國立交通大學

資訊科學與工程研究所

碩士論文

於 MIMO-OFDM 之智慧型成波束天線之研究

The Study of Beamforming Techniques and Smart Antenna in Wireless MIMO-OFDM Systems

研 究 生：張益瑋

指導教授：許騰尹 教授

中華民國九十八年八月

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研究生：張益瑋　　Student：Yi-Wei Chang

指導教授：許騰尹　　Advisor：Terng-Yin Hsu

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摘要

為了能夠有效的利用頻寬，使用智慧型天線(smart antenna)與數位訊號成波束技術(digital beamforming)可以提升多輸入多輸出 (MIMO) 的傳輸系統效能，其目地為提高訊號品質與消除其他訊號之干擾。

在這篇論文我們提出一個方法搜尋訊號的入射角來源，此演算法利用接收端的訊號去分析傳送端訊號之強度，藉由訊號強度去調整指向型天線之方向。另一方面，我們偵測進入接收端訊號的延遲，利用此延遲調整訊號，使訊號達到最佳強度，即可增加訊號的容量與訊號品質。

在 IEEE 802.11n 的系統平台而且符合 TGN 所規範的通道模型中模擬。模擬結果指出此演算法與最佳調整的效能相比，找出訊號強度對效能之影響。使用訊號偵測器去偵測訊號調整，可以提升整體系統效能。以上皆應用在多輸入多輸出的傳輸系統上模擬。

Abstract

Smart antenna and digital beamforming in MIMO-OFDM system are an efficient way to improve the performance. Two of them are cancelling the interference signal and emphasize the interested signal. They can be used the antenna array to received signals and control the direction of the maximum gain via different phase adjustment.

In this paper, we proposed a method to estimate the arrival of angle in smart antenna system. The method detects correlation of transmitted signal by search the maximal quality form transmitted-end. Moreover, according to this method, we can find an arrival angle on received-end and adjust the antenna angle to steering them. It can improve the interested signal quality. In digital beamforming system, if the signal arrival on received-end is skew, it will cause the signal performance terribly. We proposed a method to detect the channel environment to adjust the signal on received end. The received signal is computed a weighting vector to improve the SINR (Signal Interference Noise Ratio), increase capacity and enhance the signal quality.

Through simulation in IEEE 802.11n platform with TGn channel D, It will show that the proposed algorithm with smart antenna performs a little degradation than with the prefect smart antenna system. And in digital beamforming system, using this detector to detect the channel impulse response and via phase adjustment will improve some performance then channel arrival skew. All of these simulations are in MIMO-OFDM 4×4 platform.

Index Terms—***Digital beamforming; Smart antenna; MIMO-OFDM; MIMO Detection***

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民國九十八年八月十七日

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Chapter 1

Introduction

The need for high transmission rate and guaranteed quality of service has grown rapidly in wireless communication system. Orthogonal frequency division multiplexing (OFDM) is one of the multi-carrier modulation schemes. It has been considered one of the major techniques for next generation wireless communication. A receiver of OFDM system can avoid intersymbol interference if the guard interval (GI) is larger than the channel delay profile. The OFDM has been adopted in digital audio broadcasting and digital video broadcasting-terrestrial (DVB-T), it already forms the basis of the current wireless local area network (WLAN) standard, IEEE 802.11 a, g and n.

Currently, Multiple-Input Multiple-Output (MIMO) system, where antenna arrays are equipped at both the transmitter and receiver with a signal processor, antenna arrays has been considered not only improved the high-bit-rate transmission and increased the performance of system over multipath fading channel, but also for interference suppression. Therefore, the combination of MIMO and OFDM is seen as an attractive solution for high speed indoor WLANs in frequency selective fading channel environment.

Multiple antenna techniques are considered as the promising technique for the high spectral efficiency. The space division multiple access (SDMA) is one of technique multiple antenna technique, it increases total system capacity and the signal quality by digital beamforming and null interference operations.

There are some techniques to improve the signal quality, such as smart antenna and digital beamforming. It will be introduced in section 1.1 and section 1.2, respectively.

1.1. Smart Antenna

Smart antenna generally refers to any antenna arrays, which can adjust or adapt its beam pattern to emphasize signals of interest and to minimize interfering signals. Recently, smart antennas are proposed as a new technology for wireless systems that use some fixed sets of antenna elements in an array. It forms multiple fixed beams with heightened sensitivity in particular directions. Such as the signals from these antenna elements detect the signal strength, the antenna system will choose the appropriate direction from one of several fixed beam, and switches form one beam to another using digital signal processing (DSP), or RF hardware, to a desired direction.

This allows the antenna system can select the beam that gave the strongest received signal. By changing the phase of the signals used to direct the antenna elements or received from them, the main beam can be driven in different directions throughout space. This allows the smart antenna system to focus on Radio Frequency (RF) resource. It can minimize the noise, interference, and other will affect the signal quality.

