Transmitting Image in 3D Wireless Channel using Adaptive Algorithm Processing with MMSE based on MIMO principles

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Abstract. With the growing evolution of wireless communication technologies, there is still a need for higher data rates, increased system capacity, and improved service quality. OFDM WiMAX technology is now regarded as one of the most common solutions for Broadband Wireless Connectivity in Urban Areas, capable of offering faster implementation and lower costs than standard wired options. This paper proposes effective adaptive algorithm processing with MMSE for use in wireless networks based on SISO and MIMO OFDM WiMAX, enabling network performance to be enhanced in the case of non-LOS wireless communications, which are standard in urban conditions. On the performance of the system, signal attenuation, the effects of several paths, different mobility speeds and Doppler shift were studied. Combines the adaptive algorithm with MMSE, achieves improved joint channel estimation and signal detection which performs the technique effectively mobile. SNR, MSE and noise components are used to analyses mathematical models of adaptive modulation for transmitting images in SISO and MIMO systems. Simulation results show that the adaptive algorithm with MMSE would improve throughput. For example, when SNR equal 15 dB, the probability of MSE for BPSK based on MIMO principle is equal to 0.0016 with adaptive algorithm. Also, for the same value of SNR, the probability of MSE for BPSK based on MIMO principle is equal to 0.164 without adaptive algorithm. It can also be concluded that when processing signals in a receiving system under conditions of multi-path signal propagation, the use of adaptive algorithms with MMSE has a positive effect on noise immunity.

1. Introduction

Spreading of electromagnetic waves and high attenuation restrict their propagation distance in wireless transmission. Due to their lower attenuation, radio waves can propagate large distances and are thus more suitable for wireless channels. However, bandwidth constraints and channel complexity present certain challenges that must be considered during system design. Wireless signal interference caused by surface or bottom wave reflection, Doppler shift caused by transmitter or receiver mobility, and noise are some of these problems. Images may be distorted or damaged when transmitted over such a channel [1, 2]. As a result, an effective adaptive processing algorithm, channel coding technique, suitable modulation, and image denoising scheme should be used [3]. The use of transmitting images over a wireless channel is growing. Orthogonal frequency division multiplexing (OFDM) is used for transmitting images in this model [4]. For each subcarrier, most
OFDM systems use fixed modulation techniques. However, various modulation schemes such as BPSK, QPSK, 8-PSK, and 16QAM can be applied in each subcarrier of OFDM systems and it is possible to raise the efficiency of frequency of the proper selection of modulation scheme according to mean square error (MSE) to attain a soft MSE in selective fading channels with significant tap delays. Single-input single-output with OFDM (SISO-OFDM) has been applied [5, 6]. The adaptive modulation scheme of the OFDM system is one of the useful methods for enhancing the reception rate [7-9].

Combination of Multiple Input Multiple Output (MIMO) with OFDM is an attractive air-interface solution. In future wireless communication systems, MIMO technique offers great ability to greatly enhance spectral efficiency and link reliability [10, 11]. By using the frequency reuse concept, it increases system spectral efficiency. The advantage of multiple antennas has recently been shown to have the ability to achieve very high data rates. MIMO technology could also be used to improve system diversity by providing various (ideally independent) duplicates of the transmitted signal to the receiver [11]. MIMO technology is an effective method for combating fading and interference, resulting in increased link reliability. As multiple antennas are used at both ends of a transmission channel, system diversity is increased. In wireless communications systems, MIMO technology can be used to improve system efficiency and/or increase diversity gain [12]. Multiple spatial channels are formed by using multiple antennas, and it is impossible that any of the channels will fade simultaneously. In MIMO channels, frequency selectivity is achieved using the Multi-Carrier Modulation (MCM) method [13]. The OFDM technique is the most widely used MCM technique. It adapts the MIMO channel into a set of parallel flat-fading channels. As a result, each tone fades independently when a MIMO-OFDM channel is faded. MIMO strategies have recently advanced, promising a significant performance improvement for OFDM systems. MIMO-OFDM systems are promising alternatives for high-speed wireless networks [14].

Adaptive modulation refers to the similarity of modulation, coding, and other signal and protocol parameters to the radio link stipulations in this paper. [15]. To accurately evaluate the performance of the MIMO and SISO techniques in WiMAX, Adaptive processing algorithm with minimum mean square error (MMSE) in 3D channel model that accurately estimates the elevation angles of the rays are used. The performed 3D WiMAX channel model for Adaptive processing algorithm with MMSE has been verified, and there is a great match with ray tracer statistics [16, 17]. MMSE improves the bit error rate performance and hence increases channel capacity in a multi-cellular environment by providing resilience and mobility in a time variable frequency selective multi-path fading channel. This paper proposes a method for image transmission over a 3D WiMAX wireless channel. The aim is to create a spectrally efficient system with low transmission errors and high visual quality for the image received.

