

## Transmit and Receive Beamforming for OFDMA/TDD System

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**Abstract:** It is well-known that mobile communication systems are usually limited in their performance and capacity by three major impairments, which are multi-path fading, delay spread and co-channel interference (CCI). OFDMA (OFDM-FDMA) system can cope with the multi-path fading and delay spread easily due to the beneficial properties of OFDM technology. Though OFDMA scheme avoids intra-cell interference using the orthogonality among subcarriers, the scheme contains difficulty of reducing co-channel interference. Therefore, in this paper, adaptive antenna techniques are deployed into OFDMA/TDD system to minimize the co-channel interference induced by adjacent cells and to enhance the uplink performance. For the improvement of downlink performance, we apply TxAA (Transmit Adaptive Array), a kind of transmit diversity technique, into OFDMA/TDD transmitter side. Simulation results show that the downlink and uplink performance under multi-path Rayleigh fading channel improved considerably compared with the case of single antenna system.

**Keyword :** Transmit Beamforming, Receive Beamforming, OFDMA/TDD

### 1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is an effective multiplexing technique that can significantly mitigate inter-symbol-interference (ISI) induced by wireless multi-path fading channels while supporting high data rate transmission over wireless radio channels. As the technology advances, OFDM is promising to be the key modulation technique in the next generation mobile systems. It is well known that a cellular system uses frequency reuse concept to enhance the efficiency of spectral utilization, which introduces co-channel interference mainly from adjacent co-channel cells that is one of the major sources of performance degradation. In order to improve the performance of the OFDM system with co-channel interferences, researches that employ adaptive antenna array techniques into OFDM system have been proceeded recently.

In this paper, we propose an orthogonal frequency division multiple access / time division duplex (OFDMA/TDD) system with adaptive antenna array to mitigate co-channel interference and enhance uplink performance. To improve downlink performance, we employ the frequency-domain TxAA, a kind of transmit diversity strategy, into OFDMA/TDD transmitter side. For slowly varying TDD systems, the base station can measure the uplink matrix channel response and use those measurements to form the transmit weights on the downlink under the assumption of channel response reciprocity between the uplink and downlink.

### 2. Downlink and Uplink Structure of OFDMA/TDD System for Transmit and Receive Beamforming

A block diagram of an OFDMA/TDD system with adaptive antenna array for receive beamforming is shown in Fig. 1. For OFDM system, spatial signal processing can be applied to either time-domain or frequency-domain at the receiver. In our simulation, we apply frequency-domain beamforming due to its better performance compared with time-domain beamforming [1,2].

The modulated signal  $s_{m,n}$  can be expressed as

$$s_{m,n} = \sum_{k=0}^{N-1} S_{m,k} e^{j2\pi kn/N}, \quad 0 \leq m \leq N-1 \quad (1)$$

Taking the spatial channel into account, the multi-path fading channel model in time domain can be represented as

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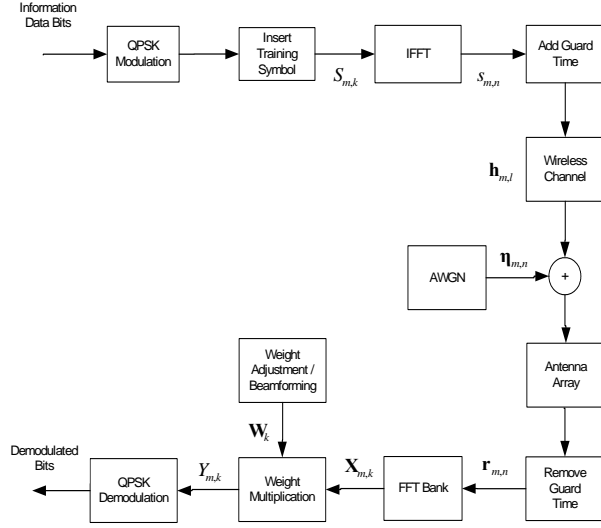


Fig 1. Uplink Structure of OFDMA/TDD System for Receive Beamforming.

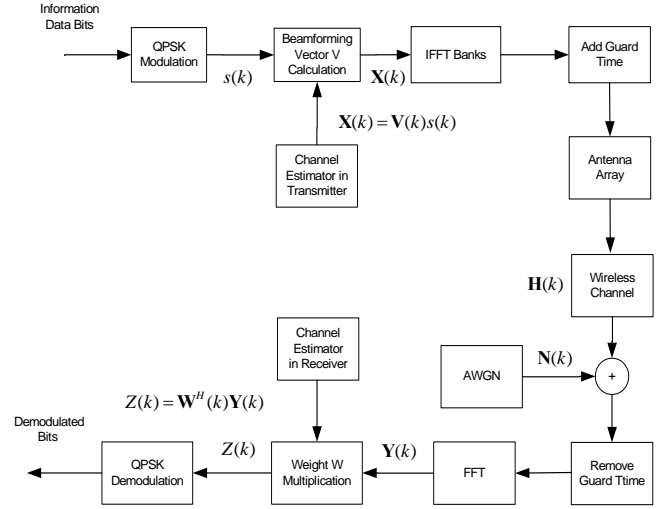


Fig 2. Downlink Structure of OFDMA/TDD System for Transmit Beamforming.