In general, smart antenna as shown in Fig.1.1 It can separate spectrally and temporally overlapped signals and enables multiple users within the same space to be accommodated on the same frequency and time slot. It can increasing the capacity.

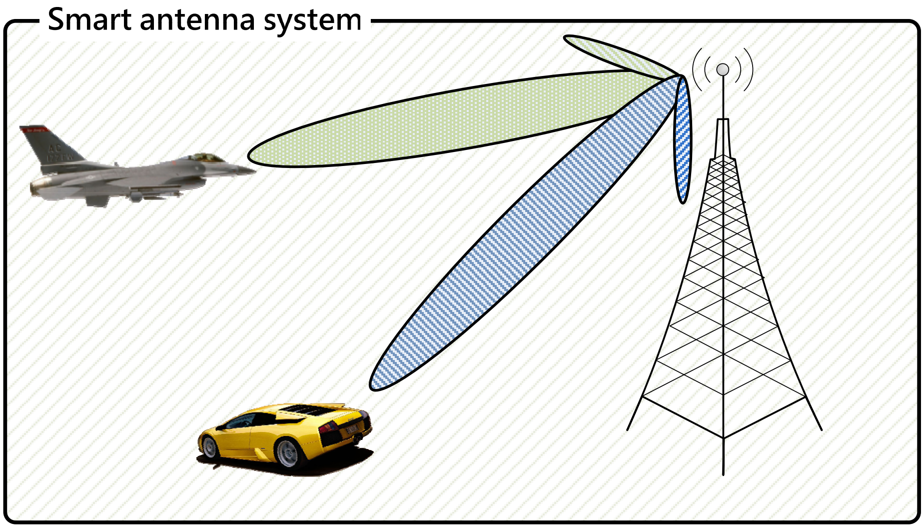


Fig.1.1 A smart antenna system

1.2. Digital Beamforming

Particularly, a digital beamforming (DBF) smart antenna offers flexibility because various algorithms can be implemented in DSP. Digital beamforming is a technology between antenna and digital. In early applications, it works in Sonar and Radar system. DBF technology has reached a sufficient level of maturity that it can be applied to communications for improving system performance. Furthermore, the most important thing is increasing capacity for incorporating DBF into future wireless communications system.

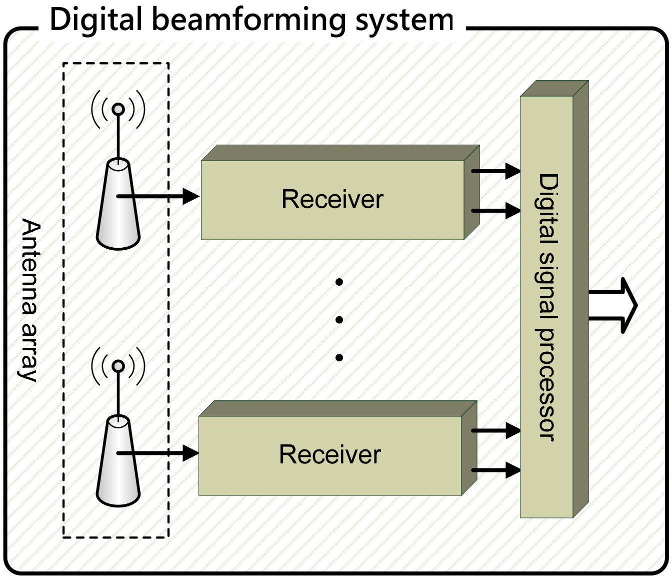


Fig.1.2 A generic digital beamforming system

A generic DBF antenna system shown in Fig.1.2 It consists of three components: the antenna array, the digital receivers, and the digital signal processing.

Digital beamforming is based on the RF signal and each antenna elements into two binary baseband signals representing cosine and sine wave. These two digital baseband signals can be used to find amplitudes and phase of the signals at each received antenna. The process of beamforming is use a weighting to change digital signals, like adjusting their amplitude and phase, such that we adding together to form the desired output. The key to this technology is the accurate translation of the analogy signal into the digital region. An optimum antenna is one that carries out the conversion of the signals that arrive at its face without introducing any distortions to the signal. It is for this reason that a digital beamforming antenna might be considered to be an optimum antenna.

Fig.1.3 depicts a simple structure that can be used for beamforming. The process represented in Fig.1.3(a) is referred to as element-space beamfroming, where the data signals from the array elements are directly multiplied by a set of weights to form the desired beam. Rather than directly weighting the outputs from the array elements, they can be first processed by a multiple-beam beamformer to form a suite of orthogonal beams. The output of each beam can then be weighted and the result combined to produce a desired output. This process is often referred to as the beam-space beamforming in Fig.1.3 (b).