2. The Proposed Method

2.1. Adaptive modulation

The proposed adaptive algorithm processing method consists of the weight processing of signals from the outputs of antenna array elements of the receiving antenna and allows for the formation of the antenna directivity characteristic, the character of which will depend on the chosen adaptation criterion. The adaptive processor will form the maximum of the directivity characteristic in the direction of the path with the maximum power and zeros to the remaining paths, based on the maximization of the signal/ (interference + noise) ratio.

The strategy under consideration is based on a correlation approach [18, 19]. First, the spatial correlation matrix for the adaptation task must be calculated:

$$R_{xx}(i,j) = E\{X(i)X^H(j)\} = \frac{1}{L} \sum_{l=0}^{L-1} X(l)X^H(j)$$  \hspace{1cm} (1)

A spectral decomposition into eigenvalues and eigenvectors could be used to represent the matrix in expression (1).

$$R_{xx}(i,j) = V\Lambda V^H$$  \hspace{1cm} (2)
where $V$ is the unitary matrix of eigenvectors; $\Lambda$ is the diagonal matrix of the eigenvalues $\lambda_n$:

$$V = [V_1 \ V_2 \ \cdots \ V_n], \quad \Lambda = \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & \lambda_n \end{bmatrix}$$ (3)

The powers of the sources, and in this case, the paths along which the signal travels, are the eigenvalues of the correlation matrix. This implies the condition that the number of sources (paths) should not be greater than the number of eigenvalues of the spatial correlation matrix, whose eigenvectors are weighting factors for processing the signal from the output of the elements of the antenna array. From the theory of adaptive antenna arrays, it is known that if you choose the maximum eigenvalue, then this number will correspond to the path through which the signal with maximum power comes, and to form a maximum in the direction of this source, you must use the eigenvector corresponding to the selected maximum eigenvalue [20].

The formation of the directivity characteristic in the adaptive processor is inaccurate, which is due to the fact that the true value of the correlation matrix is impossible to obtain due to the limited averaging time. Another feature of the presented adaptive algorithm is the need to provide a high spatial correlation for this, it is necessary that the distance between the elements of the receiving antenna array is as small as possible.

2.2. Minimum Mean Square Error

MMSE is a model that minimizes the MSE (Mean Square Error) of the received data. The MMSE estimator of the noise component is different from white noise. The variance of the component is always underestimated, and the smaller the noise variance, the larger the underestimation. The MMSE detector does not require any statistical or explicit knowledge of the parameters, it is composed of a bank of $n$ matched filters that adapt to the incoming digital signal to achieve MMSE solution.

For the channel capacity estimation, a definition is used to determine the performance of MMSE, the MMSE filtering matrix $G_{MMSE}$ can be expressed as:

$$G_{MMSE} = (H_i^H H_i + \sigma_n^2 I_{NT})^{-1} H_i^H$$ (4)

Where $H_i$ is MIMO channel matrix, $\sigma_n$ is the variance of the noise, $I$ is the identity matrix.

$$H_i = \begin{bmatrix} h_{1,1}^{(i)} & \cdots & h_{1,k}^{(i)} & \cdots & h_{1,N_T}^{(i)} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ h_{r,1}^{(i)} & \cdots & h_{r,k}^{(i)} & \cdots & h_{r,N_T}^{(i)} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ h_{N_R,1}^{(i)} & \cdots & h_{N_R,k}^{(i)} & \cdots & h_{N_R,N_T}^{(i)} \end{bmatrix}$$ (5)

2.3. System Model

A wireless communication connection between a transmitter (Tx) and a receiver (Rx) is known as a line of sight (LOS) if a straight line can be established between the network cells without any obstacles. The path loss (PL), angle distribution, and other critical parameters in channel models are determined by the connection condition, which determines whether the path is LOS or non-line-of-sight (NLOS) [21]. In the 3GPP 3D WiMAX channel, the propagation channel between each BS and UE is modelled as a set of spatial and temporal multipath components using an adaptive algorithm. It is a 3D geometric model that describes the scattering environment between the AP and the UE in azimuth and elevation. For each multipath component, the 3D model captures rays and provides information on amplitude, phase, time, delay, angle-of-departure (AOD) at BS and angle-of-arrival (AOA) at UE. To accurately evaluate the performance of MIMO systems in WiMAX, a 3D channel model based on antenna arrays was used. Adaptive signal processing with MMSE can be extended to both conventional communication systems including one receiving and one transmitting antenna and spatial signal processing communication systems with a combination of antenna array transmitting and receiving elements.
The 3D channel model is applicable to carrier frequencies of 2 GHz to 3 GHz with a bandwidth of up to 100 MHz. The distance and height of the base and mobile station location will be selected from the intended operation of the communication system in the 100 m high and 25 km range zone.

