Pre-select Diversity with the Aid of Downlink Beamforming in Indoor MC-CDMA System

Van-Su Pham, Minh-Tuan Le, Linh Mai, Mun-Hyuk Yim, Gi-Wan Yoon *Member, KIMICS*, and **Dong-Hyun Kim**, *Nonmember*

Abstract—In non-selective frequency environment, it is difficult to take the advantage of path diversity. In the literature, some methods have been proposed to solve the issue. This paper presents a new method to obtain the resolvable path in Indoor Multi-carrier Code Division Multiple Access (MC-CDMA) system by using downlink beam forming. With the aid of downlink beamforming, the most reliable path is found and chosen for the communication link. The new approach is evaluated in term of bit error rate (BER) and power consumption. The simulation results show that the new approach can get better BER performance. However, the cost of BER improvement is a small degradation in power reservation.

Index Terms—Indoor channel, Smart Antenna, Diversity

I. INTRODUCTION

RECENTLY, the demand of realization of high speed wireless data communication is critical in the development of systems for wireless ATM, media and high speed LAN networks [1]. However, in order to be successful realization, the future wireless data communication systems should offer both high potential capacity and low cost.

Unfortunately, in the indoor environment the realization of such system is constrained by the spectral limitation and the distortion. In indoor wireless communication there are a large number of communication devices operating at the same time. Thus the receiver is suffered from co-channel interference if both the transmitters are within the certain range of the receiver. In addition, the placement of obstacles and the wall structure introduce the fading and shadowing effects that seriously degrades the signal at the receiver. Moreover, as depicted in Section II, the early reflections usually reach to the receiver with almost the same power. Thus, it is difficult to get the diversity gain and to deploy the matched filter (MF) at the receiver.

Multicarrier Code Division Multiple Access (MC-CDMA) [2], [3] scheme, which is based on a combination of Orthogonal Frequency Division Multiplexing (OFDM) signaling and Code Division Multiple Access (CDMA) [4], has been considered a leading technique for the next generation high-speed wireless communication systems. Based on OFDM technique [2], MC-CDMA has relatively long symbol duration, thus it has narrow bandwidth. Consequently, the system gains a noticeable advantage of robustness in selective-fading environment [3]-[5] with a good frequency use efficiency. Another crucial advantage of using OFDM is that the modulation and demodulation can be implemented in discrete-domain by using a Discrete Fourier Transform (DFT), which can be efficiently implemented by using the Fast Fourier Transform (FFT). Therefore, the signal can be easily transmitted and received without increasing of transmitter and receiver complexities.

In addition, Adaptive Antennas (AA) [6] – so-called Smart Antennas (SA) - recently have been impressively researched and have been proven to be potential applicable to wireless system so far. Most of the works only considered the application on the downlink in which the adaptive antenna array is assumed to be implemented at only base station. With the aid of adaptive antenna array, signals from multiple terminals are spatially separated. Therefore, the terminals can use the same frequency at the same timing. Consequently, much more efficient frequency reuse is achieved [7]. Furthermore, Adaptive Antennas can strongly compress the co-channel interference [6].

In the literature, some approaches for obtaining the diversity gain in indoor wireless communication are proposed. One of them is the artificial time delay approach [8]. In this approach, each antenna in a sector consists the same data which is several chip delayed for each antenna sector. However, this approach faces on the degradation due to the interference as well as the efficiency of power consumption at the base station.

In this paper, we present a new scheme by exploiting the usage of Adaptive Antenna at the Base Station (BS) to reduce the co-channel interference as well as get the diversity gain in indoor wireless communication. First the set of pilot profiles are used. The antennas at the base station broadcast pilot signal to define the optimal beam-form, which is corresponding to the best reliable link between the transmitter and the receiver. Then, after the set of beam-form profiles is found, a sub-set of optimal beam-form is used and the signal is only transmitted via the reliable links, i.e. the beam-forms. As a result, the system can compress the co-channel interference. In addition, the power consumption is only overused at the beginning of the beamforming duration. After a while when the beam-form is defined, system can save the power since the concentration of the beam-form. Thus the proposed approach can be reduced somewhat power overhead in compared to the system that uses antenna sector.

