF=1 zone and compared to the fixed FRF cases. We can observe that the proposed hybrid subcarrier allocation and FRP can achieve significant reduction in the CCI effect and improve the BER performance especially close to the cell edge, compared to that of the fixed FRF=1. This will always be true when r_{in}/r_{out} is larger than d_{MB} , otherwise, it is only better than that of the fixed FRF=1 and slightly worse than the fixed FRF=3. Thus, considering the results of Fig. 2, 3, 4 and 5 together, it is clear that the proposed scheme can provide a minimum blocking

probability along with a reduced CCI level at the cell boundary. Therefore, an overall system performance improvement can be achieved when different FRFs are used for the different zones and FH-subcarrier subsets allocation that minimize the cost function.

5. CONCLUSION

This paper has discussed the application of FH-subcarrier subset reuse partitioning and frequency reuse partitioning to FH-OFDMA mobile consumer communication systems. From the numerical and simulation results, it was shown that a high spectral efficiency and CCI level suppression can be obtained when assigning the optimized number of random FH-subcarriers and corresponding frequency reuse distance. It was also shown that the FH-OFDMA system with the proposed FRF design scheme is a promising multiple access option employing strong FH feature to tackle the fading effect and provide higher spectral efficiency. The proposed design can be further expanded to a multiple frequency reuse partitioning approach at the cost of some trunk efficiency and error performance.

REFERENCES

- [1] J. Chuang and N. Sollenberger, "Beyond 3G: Wideband Wireless Data Access Based on OFDM and Dynamic Packet Assignment," *IEEE Communications Magazine*, pp. 78-87, Vol. 38, Issue 7, 2000.
- [2] Ju-Phil and Choi, "Performance Evaluation of AMC in Clustered OFDM System," *Journal of Korea Multimedia Society*, Vol. 8, No. 12, pp. 1623-1630, 2005.
- [3] *IEEE 802.20 Working Group; Mobile Broadband Wireless Access (MBWA)*, ITU-T Recommendation Y.1541, 2009.
- [4] R. Nee and R. Prasad, *OFDM for Wireless*

Multimedia Communications, Artech House Publisher, MA, USA, 2000.

- [5] M. Jankiraman and R. Prasad, "Performance Evaluation of Hybrid OFDM/CDMA/SFH Approach for Wireless Multimedia," *Proc. IEEE- VTS Fall VTC 2000*, Vol. 2, pp. 934-941, 2000.
- [6] J. Zander and M. Fordigh, "Capacity Allocation and Channel Assignment in Cellular Radio Systems using Reuse Partitioning," *IEE Electronics Letters*, Vol. 28, (5), pp. 438-440, Vol. 28, Issue 5, 1992.
- [7] Xuehong Mao, A. Maaref, Koon Hoo Teo, "Adaptive Soft Frequency Reuse for Inter-Cell Interference Coordination in SC-FDMA Based 3GPP LTE Uplinks," *Proc. IEEE GLOBECOM 2008*, pp. 1-6, 2008.
- [8] Yu, Yiwei, E. Dutkiewicz, Xiaojing Huang, M. Mueck, Gengfa Fang, "Performance Analysis of Soft Frequency Reuse for Inter-Cell Interference Coordination in LTE Networks," *Communications and Information Technologies (ISCIT), 2010 International Symposium on. IEEE*, pp. 504-509, 2010.
- [9] P.H.J. Chong and C. Leung, "Performance Analysis of Reuse Partitioning with Mobile Users," *Proc. IEEE ICC'99*, pp. 1852-1858, 1999.
- [10] ETSI TR 101 112:ETSI; *Selection Procedures for the Choice of Radio Transmission Technologies of the UMTS*, 2005.



Yeonwoo Lee

is currently a Professor with the Dept. of Information and Communications Eng. at the Mokpo National University, Mokpo, Chonnam, Korea, since Sep. 2005. He has been a senior researcher with 4G mobile com-

munication team at the Samsung Advanced Institute of Technology(SAIT) from Jan. 2004 to Aug. 2005. From Oct. 2000 to Dec. 2003, he has been a Research fellow with the School of Electronics and Engineering at the University of Edinburgh, UK. He received a MS and Ph.D. in Dept. of Electronics Eng. from Korea University, Seoul, Korea, in 1994 and 2000, respectively. His research interests are wireless multimedia communications, cognitive radio, IT convergence technologies.



Kyung-Ho Kim

is currently a Professor with the Dept. of Information and Communications Eng. at the Mokpo National University, Mokpo, Chonnam, Korea, since Mar. 1987. He received MS and Ph.D. in Dept. of Electronics Eng.

from Chosun University in 1983 and 1993, respectively. He also has a Ph.D. from Howard University, USA in May 2000. His research interests are communication networks, data networks, system integration, next generation wireless communication network.