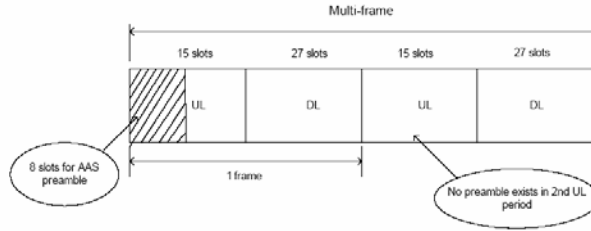


Fig 3. Frame Structure of Adaptive Antenna System.

$$\mathbf{h} = \sum_{l=0}^{L_1-1} a_l e^{j\theta_l} \mathbf{A}(\theta_l) \delta(t - \tau_l) \quad (2)$$

, where  $\mathbf{A}(\theta_l)$  represents the array response vector, which is a function of the array geometry and the direction of arrival (DOA) of  $l^{\text{th}}$  path  $\theta_l$ . By assuming that the CCI has the same property as the received signal, the desired signal including the desired signal and  $P$  co-channel interference can be expressed as

$$\mathbf{r}_{m,n} = \sum_{l=0}^{L_1-1} \mathbf{h}_{m,l,n} \cdot s_{m,n-l} + \sum_{p=0}^{P-1} \sum_{l=0}^{L_1-1} \mathbf{h}_{p,m,l,n}^l \cdot \mathbf{I}_{p,m,n-l} + \boldsymbol{\eta}_{m,n} \quad (3)$$

, where  $\boldsymbol{\eta}_{m,n}$  represents the AWGN noise of  $m^{\text{th}}$  symbol at  $n^{\text{th}}$  sample time, and  $\mathbf{h}_{p,m,l,n}^1$  defines the multi-path channel vector of  $p^{\text{th}}$  co-channel interference  $\mathbf{I}_{p,m,n}$ . The corresponding received signal in the frequency domain is represented as

$$\mathbf{X}_{m,k} = \sum_{n=0}^{N-1} \mathbf{r}_{m,n} e^{-j2\pi kn/N} \quad (4)$$

Finally, the demodulated data is obtained as follows.

$$Y_{m,k} = \mathbf{W}_k^H \mathbf{X}_{m,k} \quad (5)$$

,where  $\mathbf{W}_k$  represents the matrix including the spatial weight vectors that can be obtained from utilizing the adaptive algorithms (i.e, LMS, NLMS, RLS etc.) for each individual subcarrier [3].

To train the base station antennas, we use the following frame structure shown in Fig. 3 [4]. In Fig. 3, a multi-frame consists of 2 frames, but it can be also comprised of 1, 2 or 4 frames. The first 8 slots of uplink part in multi-frame are used as preamble to train base station antennas. If channel is varied considerably during the multi-frame period, we can't obtain the benefits of adaptive antenna array. So after 8 slot period, we utilize the pilot subcarriers to estimate time-varying channel.

A block diagram of an OFDMA/TDD system for transmit beamforming is shown in Fig. 2 [5]. To exploit transmit diversity using TxAA, the transmitter side has to know the matrix frequency response between transmit and receive antennas. Due to reciprocity between uplink and downlink channel in TDD system, transmitter can measure channel responses during the pilot training symbol duration of 8 slots and form the transmit weights on the downlink. Then appropriate weight vectors are multiplied with the output of FFT block. The transmit and receive weights can be chosen as follows. On subcarrier  $k$ , the singular value decomposition of channel matrix is as in Eq. (6).

$$\mathbf{H}(k) = \mathbf{U}_H(k) \mathbf{S}_H(k) \mathbf{Z}_H^H(k) \quad (6)$$

The transmit weight vector  $\mathbf{V}(k)$  can be chosen as in Eq. (7).

$$\begin{aligned} \mathbf{V}(k) &= \mathbf{Z}_{H1}(k) \\ \text{where } \mathbf{Z}_{H1}(k) &: \text{the first column of } \mathbf{Z}_H(k) \end{aligned} \quad (7)$$

The receiver weight vector  $\mathbf{W}(k)$  can be chosen as in Eq. (8).

$$\begin{aligned} \mathbf{W}(k) &= \frac{\mathbf{H}(k) \mathbf{V}(k)}{\mathbf{V}^H(k) \mathbf{H}^H(k) \mathbf{H}(k) \mathbf{V}(k) + \frac{\sigma_n^2}{\sigma_s^2}} \\ \text{where } \sigma_n^2 &: \text{Receiver noise variance} \\ \sigma_s^2 &: \text{Power of transmitted symbol} \end{aligned} \quad (8)$$

### 3. Simulation Results

The general parameters for the simulation is shown in table 1. The simulation parameters correspond to that of WiBro (Wireless Broadband) system, which is a kind of OFDMA/TDD system that has been actively researched in

