ABSTRACT

This paper introduces a novel merger of Multi-Carrier OFDM (MC-OFDM) systems and antenna arrays with moving beam patterns denoted Beam Pattern Scanning (BPS) Smart Antennas. The simulations reveal that high performance and low PAPR is achievable through this merger. In addition, Multi-Carrier coded-OFDM (MC-COFDM) systems are simulated and results are presented for further comparison.

1. INTRODUCTION

OFDM is a new emerging transmission technique capable of providing high data rate transmission in a frequency selective channel without the need of complicated equalizers [1]-[3]. MC-OFDM is an innovative OFDM transmission technique where each MC-OFDM user’s bit is transmitted over all available sub-carriers simultaneously. To ensure separability of bits at the receiver and reduce inter-bit-interference (IBI), orthogonal codes, e.g., Hadamard Walsh codes, are applied to the sub-carriers of each bit. Therefore, through MC-OFDM, frequency diversity can be exploited to improve the performance of the system with minimal complexity to the transmitter and receiver [4].

Properly designed MC-OFDM systems are resistive to frequency selective channel and eliminate the need for complicated equalizer. This is because by serial to parallel conversion and simultaneous transmission, the symbol period, $T_s$, is extended to $NT_s$. Therefore, if the extended bit period, $NT_s$ is greater than the channel delay spread, the transmitted signal would only experience flat fading over each sub-carrier. Moreover, since MC-OFDM signals are transmitted over all sub-carriers, there would be enough diversity available to ensure the quality of service of these systems [4]. In addition to the frequency diversity available in MC-OFDM system, various methods such as: 1) Forward Error Correction Coding at the cost of the overall system throughput [1] [2], and 2) transmit diversity [5] can be used to further improve the probability-of-error performance of an MC-OFDM system.

Recently, a powerful transmit diversity technique has been introduced called beam pattern scanning (BPS) (also known as beam pattern oscillation). In this scheme, antenna arrays are installed at the base station (BS) with their oscillating/scanning antenna patterns directed toward the desired users. To each antenna element a time varying phase shift is applied in order to steer and move the antenna pattern within one symbol duration $T_s$. The beam pattern starts sweeping at an area of space at time zero, it returns to its initial position after time $T_s$ and repeats its sweeping. Hence, the desired user stays in the antenna array at all times.

The movement of the beam pattern is small, e.g., in the order of 5% of half power beam width (HPBW). Hence, the desired user stays in the antenna array HPBW at all times. In rich scattering environments, the small movement creates a time varying channel with a small controlled coherence time $T_c$ with respect to $T_s$ [8]-[10] leads to a time diversity benefits that can be exploited at the receiver. Therefore, BPS is a transmit diversity scheme that enhances a) receiver probability-of-error performance via time diversity and b) wireless network capacity via Spatial Division Multiple Access (SDMA) [6] or spatial filtering interference reduction (SFIR) [7].

In this paper, we merge BPS transmit diversity with MC-OFDM systems and we achieve: 1) low Peak to Average Ratio (PAPR) [4], 2) high probability-of-error performance [5] [10] and 3) high capacity via directionality [6] [7]. We present the antenna array structure that make BPS possible and we simulate the (PAPR) of BPS/MC-OFDM system together with the probability-of-error performance curves.

Traditional OFDM and also MC-OFDM utilizing antenna arrays without BPS scheme are used as benchmark against BPS/MC-OFDM scheme. Adaptive antenna arrays with beam patterns directed towards intended users leads to capacity enhancement via SDMA [6] [7] [9] [10], and there is no performance benefits available. This paper highlights performance benefits achieved through BPS and MC-OFDM merger. In addition, coded version of MC-OFDM (MC-COFDM) and BPS/MC-COFDM are simulated and compared to highlight the performance improvement through BPS merger.

