Interference Suppression in M-QAM OFDM Mobile Wireless Receivers Using Antenna Arrays

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Abstract

This paper focuses on using adaptive antenna arrays at a mobile receiver for M-ary OFDM signals. The array structure is devised to mitigate co-channel and inter-channel interference as well as have equalizing effects in the frequency domain. Effects of array mobility on the steering vector are included and spatial smoothing is employed to improve the signal-to-interference plus noise performance of the array. Scenarios of variable number of co-channel interferers with different angles of arrivals as well as inter-channel interferers are considered. The effects of the size of the array, the subarrays, and the spatial smoothing are examined.

Keywords: M-QAM, OFDM Orthogonal Frequency Division Multiplexing, CCI Co-Channel Interference, mobile receiver.

Introduction

Using adaptive antenna arrays at the transmitter and receiver of M-ary communication systems for improving channel capacity through frequency reuse has been the subject of many research activities in the last decade. Use of orthogonal frequency division multiplexing (OFDM) for wireless communications has been adopted by many international standards. OFDM enables protection against fading and error bursts. The serial to parallel conversion prior to OFDM multiplexing results in reconfiguring any potential bursts of error into sparse errors per OFDM channel that can be easily recovered using error correction coding.

Employing adaptive antenna arrays for wireless communications has been significantly effected by three main obstacles, fading, inter-channel interference, and co-channel interference. The problems are more significant when the array is positioned on board a mobile receiver. Many papers have proposed remedies for mitigating co-channel interference and enhancing the performance of array based receivers using subarrays. A recent study [1] proposed an array architecture that can be adjusted to handle slow time varying channels as well as fast time varying channels. This paper utilizes the approach proposed in [1] and employs three additional factors: first spatial smoothing is employed within each subarray, second the steering vector is adjusted to include the effects of a moving array, and third an equalizing filter (taps) is positioned behind each antenna to improve the array performance in the frequency domain assuming a constrained adaptive processing algorithm.

Another problem, introduced by the use of antenna arrays is the aliasing or grating; this can occur if the antenna elements are separated by a large distance. This problem will be addressed by spatial smoothing within the sub-arrays. Spatial smoothing is also utilized to address the effects of a moving array which introduces the overlap of concurrently moving neighboring cells and their respective signals.

The adaptation algorithm used in this paper is the constrained least mean square algorithm developed by Frost [3]. Specifically this algorithm will model an array of sensors designed to respond to a desired signal, simultaneously discriminating against noise.

The process involves progressively learning the statistics of the noise arriving from all directions other than the desired angle. Noise arriving at the desired angle can be filtered out later by means of frequency domain filtering in that direction or other means To implement such an algorithm the first step is to find the optimum weight vector. The vector then isolates the sub-arrays one by one and weights each sub-array with a distinctive weight, appropriate for its respective angle and time delay.

OFDM Array Based Receiver

The basic OFDM transmission model for which this system is based on is similar to an architecture developed in [1]. A schematic for the basic model of an OFDM receiver can be seen in [1]. The model used operates at an RF Band near 40 GHz.

The covariance of the incoming signal is modeled by the sum of several co-variance matrices, one representing the desired signal and two for interference signals, both inter-channel and co-channel, in addition to a noise term, as shown here.

$$R_y^{(m)}(p) = R_s^{(m)}(p) + R_i^{(m)}(p) + R_z^{(m)}(p) + \sigma_v^2 I_S$$

R_s represents the covariance matrix of the desired signal as derived from the following M-ary signal for the l^{th} user [1]: $s_l(n) = \frac{1}{\sqrt{N}} \sum_{\substack{k \subset s_l \\ n \in [0, N-1] \\ l \in [0, L-1]}} a(k) e^{j\left(\frac{2\pi}{N}\right)kn}$.

The inter-channel interference covariance matrix is Ri and the co-channel interference matrix is Rz. The noise is assumed to be additive white Gaussian independent and identically distributed with power σ^2 .

Interference

In modeling interference it is quite important to account for both the inter-channel and the co-channel interference. The two types of interference are modeled differently and therefore are mitigated in a different manner. The figure below illustrates the difference.