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The outline of the paper is as follows. Section II provides the relevant review on Indoor channel. The proposed approach is next described in Section III. The results of computer simulations of the proposed approach are reported in Section IV. Finally, Section V includes the paper by summarizing the important points.

II. INDOOR CHANNEL MODEL

In order to evaluate the effectiveness of the channel, the channel model must be developed so that it properly describes the channel. Indoor channels are highly dependent on the specific placement such as walls and objective within the building. The general viewpoint of the propagation model of the indoor environment [9], [8] is given in the Figure 1. As depicted in the Figure 1, there is no directed path between the transmitter and the receiver. This model is so-called non-line-of-sight (N-LOS)

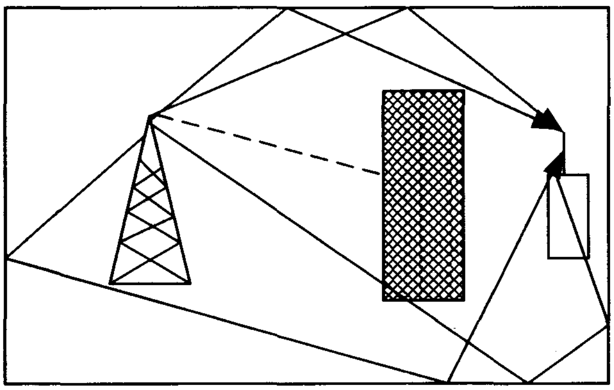

Fig. 1 Propagation of the indoor wireless communication

The typical indoor delay profile is illustrated in the Figure 2. In indoor and micro-cellular channels, the delay spread is usually very smaller, and rarely exceed a few hundred nanoseconds. Seidel and Rappaport [10] reported delay spreads in four European cities of less than 8 ms in macro-cellular channels, less than 2 ms in micro-cellular channels, and between 50 and 300 ns in pico-cellular channels. As can be seen from the figure, in an indoor environment, early reflections often arrive with almost identical power. This gives a fairly flat profile up to some point, and a tail of weaker reflections with larger excess delay. In addition, the channel is in rich scattering with a small difference among the arrival path.

Let the arrival time of the l-th cluster of the rays be denoted by T_l and the arrival time of the k-th ray measured of the l-th cluster by τ_{kl}. T_l and τ_{kl} are completely defined by the independent inter-arrival exponential probability density function [11].

$$p(T_l \mid T_{l-1}) = \Lambda e^{-\Lambda(T_l - T_{l-1})}$$
$$p(\tau_{kl} \mid \tau_{(k-1)l}) = \lambda e^{-\lambda(\tau_{kl} - \tau_{(k-1)l})} \quad (1)$$

where arrival rate λ and Λ satisfy that λ is much greater than Λ.

Moreover, the shadowing effect resulted from the obstacles in the system can be generally modeled as the log-normally distributed [9]. The probability density function of this distribution is given in the following equation.

$$f_p(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left\{ \frac{(x - \mu(d))^2}{2\sigma^2} \right\} \quad (2)$$

In the equation (2) σ is the logarithmic standard deviation of the shadowing, and is computed as function of the radio path distance between the transmitter and the receiver as given in the equation (3):

$$\mu(d) = \mu(d_0) - 10\beta \log\left\{ \frac{d}{d_0} \right\} \quad (3)$$

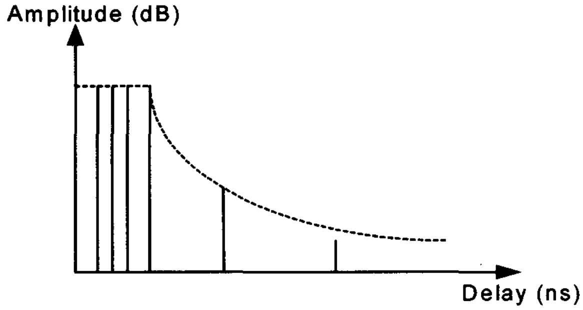

Fig. 2 A typical delay profile of the indoor channel

III. THE PROPOSED PRE-SELECT DIVERSITY BY DOWNLINK BEAMFORMING

With the aforementioned channel model in section I, the average delay spread is several tens [ns] and maximum delay one is less than 200 [ns] [12]. It is obviously that the average delay spread is small compared to the chip duration T_C. Thus we cannot achieve effective path diversity. In addition, we have to take into consideration the shadowing effects due to the absorption of wall as well as other obstacles.