In this paper, the contribution is use the cross-correlation and auto-correlation value to detect the arrival of angle and adjust antenna to steering them in smart antenna system. In digital beamforming system, we calculate the weighting vector which can achieve the same effect with smart antenna. We have two things to do. First, we can find the best arrival of angle and adjust the antenna to steering them. Second, use DSP to calculate the weighting to cancel the interference signal.

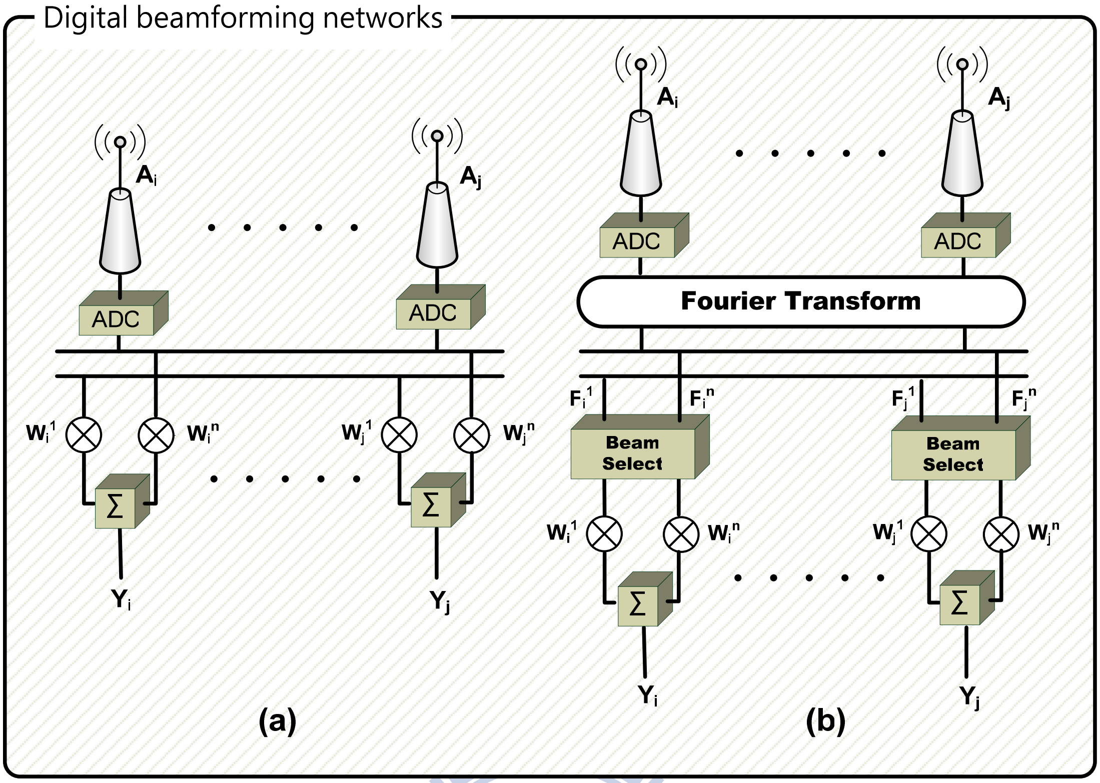


Fig.1.3 Digital beamforming networks

Panel (a) shows an element space beam former.

Panel (b) shows a beam space digital beam former.

This paper is organized as follows: section 2 describes the IEEE 802.11n PHY Specification, the beamforming and smart antenna system modelling. Section 3 proposed an algorithm to detect the arrival of signal. Section 4 analysis the beamforming delays and adjusts the signals to arrival at the same time, or discuss some problems. Section 5 shows the simulation results and section 6 conclusions the paper with some remarks.

Chapter 2
System Platform

This chapter is going to describe complete simulation environments form MIMO-OFDM specification of IEEE 802.11n PHY layer of the TGn Sync Proposal which operate at 2.4GHz band with 20MHz bandwidth.

Section 2.1 describes the 4×4 MIMO transceivers and the packet format of 802.11n and the MIMO encoder/decoder for both 4×4 MIMO.

2.1. IEEE 802.11n PHY Specification

Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier modulation that achieves high data rate and combat multi-path fading in wireless networks. The main concept of OFDM is to divide available channel into several orthogonal sub-channels. All of the sub-channels are transmitted simultaneously, thus achieve a high spectral efficiency. Furthermore, individual data is carried on each sub-carrier, and this is the reason the equalizer can be implemented with low complexity in frequency domain.

2.1.1. Transmitter

The transmitter block diagram of MIMO-OFDM specified in IEEE 802.11n proposal is shown as Fig 2.1. The source data is first scrambled to prevent a succession of zeros or ones, and then it is encoded by convolution encoder, which is used as Forward Error Correction (FEC). The FEC-encoded bit stream is punctured in order to support four coding rates, 1/2, 2/3, 3/4 and 5/6. Then the punctured bit stream is parsed into spatial streams, according to the number of transmit antennas (there are 2 or 4 spatial streams in this thesis).

