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Interference Situation Adaptation Scheme for Organized Beam-hopping Based Systems

HONGLIN HU, MARTIN WECKERLE, JIJUN LUO, and EGON SCHULZ
Siemens AG Communications, Future Radio
Com MN PG NT RI 4, St. Martin Str. 76, D81541, Munich
GERMANY

Abstract: - In organized beam-hopping (OBH) based systems, the organized hopping pattern is changeable according to the distribution of the mobile stations (MS) in the cell. However, the changed beam-hopping patterns may cause severe co-channel interference for the users which are hit by more than one beam. In this paper, we develop an interference situation adaptation scheme for OBH-based systems. The interference situation adaptation scheme is based on the required quality-of-service (QoS) of the user, and helps the users to avoid severe co-channel interference. Specifically, the data transmission will adaptively select a separately serving mode, a diversity mode, or even a data splitting mode.

Key-Words: - Organized beam-hopping, interference, adaptation, beamforming.

1 Introduction

Opportunistic beamforming (OB) technique induces random fading, hence increases the performance of multiuser diversity greatly [1]. However, if the number of users is small, the performance of the opportunistic beamforming technique is not so satisfactory. Moreover, the opportunistic beam-forming technique relies on the training sequences to estimate the real-time signal to interference plus noise ratio (SINR) of each activated beam (or weighting vector) for each user, thus costs a large amount of system resources.

In our previous research, we proposed a new organized beam-hopping (OBH) scheme [2]. The basic idea of OBH scheme is to hop the beamforming vectors in an organized pattern, rather than randomly select a beamforming vector as in the opportunistic or random beamforming schemes. In the OBH-based systems, each BS firstly forms a number of predefined beams that allow covering the whole cell or sector. Then, the base station (BS) is assigned with a specific beam-hopping pattern, which is a list containing beams (channels) of operation in the specific order of hopping. According to the beam-hopping pattern, the BS pseudo randomly hops the transmitted beam among the predefined beams at a given fixed hopping rate. Between a certain number of consecutive hops the BS transmits an omni-directional broadcast signal. This broadcast signal contains synchronization sequences as well as the information about the used beam-hopping pattern, i.e. the table describing the order of hops, and the information about the next used beam number.

When a mobile station (MS) enters the cell, it firstly synchronize itself with the serving BS, then it obtains the information about the hopping pattern and the number of the next used beam from the broadcasted system information. We assume a full power transmission scheme has been adopted by all the BSs. The MS measures the broadcasting signal from the detectable BSs, and then anticipates the received signal power from the BSs when they use the next beams. Furthermore, the MS feeds back the expectable SINR information to the BS. According to the feedback information and its scheduling policy, e.g., round robin (RR), first come first serve (FCFS), shortest job first (SJF), etc., the BS decides to which MS the data should be transmitted when using the ith beam.

In the initialization of the OBH-based system, the orthogonal beam-hopping pattern is temporally assigned for adjacent cells, in order to decrease inter-cell co-channel interference. However, the organized pattern is changeable according to the distribution of the MS in the cell. If there is no feedback information for one beam, the BS will ignore this beam during the next hopping round, until one MS feeds the information back for this beam and the BS needs to re-activate this beam according to the scheduling policy. Consequently, the OBH scheme could achieve good performance in the scenarios of both large and small number of users. In addition, with only effective SINR feedback, the uplink traffic and signal processing efforts at the BS are highly reduced in the OBH-based systems.

The change of the beam-hopping pattern enables the OBH-based system to avoid the case that some of the beams in the pattern could not hit any MS or some MSs could not be hit by all the organized beams. However, the changes might destroy the orthogonality between the beam-hopping patterns by occurring possible hits of beams from adjacent cells, i.e., point to the same area. As a result, if the frequency reuse factor is 1 for adjacent cells, the changed beam-hopping patterns may cause severe co-channel interference for the users which are pointed by more than one beam. Especially, when a MS is at the boundary of a cell, and the beams from the adjacent cells are pointing at it at the same time, the co-channel interference power will be probably at the same level of the transmitted signal power. Also, the handoff for the MS in this case could not be processed.