In order to reduce fading distortion and use effective transmit power at the base station, we proposed the approach for beam forming as described in the following part. At first, all antennas transmit their own pilot signals over channel to the receiver with equal power.

Let's denote the chip of the $m-th$ sub-carrier at the time interval iT of the antenna $n-th$ is $p_{nm}(i)$. Thus the multicarrier transmitted signal at the antenna i-th is given as:

$$s_{pn}(t) = \sum_{m=0}^{N-1} \sum_{i=-\infty}^{\infty} p_{nm}(i) e^{j2\pi f_m (t - iT)} g(t - iT) \quad (4)$$

where f_m is the frequency of the m-th subcarrier given as: $f_m = f_0 + m/T$ (m=0,1,2,...,N-1); herein N is the number of subcarrier.

Moreover, let's represent the impulse response of the indoor channel is $h_{ij}(t)$. Thus, the receive antenna at the receiver catches signals on different paths with different instantaneous incident power as:

$$r_j(t) = s_{pn}(t) * h_i(t) + n(t) \quad (5)$$

In the equation (5), j is the index of the $j-th$ coming signal path and $h_{ij}(t)$ is the channel impulse response from the source $i-th$ to the receiver in the $j-th$ path.

During the beam-form defining, at the receiver, the Maximal Ratio Combining (MRC) technique [9] is applied to get the signal. The merit figure of each pilot set is recorded at the receiver in term of received SNR. Then the merit figure is fed back to the transmitter to form the beam structure and to choose the optimal beam-from. After a short time of adjusting the pilot set, a set beam-form profiles, which includes all the possible optimal beam-forms, is defined at the transmitter. Due to the distinguish pilots, at the transmitter we can choose sub set of the beam-form – so the paths-which have better quality of propagation, i.e. the paths from the antenna which result in the better BER performance. Then, all the optimal beam-forms in the chosen sub-set are simultaneously used to transmit multi-beam to the receiver.

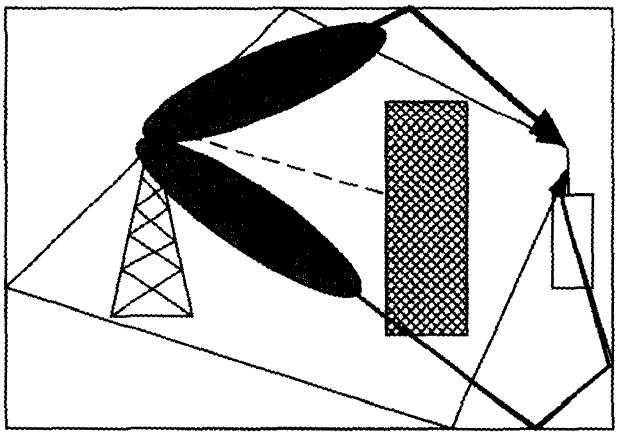

Fig. 3 The downlink beamforming approach for the indoor wireless communication

It is noted that the success sub-set of paths is chosen in a manner so that it also meet the demand of the difference in time resolvable. Therefore, we can get the same time the requirement of power consumption reservation and high quality of communication link. Consequently, after a very short time of beam-form profile created, the system can provide better reliable communication with less cost of transmitter power.

IV. COMPUTER SIMULATION RESULTS

A. Setup for computer simulation

To verify the proposed approach, the computer simulation is executed. The main parameters for computer simulation are given in the Table 1.

In addition, the delay power profile of indoor wireless channel used for this simulation can be found in the literature [11]. The number of transmit antennas is 5. The primary modulation scheme for transmit symbol is QPSK. The number of branch for MRC is set to 3. The number of simultaneous beam-forms in the profile is set to 2.

Besides, the channel is assumed that there do not exist any direct path between the transmitter and the receiver.