In Section 2, we present BPS/MC-OFDM receiver structure and the received signal. In Section 3, we present the probability-of-error performance and PAPR simulation results. Section 4 concludes the paper.
2. BPS/MC-OFDM RECEIVER DESIGN

From Figure 1, considering all antenna elements \((m)\), the total normalized downlink transmitted signal, \(t,t \in [0, NT_c]\) is
\[
x(t) = \sum_{n=0}^{L-1} b[n] \cdot \sum_{m=0}^{M-1} \cos(2\pi f_c n + m\theta(t)) |g_{NTc}(t - NT_c)|
\]
where \(b[n] \in \{+1, -1\}\) is the transmitted bit, \(i \in \{0, 1, 2, \ldots\}\) is the \(i^{th}\) group of \(N\) bits simultaneously converted to parallel, \(\beta^k\) is the \(k^{th}\) bit, \(n^h\) sub-carrier orthogonal codes' element, \(f_c\) is the carrier frequency and \(g_{NTc}(t)\) is a rectangular waveform of unity height over zero to \(NT_c\).

In (1) the frequency offset induced by \(\theta(t)\) in the transmitted signal is minimal and is ignored in this paper. At the receiver, since the transmit diversity leads to an \(L\)-fold time diversity, the received signal can be divided into time slots \([NT_c/L, (l+1)NT_c/L], l \in \{0, 1, \ldots, L-1\}\) and each individual slot demonstrates independent fades. For simplicity of presentation, we consider \(l = 0\) and we ignore the pulse shaping function, \(g_{NTc}(t)\) and the received signal can be represented as
\[
r_l(t) = \sum_{n=0}^{L-1} \alpha^l_n \cdot b[n] \cdot \cos(2\pi f_c n + n\theta(t)) |t + \Delta\gamma(t, \phi) + \xi^l_n| + n_l(t)
\]
(2)

Here,
\[
AF(t, \phi) = \frac{1}{M} \left[ \frac{\sin(M/2 \cdot \gamma(t, \phi))}{\sin(M/2 \cdot \gamma(t, \phi))} \right]
\]
(3)
is the normalized antenna array factor, \(n_l(t)\) is an additive white Gaussian noise (AWGN), which is considered independent for different time slots \(l\), \(\alpha^l_n\) is the Rayleigh fade amplitude on \(n^h\) sub-carrier in the \(l^{th}\) time slot, and \(\xi^l_n\) is the fading phase offset in the \(n^h\) sub-carrier in the \(l^{th}\) time slot (hereafter, this phase offset is assumed to be tracked and removed). The Rayleigh fade amplitudes, \(\alpha^l_n\), are independent Gaussian Random variables over time \(l\) and correlated over sub-carriers \(n\) with the correlation coefficient between sub-carriers \(n^1\) and \(n^2\) characterized by [11]

\[
\rho_{n^1, n^2} = \frac{1}{1 + (n^1 - n^2) \cdot (\Delta f_{\phi})^2}
\]
(4)
where \((\Delta f_{\phi})\) is the coherence bandwidth of the channel. Moreover, in (2),
\[
\gamma(t, \phi) = (2\pi d/\lambda) \cdot \cos \phi + \theta(t)
\]
(5)
where \((2\pi d/\lambda) \cos \phi\) is the phase offset caused by the difference in distance between antenna array elements and the mobile (assuming the antenna array is mounted horizontally). We assume narrow beamwidth antenna array with mobile located at \(\phi = \pi/2\). Hence, (5) can be approximated by \(\gamma(t, \phi) = \gamma(t) = \theta(t)\). Moreover, assuming that antenna array peak is directed towards the intended mobile at time \(t\), and small movements of antenna array pattern over \(NT_c\), the array factor is well approximated by \(AF(t, \phi) \approx 1\).