In this paper, we propose an interference situation adaptation scheme for the OBH-based systems. The interference situation adaptation scheme is especially useful when there are several beams pointing to the same user at the same time.

2 Interference Situation Adaptation Scheme

Since the changed beam-hopping patterns may cause severe co-channel interference for the individual users, it will be helpful if the MS measures the broadcasting signal from the detectable BSs, and then anticipates the received signal power from the BSs when they use the next beams. Consequently, based on the estimation of the future signal and/or co-channel interference power, the MS will find whether it needs to be served only by one BS, or by multiple BSs. In other words, the MS will decide whether it needs a separately serving mode, a diversity mode, or even a data splitting mode and report its preferred mode back to the BS. Here we note that the decision could also be conducted at the BSs, based on the feedback of the MSs.

2.1 Separately Serving Mode

In the separately serving mode, the MS transmit the data with only one BS, while enduring the co-channel interferences from the other BSs. Separately serving mode typically happens when the MS is quite near to one BS and far away from the other BSs. In this case, the received signal power from the nearby BS is much higher than the co-channel interferences from the far away BSs. As a result, even if the beam-hitting happens, separately serving mode is enough to support the required quality-of-service (QoS) of the MS.

2.2 Diversity Mode

In the diversity mode, the MS requests multiple BSs to communicate with it at the same time. Diversity mode is applied when the received signal from each BS respectively is not powerful enough to support the required QoS of the MS, unless macroscopic space diversity is exploited. For example, when the MS is at the boundary of the cells and beam-hitting happens, the received signal power from the neighboring BSs will be at the same level. In such a scenario, macroscopic space diversity will be an advisable choice. With the macroscopic space diversity, the MSs in the OBH-based system will not suffer from the severe co-channel interference. On the contrary, even the orthogonality of the beam-hopping patterns is disturbed, the users which are pointed by multiple beams from different BSs could benefit from macroscopic space diversity. If more than one active MS is located in the nearby place, they could benefit from the diversity mode according to the scheduling algorithms. For example, they could be served one by one in time domain and the total throughput will not decrease.

2.3 Data Splitting Mode

In the case that either the channels between the two BSs and the MS are perfectly known prior to transmission or the data link with each BS is good enough and could be separated by, e.g., orthogonal codes, it is also possible to apply a data splitting mode. In the data splitting mode, the MS communicates with multiple BSs simultaneously, by receiving from the two BSs and transmitting to the BSs different data streams. In this mode, radio resources from the serving BSs for the MSs will be considered as a single server, so that the trunking gain and multiplexing gain resulting in less service response time can be obtained. However, for the data splitting mode additional system requirements have to be considered. Due to the limitation of the paper, in the following performance evaluation, we only analyze the separately serving mode and the diversity mode.

When we ignore the data splitting mode, the generally idea of the proposed interference situation adaptation scheme could be illustrated by Fig. 1. That is, when the MS is close enough to a BS, it will apply a separately serving mode. However, when the MS moves to the cell border and the interference situation could no more sustain the required QoS, the transmission will change into diversity mode.

3 Performance Evaluations

In the following performance evaluation, we consider a coherent detection of two kinds of typical digital signals, namely square M-ary quadrature amplitude modulation (MQAM) and M-ary phase-shift keying (MPSK). For an L-channel maximal ratio combining (MRC) reception of MPSK signal, it can be shown that the average symbol error rate (SER) $\overline{P}_{e,\text{MPSK}}$ can be given by [3]

$$\overline{P}_{e,\text{MPSK}} = \frac{1}{\pi}\int_0^{(M-1)\pi/M}\prod_{l=1}^{L} I_l\left(\overline{\gamma}_l, g_{\text{MPSK}}, \theta\right)d\theta, \quad (1)$$