Mathematically, the behaviour of the multipath channel can be described by the time-variant \( h(t,\tau) \) [22, 23].

\[
h(t, \tau) = \sum_{n=1}^{N} a_n(t) \delta(\tau - \tau_n(t))
\] (6)

where \( a_n(t) \) is the time-varying amplitude of the nth path, \( \tau_n(t) \) is the time-varying propagation delay of the signal for the nth path, \( N \) is the number of paths.

The impulse response for the 3D WiMAX channel under consideration will be of the form [24].

\[
h(t, \tau) = h_{LOS}(t, \tau) + h_{RB}(t, \tau) + h_{RO}(t, \tau)
\] (7)

where \( h_{LOS}(t, \tau) \) is the component describing the direct path; \( h_{RB}(t, \tau) \) the component describes reflection from the building; \( h_{RO}(t, \tau) \) the component describes the reflection from the objects.

3. Results

Computer simulations were used to evaluate the performance of the proposed channel estimation method for SISO-OFDM and MIMO-OFDM for different multipath radio channels. We provide performance evaluation results for transmitting images in WiMAX using the newest 3GPP 3D channel model in this section. The carrier frequency of 2.5GHz was chosen for transmitting and receiving antennas to have moderate signal attenuation for the selected wireless range. For the selected wireless range, this will provide moderate signal attenuation.

The distance and high of the positions of the base and mobile stations would be chosen from the intended operation of the communication system in a zone with a height of 50 m and a distance of around 25 km. The base station is assumed to be stationary and in a fixed position, while the mobile moves at a constant speed of V-Ms.=30 km/h. All SISO and MIMO system nodes will be simulated in this research. Modelling allows us to analyze the performance of individual system nodes based on the parameters; as a result, we obtain probabilistic characteristics for each experiment that is dependent on several random parameters.

Figure 1 shows how, depending on the modulation type, an increase in transmission speed affects the bit error rate (BER). Different modulation types, such as BPSK, QPSK, 8-PSK, and 16-QAM, are used to evaluate the performance of the adaptive algorithm on the 3D transmission channel. 16-QAM modulation has the highest BER, while BPSK modulation has the lowest BER. For all types of modulation studied, the BER in the transmitted message is significantly reduced when the adaptation algorithm is used. The result of image transmission is compared with and without the use of data processing according to the adaptive algorithm.

![Figure 1. Probability of bit error BER as a function of SNR without adaptation](image-url)
Table 1. shows the BER for MIMO system for different type of modulations using different values for SNR.

| SNR (dB) | BPSK Without adaptive | BPSK With adaptive | QPSK Without adaptive | QPSK With adaptive | 8-PSK Without adaptive | 8-PSK With adaptive | 16-QAM Without adaptive | 16-QAM With adaptive |
|----------|------------------------|--------------------|------------------------|--------------------|------------------------|--------------------|------------------------|------------------------|
| 5        | 0.0741                 | 0.0003             | 0.4854                 | 0.0484             | 0.5361                 | 0.3316             | 0.6815                 | 0.2414                 |
| 6        | 0.0527                 | 7.2 * 10^{-5}      | 0.4524                 | 0.0321             | 0.4954                 | 0.2778             | 0.6461                 | 0.1862                 |
| 7        | 0.351                  | 7.3 * 10^{-6}      | 0.4161                 | 0.0181             | 0.4539                 | 0.2271             | 0.6023                 | 0.1351                 |
| 8        | 0.0221                 | 0                   | 0.3767                 | 0.0102             | 0.4064                 | 0.1769             | 0.5572                 | 0.0957                 |
| 9        | 0.0125                 | 0                   | 0.3365                 | 0.0044             | 0.3645                 | 0.1324             | 0.5078                 | 0.0621                 |
| 10       | 0.0062                 | 0                   | 0.2911                 | 0.0018             | 0.3174                 | 0.0932             | 0.4592                 | 0.0377                 |
| 11       | 0.0028                 | 0                   | 0.2481                 | 0.0005             | 0.273                  | 0.0615             | 0.4067                 | 0.021                  |
| 12       | 0.001                  | 0                   | 0.2079                 | 9.9 * 10^{-5}      | 0.23                   | 0.0383             | 0.3566                 | 0.01                   |

From table 1, it can be seen that for BPSK modulation, the error probability when using adaptive modulation is less than the error probability without using adaptive modulation by more than 4 orders of magnitude when the SNR is equal to 5dB and 6 dB, and this difference ratio increases with increase of the SNR. From table 1 also can be noted that the error probability for BPSK modulation is less than the error probability for QPSK,8-PSK and 16-QAM at the same SNR. It can be concluded from this that the probability of error is susceptible to changing the type of modulation for the same system, that is, BER changes due to the changes in the order form of modulation.