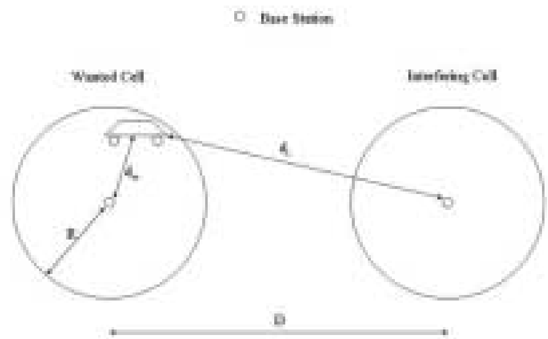

Figure 1. Inter-channel vs. Co-channel interference

The smaller, concentric circles represent the base station in each of the two neighboring cells. If the receiver depicted in the left-hand cell is receiving its desired signal d_w, it also receives other signals directed towards other receivers in the same cell, transmitted at different frequencies [7]. This is called inter-channel interference, which is easily filtered out by the receiver since it is transmitted at a different frequency than the desired signal. The neighboring cell is also transmitting signals at various frequencies and a signal which is transmitted to a receiver in that cell, at the same frequency as the desired signal intended for the above referenced receiver can interfere with the reception of the desired signal. This is called the co-channel interference.

Each type of interference is modeled differently due to the fact that each type comes from a different base station. R_i represents the co-variance matrix of the inter-channel interference used. The expression for R_i for an M-ary OFDM based signal can be found in [1]. This co-variance matrix is similar to that of the desired signal. This is due to the fact that both the inter-channel interference and the desired signal are both transmitted by the same base station so naturally the data will look similar in format, the difference lies in the steering vector, which directs the signal at a different angle. The co-channel interference is modeled as a narrowband signal as has been developed in [1].

Mobile Array Receiver

The use of an array receiver, improves desired signal reception, while minimizing various types of interference. The maximum SINR criteria paired with constraint based beam forming used within the channel estimator handle the processing of the incoming signals. The antenna elements are carefully placed close enough to prevent spatial aliasing, yet spaced far enough apart to obtain uncorrelated fading. This model will effectively handle the case where the reception is over slow time-varying channels, however it is inadequate for systems where reception over fast time-varying channels.

This model makes the system much more resistant to interference, as well as allowing the constraints to be more general. The constraints are designed to maximize angle diversity between the signal and interference. The spacing of the inner-array antenna elements should be on the order of a fraction of the wavelength, where the spacing of the sub-arrays should be on the order of five to ten times the wavelength. The increased spacing is to obtain sufficiently low fading correlation.

This paper uses the Frost Constraint Least mean Squared Algorithm. The constraining array has a frequency response which fits the OFDM system used for transmission. The constraint matrix C matrix is represented by $C = [c_1 \quad c_2 \quad \dots \quad c_K]$ which is frequency dependent and depends on the number of taps behind each antenna element and the duration between taps (see [3] for a description of C).

Another problem which can affect system performance is the mobility of the array based receiver.
Assuming an array moving at a constant speed v, in direction θ, the motion of the array has dual resultant effects on the received signal. Obviously there is error due to the physical displacement of the array. This is due to the fact that the phase as seen by the first sensor is not the same without accounting for the motion of the array. This, in turn, causes a differential phase change since the path lengths are now different at each source. The motion also causes a Doppler effect [6] sparking a change in the wave numbers.

This motion will correlate the signal from antenna to antenna. The effect of the velocity also necessitates a change in the steering vector to a format similar to that shown here [6].

$$d_m = \left[1 \quad e^{-j\omega_0 (1+v\sin\theta\sin\theta_d / c) L_1 \sin\theta_d / c} \quad \dots \quad e^{-j\omega_0 (1+v\sin\theta\sin\theta_d / c) L_{M-1} \sin\theta_d / c}\right]^T$$

This change will also reflect on the time averages sample array covariance. A moving array can effectively complicate the interference received despite the use of antenna arrays due to the fact that the multi-path propagation can cause the optimum beam former to form nulls in the direction of interference, as well as possibly cancel the desired angle in the output. To effectively handle this case a spatial smoothing is introduced to the system. The process of spatial smoothing involves taking an average of the received signal over a smaller subset within the array and then moving that subset down one element. In addition to compensating for the correlation introduced by the motion, the spatial smoothing also aids in mitigating co-channel interference.

$$\hat{R}(k) = \frac{1}{K}\sum_{k=0}^{K-1} r(t_k) r^+(t_k)$$

The proper method to address the decoding of a received signal from a moving array is through the use of an optimally weighted covariance averaging scheme (spatial smoothing). The number of spatially smoothed subarrays K can be found using $K = \frac{\lambda}{v\delta \in \sin(\theta - \theta_i)}$. Clearly, K depends on the angular separation between the sources [6]. Naturally the closer the sources, the larger the number of subarrays needed.