where

$$I_l\left(\overline{\gamma}_l, g_{\text{MPSK}}, \theta\right) = \int_0^{\infty}\exp\left(-\frac{g_{\text{MPSK}}\gamma_l}{\sin^2\theta}\right)p_{\gamma_l}\left(\gamma_l\right)d\gamma_l, \quad (2)$$

and $\overline{\gamma}_l$, γ_l are the average and instantaneous SINR per symbol corresponding to the lth channel respectively. In addition, $p_{\gamma_l}\left(\gamma_l\right)$ is the pdf of γ_l, and

$$g_{\text{MPSK}} = \sin^2\left(\pi/M\right). \quad (3)$$

Comparably, for an L-channel MRC reception of square MQAM signal, it can be shown that the average SER $\overline{P}_{e,\text{MQAM}}$ can be given by [3]

$$\overline{P}_{e,\text{MQAM}} = \frac{4}{\pi}\left(1-\frac{1}{\sqrt{M}}\right)\int_0^{\pi/2}\prod_{l=1}^{L} I_l\left(\overline{\gamma}_l, g_{\text{MQAM}}, \theta\right)d\theta - \frac{4}{\pi}\left(1-\frac{1}{\sqrt{M}}\right)^2\int_0^{\pi/4}\prod_{l=1}^{L} I_l\left(\overline{\gamma}_l, g_{\text{MQAM}}, \theta\right)d\theta, \quad (4)$$

where

$$I_l\left(\overline{\gamma}_l, g_{\text{MQAM}}, \theta\right) = \int_0^{\infty}\exp\left(-\frac{g_{\text{MQAM}}\gamma_l}{\sin^2\theta}\right)p_{\gamma_l}\left(\gamma_l\right)d\gamma_l, \quad (5)$$

and

$$g_{\text{MQAM}} = 3/\left[2\left(M-1\right)\right]. \quad (6)$$

Furthermore, the other variables have the same meaning as the corresponding variables in (1).

For the separately serving mode, there is L=1. Comparably, for the diversity mode, L is the number of the BSs involved in the diversity process. In addition, we suppose a multipath/shadowing fading environment, which consists of gamma/log Nakagami-m multipath fading superimposed on log normal shadowing. This type of composite fading is the typical scenario in congested downtown areas with slow moving pedestrians and vehicles. Also the composite multipath/shadowing fading can be observed in other scenarios, such as land mobile systems subject to vegetative and/or urban shadowing [4]. Therefore, the pdf of the SINR per symbol of the lth channel, γ_l, can be given by [3]

$$p_{m_l\sigma_l}\left(\gamma_l; m_l, \mu_l, \sigma_l\right) = \int_0^{\infty}\frac{m_l^{m_l}\gamma_l^{m_l-1}}{q^{m_l}\Gamma\left(m_l\right)}\exp\left(-\frac{m_l\gamma_l}{q}\right) \times\frac{10/\ln 10}{\sqrt{2\pi}\sigma_l q}\exp\left[-\frac{\left(10\log_{10}q-\mu_l\right)^2}{2\sigma_l^2}\right]dq, \quad (7)$$

where $\Gamma(\cdot)$ is the gamma function, and m_l is the Nakagami-m fading parameter of the lth channel, which ranges from 1/2 to ∞. Specifically, m=1 represents Rayleigh fading, $m\to\infty$ corresponds to the conventional Gaussian scenario, and m=1/2 describes the worst case fading, i.e., one-side Gaussian fading. By varying the fading parameter m, Rician and many other distributions can also be closely approximated by Nakagami-m distribution. In addition, μ_l (dB) and σ_l (dB) are the mean and standard deviation of $10\log_{10}\gamma_l$.