TABLE 1. SIMULATION PARAMETERS

Parameters	Value
Center Frequency	2.3GHz
Sampling Frequency	10MHz
Number of Subcarriers	1024
Number of Effective Subcarriers	768
Number of Pilot Subcarriers	96
Cyclic Prefix	128
OFDMA Symbol Duration	115.2 us
TDD Frame Duration	5 ms
DL slots / Frame	27
UL slots / Frame	15
Modulation	QPSK
Wireless Channel	Ped B 10km / h
Tx /Rx Antenna Configuration of Base Station	8 elements ULA (Uniform Linear Array)
Tx /Rx Antenna Configuration of Subscriber Station	1 element

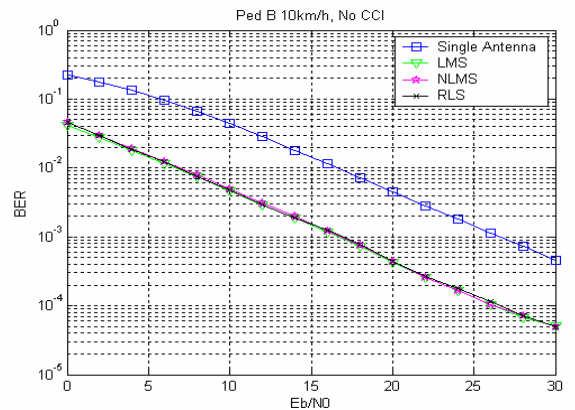


Fig 4. Uncoded BER Performance of Adaptive Array in Ped B 10km/h channel without Co-Channel Interference (OFDMA/TDD Uplink).

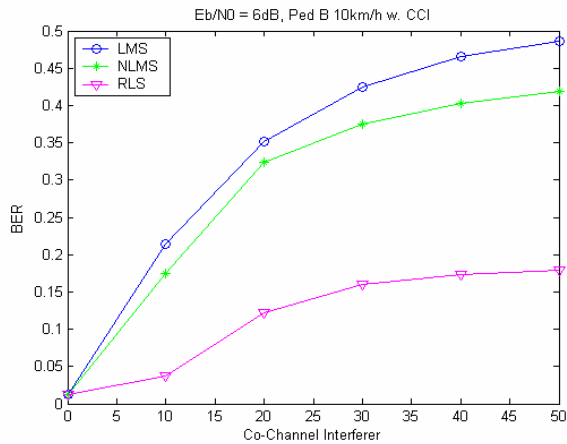


Fig 5. Uncoded BER Performance of Adaptive Array in Ped B 10km/h channel with Co-Channel Interference (OFDMA/TDD Uplink).

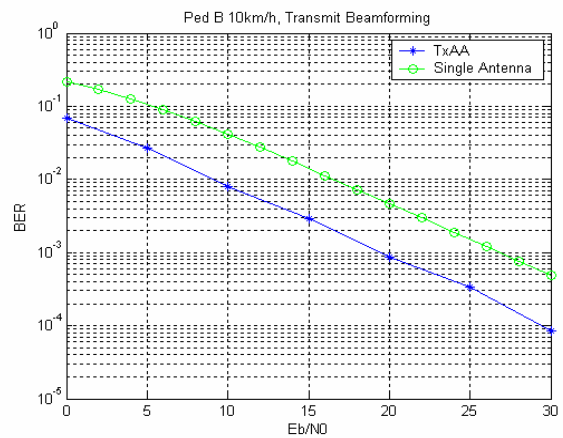


Fig 6. Uncoded BER Performance of Transmit Adaptive Array in Ped B 10km/h channel (OFDMA/TDD Downlink).

Korea for 2.3GHz low-mobility WMAN (Wireless Metropolitan Area Network) deployment.

Fig. 4 shows uplink BER performance of frequency-domain adaptive array in Ped B 10km/h channel without co-channel interference. LMS, NLMS, RLS algorithms are simulated as adaptive algorithm for training the base station antennas. Without co-channel interference, the performances of system using LMS, NLMS, RLS adaptive algorithm are very similar. At the target BER of  $10^{-3}$ , about 9dB array gain can be achieved with the adaptive array, compared to the single antenna system.

Fig. 5 shows uplink BER performance of frequency-domain adaptive array in Ped B 10km/h channel with co-channel interference. LMS, NLMS, RLS algorithms are simulated as adaptive algorithm for training the base station antennas. With co-channel interference, the performance of system using RLS adaptive algorithm is better than the cases using LMS or NLMS adaptive algorithms.

Fig 6 shows downlink BER performance of frequency-domain TxAA utilizing the reciprocity of TDD system in Ped B 10km/h channel. At the target BER of  $10^{-3}$ , about 7dB gain can be achieved with TxAA, compared to the case of single antenna system.

#### 4. Conclusions

In this paper we propose OFDMA/TDD system with adaptive antenna array to mitigate co-channel interference and enhance uplink performance. To improve downlink performance, we employ the frequency-domain TxAA, a kind of transmit diversity strategy, into OFDMA/TDD transmitter side.

Simulation results show that OFDMA/TDD system with antenna array can achieve about 9dB receive beamforming gain and 7dB transmit beamforming gain compared with the case of single antenna system at the target BER of  $10^{-3}$  in Ped B 10km/h channel.

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