The interleaver changes the order of bits for each spatial stream to prevent burst error. Then the interleaved sequence of bit in each spatial stream is modulated (to complex constellation points), there are four kinds of modulations, BPSK, QPSK, 16-QAM and 64-QAM.

To transform the signal after modulator in frequency domain constellations into time-domain constellations, Inverse Fast Fourier Transform (IFFT) is used. There are 64 frequency entries for each IFFT, or 64 sub-carriers in each OFDM symbol. 52 of them are data carriers, 4 of them are pilot carriers and the rest 8 are null carriers. Finally, the time domain signals appended to the Guard Interval (GI) of 1/4 symbol length, are transmitted by RF modules.

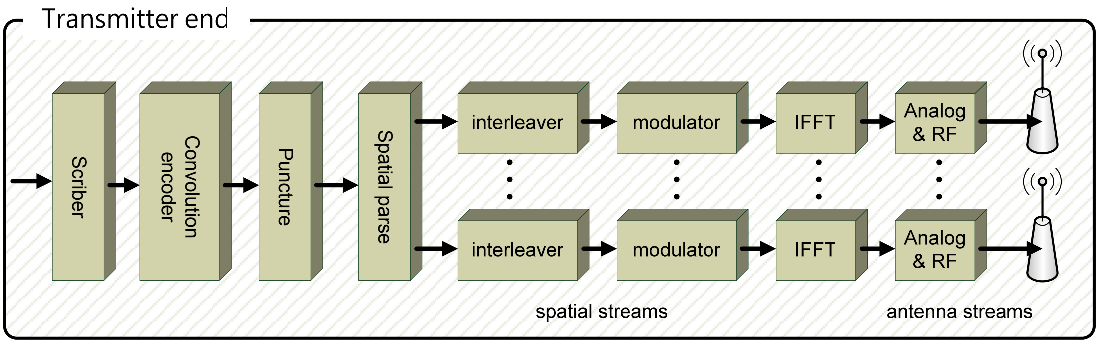


Fig.2.1 IEEE 802.11n MIMO transmitter

2.1.2. Receiver

The receiver block diagram is shown as Figure 2.2. Signals received from the RF modules are first synchronized to recognize each OFDM symbol. Through the Smart antenna and digital beamforming function blocks, use the proposed algorithm to handle the signals that the receive signal have large of energy. After the proposed algorithm, each OFDM symbol is transformed to frequency domain by the Fast Fourier Transform (FFT). If the OFDM symbol belongs to long preamble (described in section 2.1.3), then it is used for channel estimation [1]

To exploit the spectrum efficiency, large number of antennas and/or high order QAM constellations are often employed, which leads a challenge to design the MIMO detection [2] with acceptable complexity and sub-optimal. For linear detection approaches, Zero-Forcing (ZF) or Minimum Mean Square Error (MMSE) uses the inverse of estimated channel response to extract the desired signals. Another category is the nonlinear approaches such as V-BLAST and the maximum likelihood detection (MLD). The MLD algorithm gains the optimal performance but also with the intractable computation complexity [3].

After separated by decoder, the spatial streams are demodulated to bit-level streams. Then these bit-level data streams are de-interleaved and merge to single data stream. Finally, the data stream is decoded by FEC which includes de-puncturing, and de-scrambler.

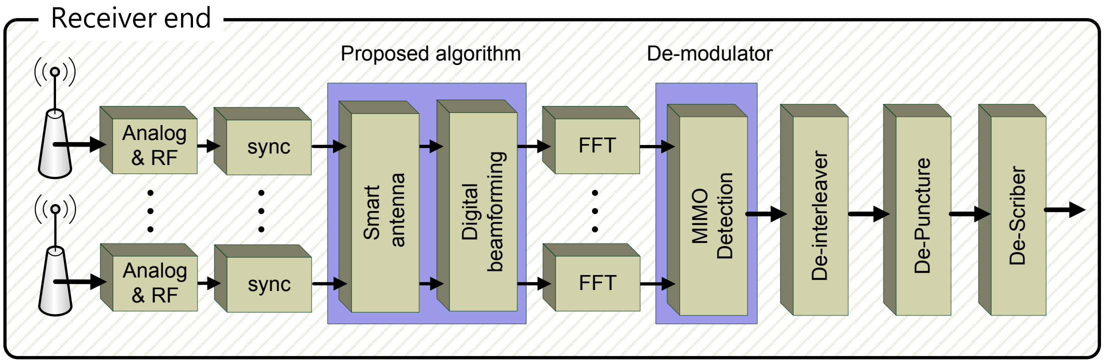


Fig.2.2 IEEE 802.11n MIMO receiver

2.1.3. Packet Format

The packet format fields are shown as Fig2.3. The L-STF (Legacy Short Training Field), the L-LTF (Legacy Long Training Field), L-SIG (Legacy Signal Field) and HT-SIG (High Throughput Signal Field) comprise the legacy compatible part of the PPDU preamble which allows PHY layer interoperability with 802.11a and ERP-802.11g modems.