In composite gamma/log normal fading environment, by using Gauss-Hermite quadrature integration, the integral $I_l\left(\overline{\gamma}_l, g, \theta\right)$ can be expressed as [5]

$$I_l\left(\overline{\gamma}_l, g, \theta\right) \approx \frac{1}{\sqrt{\pi}}\sum_{i=1}^{Q} W_i\left(1+\frac{10^{\left(\sqrt{2}\sigma_l x_i+\mu_l\right)/10}g}{m_l\sin^2\theta}\right)^{-m_l}, \quad (8)$$

where Q is the order of the Hermite polynomial, which can be set to 20 for excellent accuracy [5], and the parameter g can be either g_{MPSK} or g_{MQAM}, depending on the modulation type. In (8), x_i and W_i are the ith zero and weight factor of the Q-order Hermite polynomial, respectively [6, Formulas (25.4.46)]. Both the zeros and the weights factors of the Hermite polynomial are tabulated in [6, Table (25.10)] for various polynomial orders Q.

Furthermore, the average path loss in the multipath/shadowing fading environment could be written as [7]

$$\overline{PL}\left(d\right)(\text{dB}) = \overline{PL}\left(d_0\right) + 10n\log_{10}\left(\frac{d}{d_0}\right), \quad (9)$$

when the distance between the transmitter and the receiver is d. In (9) d_0 is a known received power reference point, namely closed-in reference distance, and n is the path loss exponent.

4 Numerical Results

We consider a beam-hitting scenario in an OBH-based system, and the served MS is moving from one BS to another BS. We assume the SNR at the boundary of the cell is 15dB and define the target SER of the MS as 5×10^{-2}. Furthermore, we set $\overline{PL}\left(d_0\right)$=60dB, d_0=100m, the path loss exponent n=4 corresponding to a shadowed urban environment, fading parameters m_l=1 (l=1…L) representing the Rayleigh fading, the SNR standard deviations σ_l =10dB (l=1…L), the cell radius R=1000m, and the additive white Gaussian noise N=-102dBm. The number of involved BSs is L=2. Then we could get the performance of the average SER of the MS versus the distance between the MS and one BS (defined as D), when the interference situation adaptation scheme is applied for the OBH-based system, as shown in Fig. 2 and Fig. 3.

Specifically, Fig. 2 shows the performance for QPSK signal and Fig. 3 shows the performance for the 16QAM signal. Furthermore, as comparisons, we also give the average SER performance when the MS is always served by only one BS (i.e., separately serving mode), or always served by two BSs (i.e., diversity mode).

From Fig. 2 corresponding to QPSK signal, we could see that in the first stage, i.e. $D \leq 475$m, the MS1 is in the separately serving mode, because the MS1 could be served only by the nearby BS1 and endures the co-channel interference from the other BS2, see Fig. 1. This has the advantage that the same resources could be used by the MS1 that is served by BS1 and another MS2 that is served by BS2 simultaneously, resulting in higher sum throughput from a system level point of view. However, as D increases to 500m, the SINR of at the MS1 could no longer support the target SER. Consequently, the MS1 changes into the diversity mode and be served by the two BSs at the same time. Note, that during diversity mode the MS2 could not be served by BS2 and, consequently, has to be scheduled to another time slot. Then, as the MS1 moves closer to BS2, it will change back to the separately serving mode again and served by BS2. Note that when the adaptive modulation schemes are applied, lower SER indicates potential higher throughput for the actually served MS. This could help to mitigate the potential decrease of the total throughput which could be expected during diversity mode, since only MS1 instead of MS1 and MS2 are served by the two BSs. In addition, the evaluation of the system performance will depend heavily on the traffic model and scheduling mechanism resulting in types of queuing models. More accurate statements will be drawn through a systematic analysis in the future work.

Comparably, as we could observe from Fig.3, the switch of the transmission mode happens at D=325m for 16QAM signal. Note that for the same SER, 16QAM signal requires a much higher SINR than that of QPSK signal. As shown in Fig. 3, even the diversity mode could not support the required SER at the cell border. Nevertheless, by using adaptive modulation strategy, the lower order modulation schemes, such as QPSK or BPSK, could be employed at the cell border.

From Fig. 2 and Fig. 3, we could easily understand that the diversity mode always has the best SER performance, on the cost of more radio resources.