Results

The performance of the system is analyzed by examining the optimal signal-to-interference plus noise ratio at the output of the array OSINR versus the power of the co-channel interference CCI, OSINR is given by the following [1]:

$$OSINR^{(m)}(p) = \frac{\left[w_b^{(m)}\right]^H (p) * R_S^{(m)}(p) * w_b^{(m)}(p)}{\left[w_b^{(m)}\right]^H (p) * \left(R_i^{(m)}(p) + R_v + R_z^{(m)}(p)\right) * w_b^{(m)}(p)}$$

The receiving array is split into M sub-arrays with S antennas per sub array. The model is set up to support 8 independent users (L) with the possibility of 64 QAM signals total, effectively allowing each independent user to have 8 unique orthogonal OFDM signals. The total number of antennas is M*S. The received signal consists of a sum of the desired OFDM signal, interference, co-channel interference and a noise element. The performance results were obtained by varying the number of co-channel interferers (Z) from one to 6, the number of sub-arrays (M) from one, to three, to five, the number of spatially smoothed sub-array elements (S) from eight to ten to twelve and finally the velocity (v) from 30 miles per hour to 200 miles per hour. The test assumed an array with six antenna elements per subset with the implementation of the spatial smoothing. In varying the number of co-channel interferers holding M = 1, SL = 8, and v= 30 MPH the output OSINR decreases as the number of co-channel interferers Z increases which is expected. The results are shown in Figure 2. The next test was for a varying number of antenna elements in each sub array, from eight to ten to twelve, holding M = 3, with one co-channel interferer (Z = 1) again moving at 30 MPH. The results are consistent with the notion that OSINR improves as the number of antenna elements per subarray is increased. The results are shown in Figure 3. The next test involves varying the number of sub-arrays from one to three to five, holding SL = 8 again with one co-channel interferer and motion still at 30 MPH. Figure 4 shows that increasing the number of subarrays does improve the performance of the array. The final test was that of varying the velocity of the mobile receiver. Figure 5 shows that the performance at 200 mph is inferior to that at 30 mph particularly when the number of co-channel interferers increases. The effects of increasing the number of spatially smoothed arrays are more pronounced in this case.

Conclusions

An array architecture which includes subarrays is devised as a wireless receiver for M-ary OFDM based mobile communication systems. Spatial smoothing is employed to mitigate co-channel interference and to reduce the effects of receiver mobility. The results as measured using optimum signal-to-interference plus noise ratio indicate that quality signal reception in certain scenarios of interference is possible depending on the number of interfering signals, noise level, and receiver velocity.

References

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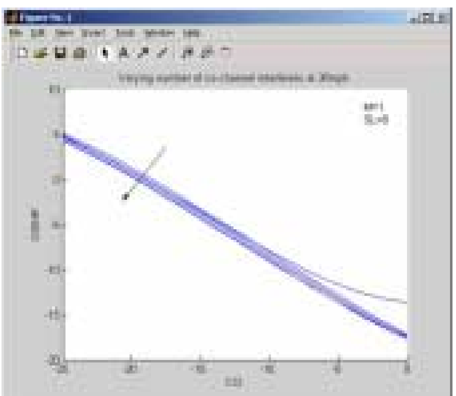

Figure 2. Varying Number of Co-channel Interferers

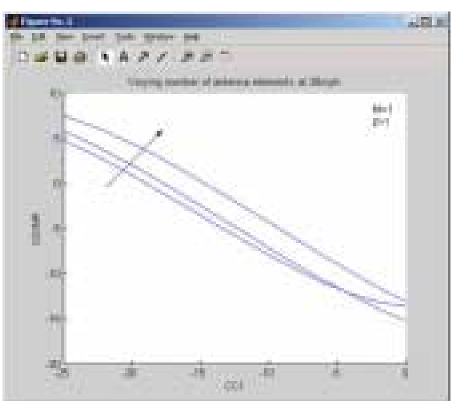

Figure 3. Varying Number of Antenna Elements

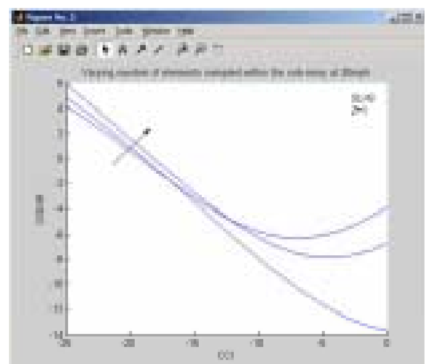

Figure 4. Varying Number of Sub-array Elements

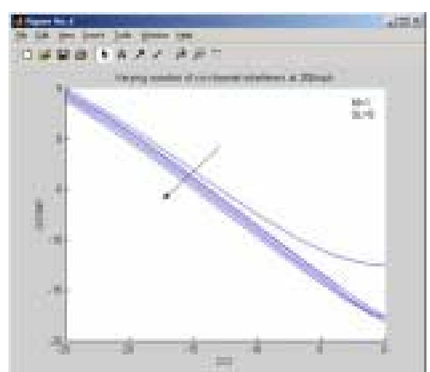

Figure 5. Varying Number of Co-channel Interferers (200 MPH)