The HT-STF fields stands for High-Throughput Short Training Field, and it is short preamble of MIMO-OFDM systems which is used for synchronizing to recognize each OFDM symbol. The HT-LTF fields stand for High-Throughput Long Training Field, that is, the long preambles for MIMO-OFDM systems. The long preambles are used for channel estimation as described in [3]. The payload parts shown as DATA fields in Fig, each symbol consisting of 52 data sub-carriers and 4 pilot sub-carriers, are used for the adaptive channel estimation algorithm [4].

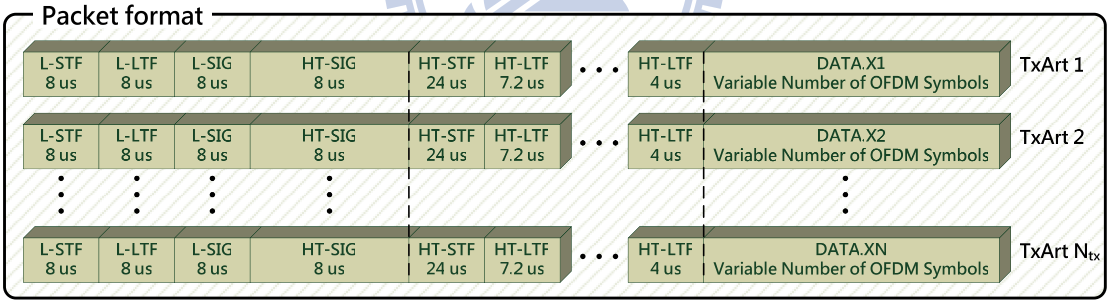


Fig.2.3 IEEE 802.11n packet format

2.2. Channel model

There are many imperfect effects during transmitted signals through channel, time invariant multipath energy factor, beamforming delay and Additive White Gaussian Noise (AWGN), and so on. The block diagram of channel model is shown in Fig.2.4.

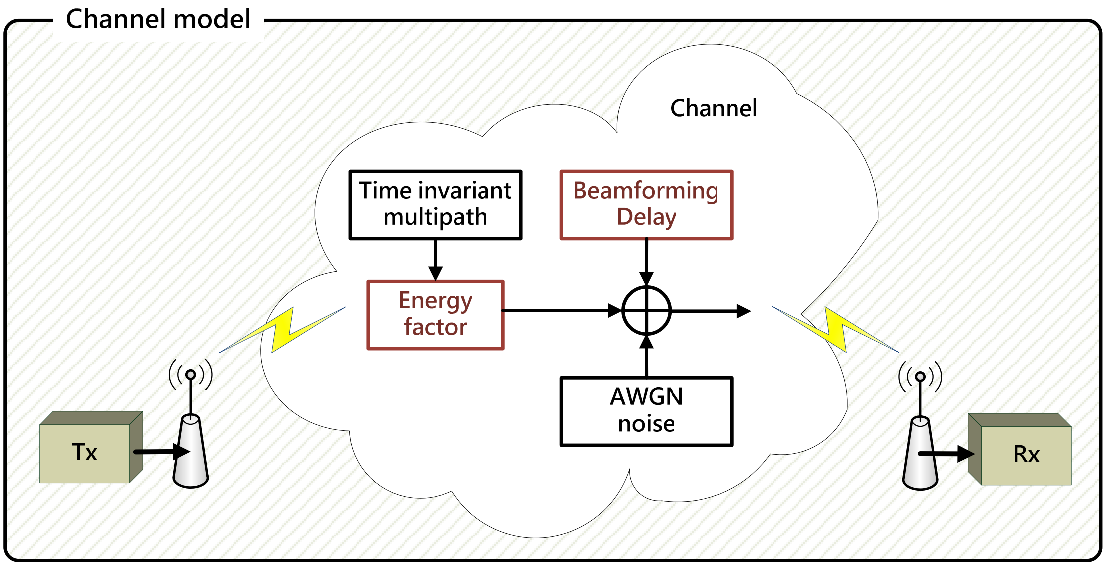


Fig.2.4 Block diagram of channel model

2.2.1. Channel noise model

Wideband Gaussian noise comes from many natural sources, such as the thermal vibrations of atoms in antennas, "black body" radiation from the earth and other warm objects, and from celestial sources such as the sun. The AWGN channel is a good model for many satellite and deep space communication links. On the other hand, it is not a good model for most terrestrial links because of multipath, terrain blocking, interference, etc. The signal distorted by AWGN can be derived as

$$r(t) = s(t) + n(t)$$

where $r(t)$ is received signal,

$s(t)$ is transmitted signal,

$n(t)$ is AWGN.