5 Conclusions

This paper proposes an interference situation adaptation scheme for OBH-based systems. The interference situation adaptation scheme works well for the beam-hitting scenario.

References:

[1] H.L. Hu, M. Weckerle, J. Luo and E. Schulz, "Organized beam-hopping scheme for mobile communication systems," to appear in *IEEE/CIC GMC'05*. Mar. 2005.

[2] P. Viswanath, D. N. C. Tse, and R. Laroia, Opportunistic Beamforming using Dumb Antennas, *IEEE Trans. Inform. Theory*, Vol. 48, No. 6, 2002, pp. 1277-1294.

[3] M.-S. Alouini and A.J. Goldsmith, A unified approach for calculating error rates of linearly modulated signals over generalized fading channels, *IEEE Trans. Commun*., Vol. 47, No. 9, 1999, pp. 1324-1334.

[4] H.L. Hu and J.K. Zhu, Performance analysis of distributed-antenna communication systems using beam-hopping under strong directional interference, *J. Wireless Personal Commun.*, Kluwer/Springer Publishers, Vol. 32, No.1, 2005, pp. 89-105.

[5] M. Alouini and M.K. Simon, A unified approach to the performance analysis of digital communication over generalized fading channels, *Proc. IEEE*, Vol. 86, No. 9, 1998, pp. 1860-1877.

[6] M. Abramowitz and I. A. Stegun, *Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables,* 9th ed. New York, NY: Dover, 1970.

[7] Theodore S. Rappaport, *Wireless Communications Principles and Practice*, Englewood Cliffs, NJ: Prentice-Hall Inc., Chap. 2 and 3, 1996.

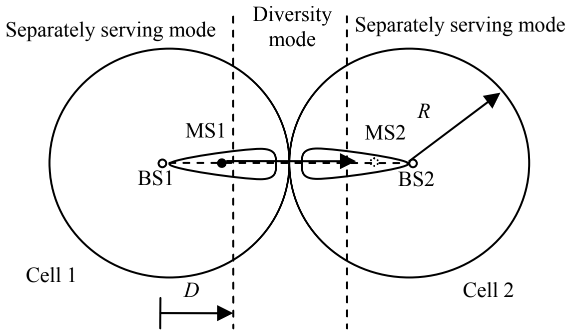

Fig. 1. Illustration of the interference situation adaptation scheme.

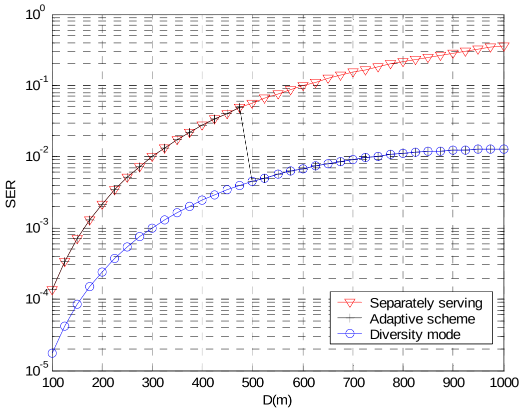

Fig. 2. Performance evaluation and comparison for QPSK signal.

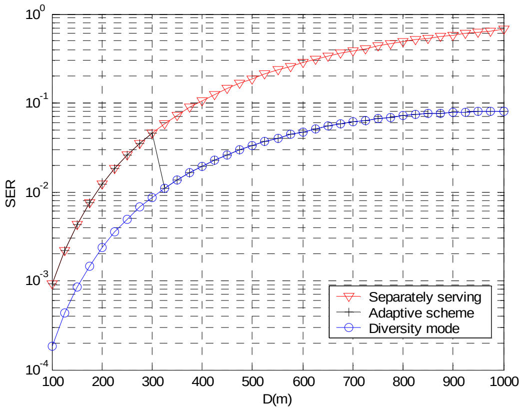

Fig. 3. Performance evaluation and comparison for 16QAM signal.