The received signal for each sub-carrier, \(n\) and time slot \(l\) can be represented by

\[
r_l^n = \frac{1}{L} \left[ \frac{\alpha_l^n \cdot b[n]}{\alpha_l^n} \right] \sum_{j=0}^{L-1} \sum_{k=0}^{N-1} \frac{\alpha_l^n \cdot \beta_l^k \cdot \beta_l^{n^h} \cdot \gamma(t, \phi)}{L} + n_l^n, \quad n \in \{0, 1, \ldots, N-1\}, \quad l \in \{0, 1, \ldots, L-1\}
\]
(6)
where \(n_l^n\) is a zero-mean Gaussian random variables with variance \(N_s/2\). In (6), the first term represent the \(l^{th}\) and \(n^h\) component of the desired signal, the second term represents the inter-bit-interference as a result of fading and the third term represents the noise. The factor \(1/L\) is the direct consequence of dividing the received signal into \(L\) partitions creating \(L\)-fold time diversity. The combiner is designed to utilize Minimum mean square error combining (MMSEC) in frequency domain, and then Equal Gain Combining (EGC) in time domain.

3. SIMULATED PERFORMANCE

Simulations are provided for MC-OFDM systems with antenna arrays. The assumptions for these simulations are follow: 1) \(N = 32\) sub-carriers in the MC-OFDM system; 2) \(L = 7\) independent fades are assumed as the result of the beam-pattern movement in the duration \(NT_c\) (see [8]); and 3) Frequency-selective channel with four-fold frequency diversity over the entire bandwidth.

Simulation results are presented in Fig. 2. The top curve in Fig. 2(a) represents the performance results for the benchmark system, i.e., traditional OFDM system with antenna array and without transmit diversity. The next curve represents MC-OFDM system performance with antenna array without BPS scheme. The BPS/MC-OFDM shows a 15 dB and 5 dB improvement in performance at probability-of-error of \(10^{-3}\) compared to the traditional OFDM system and MC-OFDM system respectively. This vast performance improvement is generated via time diversity created by beam pattern movement and is exploited using BPS/MC-OFDM receiver.

Fig. 2(b) shows the comparison of the coded MC-OFDM with antenna array, with and without scanning (MC-COFDM). A \(1/2\) rate convolution code is considered and soft viterbi algorithm is used for decoding. The simulation reveals that up to 6 dB and 5.5 dB improvement in performance is achievable via BPS scheme at the probability-of-error of \(10^{-3}\) comparing to COFDM and MC-COFDM systems. This clearly reinforce that BPS antenna arrays create time diversity that highly enhances the probability-of-error performance of MC-OFDM systems.
Despite the vast improvement in probability-of-error performance when applying forward error correction coding to MC-OFDM system, the decrease in the throughput make it a less attractive solution. However, comparing figures 3(a) and 2(b), it is clear that BPS/MC-OFDM scheme offers a better performance at the probability-of-error $10^{-3}$, compared to the traditional MC-COFDM, without sacrificing the throughput of the entire system.

Simulations of PAPR shows that MC-OFDM, in general leads to a lower PAPR compared to OFDM systems. (e.g., 98% of the MC-OFDM transmissions demonstrate PAPR < 9 while it is just 83% for traditional OFDM systems). The same results are generated for BPS/MC-OFDM systems (see Fig. 3). The simulations had proved that BPS and MC-OFDM merger is a superior technique capable of delivering high probability-of-error performance as well as reducing the PAPR problem in traditional OFDM systems. This makes BPS merger with MC-OFDM a very attractive scheme.

4. CONCLUSIONS

The merger of BPS and MC-OFDM (BPS/MC-OFDM) was introduced and the PAPR together with the probability-of-error performance was studied. Time diversity is created using BPS scheme that highly enhances the probability-of-error performance of MC-OFDM systems. Besides that, the inherent unique transmission method of MC-OFDM also lowers the PAPR problem compared to traditional OFDM system. This makes BPS/MC-OFDM merger a very competitive technique in wireless communications. The simulations performed also reveal that better performance is achievable via BPS/MC-OFDM compared to MC-COFDM without reducing the throughput of the system inherent in MC-COFDM systems. The cost of deploying BPS/MC-OFDM system is minimal due to the fact that the complexity of BPS system is mainly at the base station and the receiver complexity itself is minimal because the diversity components enter the receiver serially in time. Therefore, major improvement in performance at a minimal cost made BPS/MC-OFDM a promising candidate in future wireless communications.

REFERENCES