2.2.2. Beamforming delay model

In the Fig.2 a uniformly space linear array is depicted with K identical isotropic element. Each element is weighting with a complex weighting V_k with k = 0,1,…,K-1, and the antenna element spacing is donate by d. If the plane wave arrival at the angle θ with respect to the array normal. We assume that a signal $s(t)$ is generated by a source in the "far-field" of the smart antenna. The impinging signal of the antenna array is approximately a uniform plane wave. We also assume all element are equally spaced and far field conditions such that r >> d. By the element k and element k-1(k is less then receiver end number), the differential distance along the two ray path is $d\sin\theta$.

We respect to antenna k and antenna k-1 experience a time delay of $\Delta\tau = \frac{dsin\theta}{v_0}$, v_0 is the wave speed. If $s(t)$ is a narrowband signal with carrier frequency f_c, then the time delay $\Delta\tau$ corresponds to a phase shifter of $\Delta\psi = 2\pi\frac{dsin\theta}{\lambda_c}$ where λ_c is the wavelength corresponding to the carrier frequency, i.e. $\lambda_c = \frac{v_0}{f_c}$. When incoming signal form a direction to the array normal (θ=0), the time delay and phase shift between the two antenna are zero.

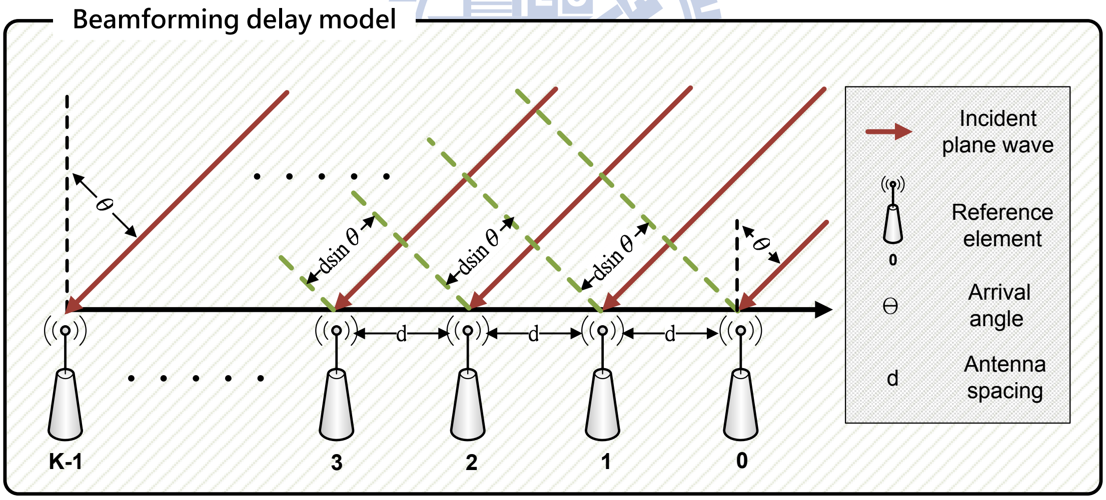


Fig.2.5 A uniformly spaced linear array

The steering vector will be defined as it contains the response of all elements of all elements of the steer to source with a single frequency component. Since the array response is different in different directions, array vector is associated with each directional source.

So in Fig 2-5, the steering vector is given by:

$$a(\theta) = [1, e^{-j\frac{2\pi d}{\lambda_c} sin\theta}, e^{-j2\frac{2\pi d}{\lambda_c} sin\theta}, \ldots, e^{-j(K-1)\frac{2\pi d}{\lambda_c} sin\theta}].$$

2.2.3. Energy factor

On the smart antenna, it is able to enhance the received signal form the transmitter and tune out unwanted interferences. The smart antenna use directional antenna on the receiver end to feel the different strength of signal on the different directions of arrival. On this paper, we use energy factor to simulate the directional antenna behavior.

The energy factor is defined as the strength of the received signal. We use Laplacian distribution to generate the power angular spectrum. Each channel tap exhibits Laplacian power azimuth spectrum (PAS) [5] in the domain and the angular spread (AS) is the second moment of PAS. The shape is $p(\phi) = \frac{1}{\sqrt{2\sigma}} e^{-\left|\sqrt{2\phi}/\sigma\right|}$ where Φ is azimuth angle and σ is Angular Spread (AS). Fig is the example of Laplacian distribution. The horizontal axis is arrival degree and the vertical axis is the power of signal. On received end, we use the directional antenna to scan transmission environment. If we find the direction-of-arrival (DOA) of the signal-of-interest (SOI), we adjust the antenna to focus on the SOI while turning the SOI has large signal strength.