The project also focuses on how MIMO-OFDM and SISO-OFDM systems could transmit images in a 3D communication channel based on adaptive processing algorithm with MMSE. The image investigated in this work has a resolution of 700 × 560 pixels and 8 bits of depth. The root mean square (RMS) power of the received signal was calculated for each pixel, and the error between the original and received images was measured using the mean square error (MSE) metric.
square error (MSE) was used to estimate errors during transmission via 3D WiMAX channel to quantify the effect of adaptation on the quality of the transmitted image.

\[
MSE = \frac{1}{MN} \sum_{j=1}^{M} \sum_{k=1}^{N} (x_{j,k} - \hat{x}_{j,k})^2,
\]

where \(M\) and \(N\) are the dimensions of the images in pixels; \(x\) is the original image; \(\hat{x}\) received image; \(x\) and \(\hat{x}\) are grayscale (8 bits of information) or brightness of the original and resulting image, respectively.

We simulated MIMO-OFDM system with parameters bandwidth (BW)= 20kHz, the spread of subpaths, relative to the main path, is characterized by the values \(\sigma_{AOD} = 5^\circ\), angles of departure (AoD) and \(\sigma_{AOA} = 35^\circ\), angles of arrival (AoA), for simplicity are considered the same in both planes. The OFDM signal parameters correspond to the number of subcarriers equal to 1024. The resulting duration of the entire frame of the OFDM symbols will be 0.41 \(\mu s\), the number of pilot signals is equal to 150, and the cyclic prefix duration will be chosen equal to 1/4 of the duration of the signal, which will avoid inter-symbol interference, according to the obtained maximum signal delay in channel modelling.

For 3D wireless channel adaptive algorithm with MMSE based on MIMO-OFDM system, let's construct the dependence of the MSE probability on SNR for various types of modulation. The figures below clearly demonstrate how an increase in the transmission speed affects the probability of MSE depending on the type of modulation.

![Figure 3. The MSE of the received image on the SNR based on adaptive algorithm with MMSE for BPSK modulation](image-url)
Figure 4. The MSE of the received image on the SNR based on adaptive algorithm with MMSE for QPSK modulation

An analysis of the presented figures shows that the normalized value of the mean square error is significantly reduced for the MIMO system using an adaptive algorithm and already at a signal-to-noise ratio.

The figures below show the image transmission results for the case with and without an adaptive algorithm at SNR = 10 dB (a with adaptation; b without adaptation). Figure 5 shows the original, figure 6 and 7 show the received image over the communication channel with the SISO-OFDM system for the modulation type BPSK and QPSK respectively. Figure 8 and 9 show the result of the received image over the communication channel for the MIMO-OFDM system with the modulation type BPSK and QPSK respectively.

Figure 5. Original Image
Figure 6. Transmission of the image over the communication channel with the SISO-OFDM system for BPSK modulation.

Figure 7. Transmission of the image over the communication channel with the SISO-OFDM system for QPSK modulation.
From figures 6 and 7 above, it can be seen that when using the adaptive processing algorithm in SISO-OFDM, MSE is reduced by more than 25 times for the modulation types BPSK and QPSK. Also, as seen in figures 8 and 9, MSE for the modulation types BPSK and QPSK is reduced by more than 10 times when using the adaptive processing algorithm in MIMO-OFDM.
With a fixed SNR level of 10 dB, the presented image transmission results show how adaptive algorithms with MMSE can increase the performance of the transmitted image in 3D WiMAX channel system.

4. Conclusion
On the basis of MIMO-OFDM, an algorithm for an adaptive signal processing system with MMSE for 3D system is presented. An example of image transmitting with and without the adaptation algorithm demonstrates the effectiveness of the MMSE with adaptation algorithm. At a fixed SNR level of 10 dB, the results show that using the MMSE with adaptation algorithm reduces the probability of errors in the transmitted message. When processing signals in receiving device in conditions of multipath signal propagation, the use of adaptive algorithms improves the noise immunity of the information transmission system.

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