Table 1 : Parameters for simulation

Parameter	Value
Sampling rate	20Mhz
Symbol part duration	3.2μs
Cyclic Prefix	0.8μs
Number of subcarriers	52
Sub-carrier spacing Δf	0.3125Mhz
Processing gain	64

B. Simulation results

First, the system performance in term of BER is evaluated. The simulation result is presented in the Figure 4. It can be seen from the Figure 4 that the proposed approach has a significantly lower BER in compared with that of system using antenna sector and the conventional system without using any aid – single antenna. The improvement is rather higher when the average bit energy over noise (EbN0) increases. This is because, at high EbN0, with the aid of beam-form (i.e. the optimal paths), we can concentrate the signal power only on the main beam. Thus, at the receiver, the SNR is improved significantly. Consequently, at the same EbN0, the proposed approach can get the lower BER.

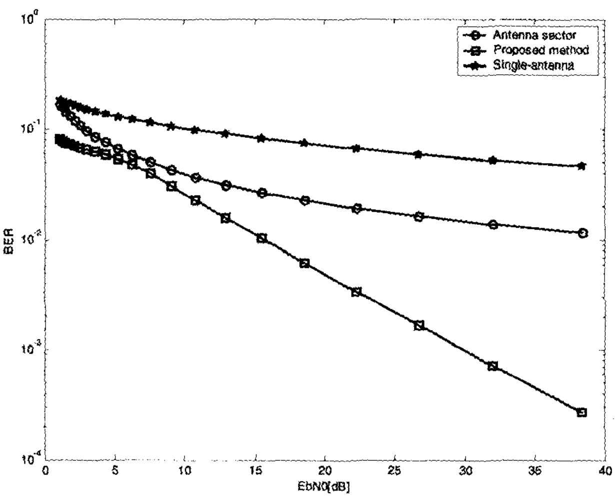

Fig. 4 BER performance of the proposed approach and that of the counterparts

The average power consumption versus the offered traffic load is shown in the Figure 5. Herein, the power consumption is recorded at that the system can still maintain the BER over the barrier BER_0. From the figure, we can see that the proposed method is moderately suffered from overhead power consumption in comparison with single-antenna system. However, the result also shows that power consumption of the proposed approach is less than that of the system using antenna sector.

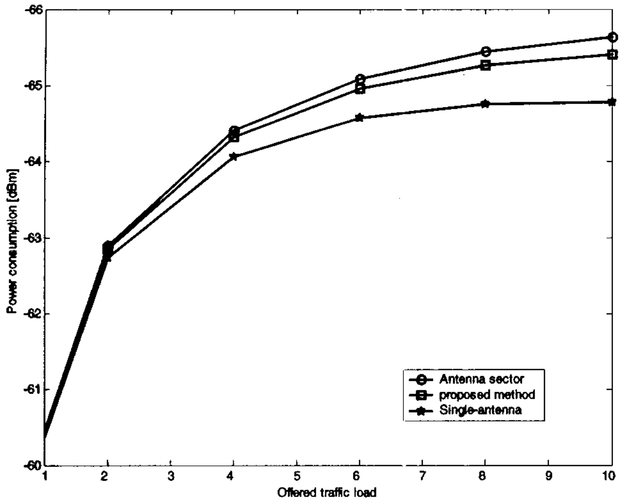

Fig. 5 Power consumption comparison for evaluating the proposed approach

IV. CONCLUSIONS

In this paper, we present a new approach for taking advantage of the resolvable path in indoor DS/CDMA system. The proposed approach exploits the usage of downlink beamforming in which the best link is found and chosen for real communication. Thus, the communication link is more reliable than that of conventional system. Consequently, BER performance of the system is considerably improved. Although the proposed approach is little suffered from power consumption at the beginning for choosing the best link, it can be potentially applicable in future high performance wireless communication systems.

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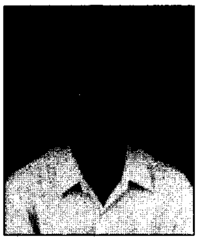

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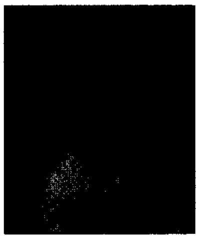

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