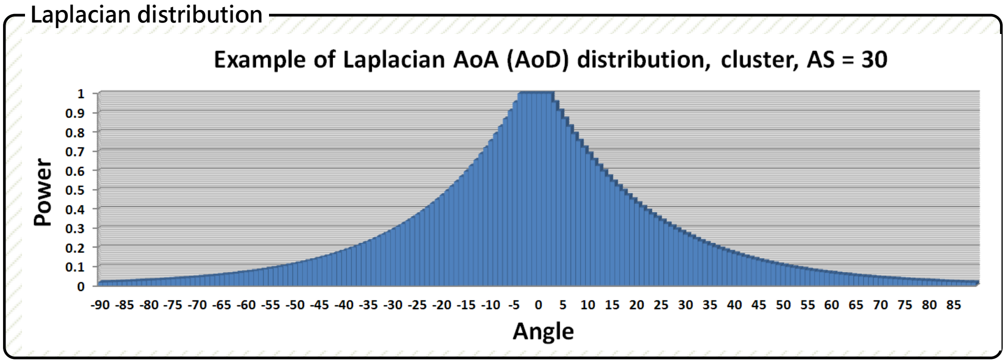


Fig.2.6 Example of Laplacian AoA (AoD) distribution, cluster, AS = 30

2.3. System Description

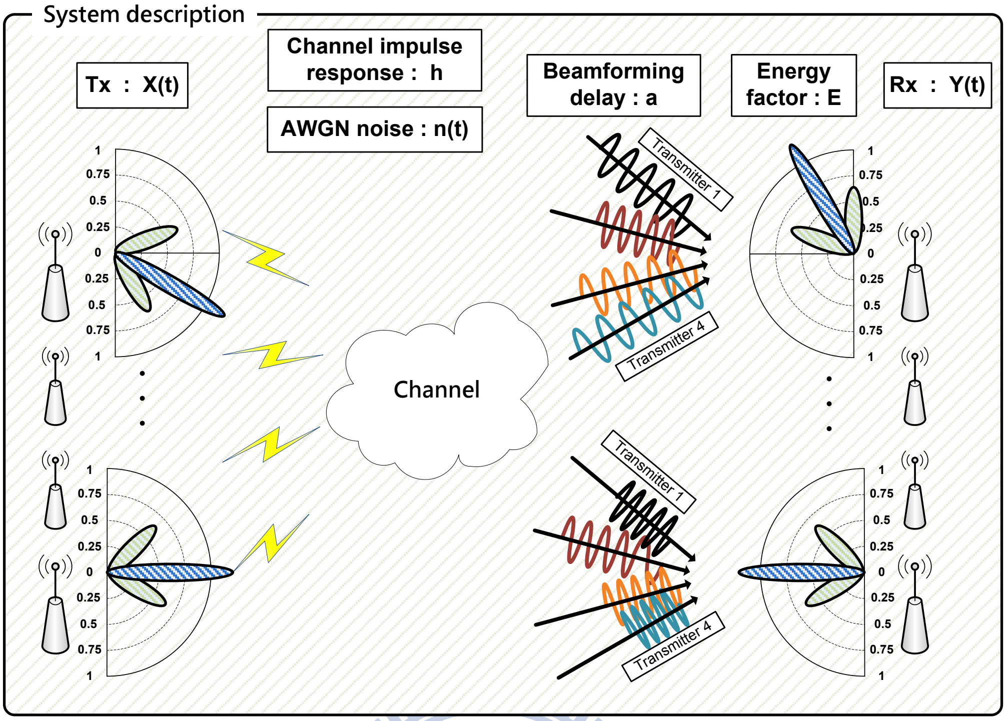


Fig.2.7 The system description of the MIMO-OFDM system

Consider a $N_T \times N_R$ spatial multiplexing MIMO system, where N_T and N_R are the number of transmitted and received antennas. The data is encoded by scrambler, convolutional code, puncture, interleaver, *N*-QAM modulation and transmitted over the N_T antennas simultaneously. Assuming perfect timing and frequency synchronization, the received baseband signal for $N_T \times N_R$ MIMO system is modeled as following:

$$\boldsymbol{Y(t)} = E \times a \times (h_{ij} \otimes X\boldsymbol{(t)}) + \boldsymbol{n(t)} \qquad \text{……………………….(1)}$$

where E is energy factor, $A = [a(\theta_1) \ \ldots \ a(\theta_T)]$ is an T×R matrix of beamforming delay vector, $\boldsymbol{x} = \left[x_1, x_2, \ldots, x_{N_T}\right]^T$ ($[*]^T$ means transpose), x_i is the transmitted signal modulated with N-QAM constellation in the i-th transmitted antenna in the transmitted signal space; $\boldsymbol{y} = \left[y_1, y_2, \ldots, y_{N_R}\right]^T$ denote the received symbol vector in the received signal space, and $\boldsymbol{n} = \left[n_1, n_2, \ldots, n_{N_R}\right]^T$ indicates an independent identical distributed (i.i.d.) complex zero-mean Gaussian noise vector with variance σ^2 per dimension. Moreover, the frequency selective fading is represented by the $N_R \times N_T$ channel matrix H, whose elements hij represent the complex transfer function from the j-th transmit antenna to the i-th receive antenna.

2.4. Problem Statement

On the smart antenna system, we will analysis the signal quality and discuss how to detect the arrival of angle in smart antenna system. If rotate the antenna to steering the arrival of angle, how much gain can we improve then the antenna did not rotate. On digital beamforming system, calculate the weighting to cancel the interference signals and emphasize the interest signals. If the channel arrivals is skew, how to detect the channel and how to adjust the signals, and how to improve the system performance using the weighting vector.

Section 3 will propose an algorithm to detect the arrival of angle. Then analysis the channel environment and adjust them in digital beamforming techniques. Section 3 and 4 will discuss these problems.

Chapter 3

The Proposed Smart Antenna Algorithm

In the standard of IEEE 802.11n, each MIMO-OFDM symbol has short preambles and long preambles which that they can be used to estimate the signal arrival or not, or recognized the arrival of which transmitter signal. The received symbols are used to propose method which calculates the correlation value to estimation the arrival of angle. Use this information to rotate the antenna angle to steering the maximal of correlation value which can improve performance.

In section 3.1 and 3.2, the Arrival-of-arrival (AOA) estimation scheme and detection algorithm will be introduced.

3.1. Detection algorithm introduction

This section will introduce how to find the arrival of angle (AOA), used this AOA to rotate the antenna beam to acquire the strongest received signal. On Fig.3.1, it is a block diagram of the smart antenna on receiver end. When the packet detection detects the signal arrival and symbol boundary detection determines the starting of the symbol, we can get the perfect timing and frequency synchronization. Then used the ideal short preambles and received signals to calculate the correlation value which it can say that the relatively of signal. Basically, if the correlation value is large, it will have large possible to say the signals come from these short preambles which the transmitted end sends.

For example, when receiver 1 received the signals, the signals are combine the transmitter's signals including transmitter1, transmitter2...etc. All of these will let the signal cannot recognize quickly and clearly. The directional antenna to direct the signal of interest and it can be getting the higher gain of the signals. When the receiver end gets the higher gain of interest signal, it will have large signal powers and qualities. Use correlation values to quantize these situations which can estimate the signal come from. That is, the maximal correlation value, which can rotate the antenna beam to this arrival of angle. Then by pass the signal to next stage.

There are some of steps of detection algorithm, which can be discussed in next section.

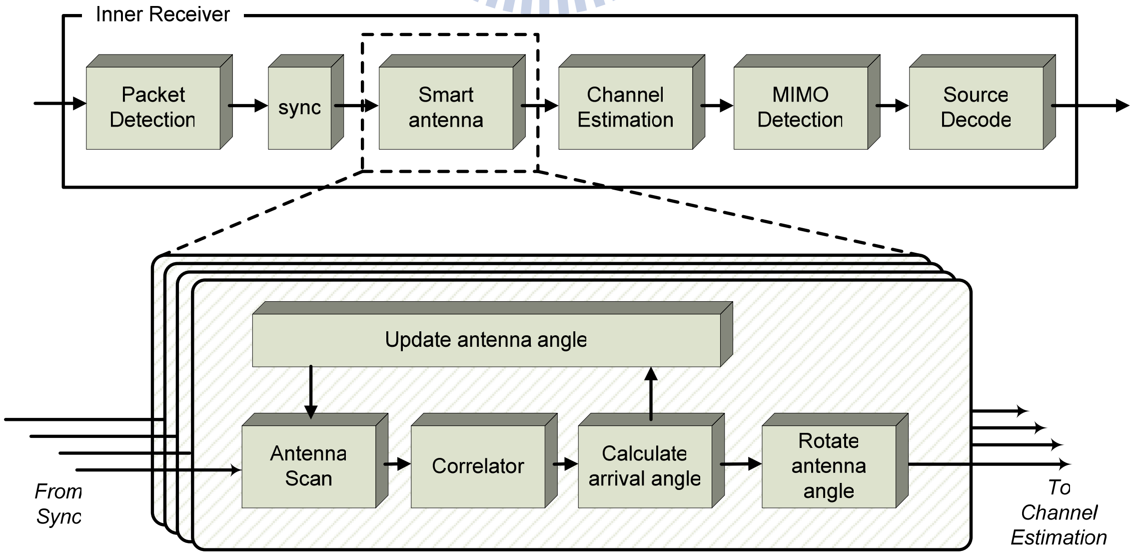


Fig.3.1 Smart antenna block diagram

3.2. Detection algorithm

The proposed algorithm has four steps to detect the arrival-of-angle,

1. Antenna scan form -90° to 90°
2. Use auto-correlation and cross-correlation to quantize the strength of signals.
3. By correlation value, use algorithm to calculate the angle of interest signal.
4. Update and rotate the antenna angle to receive signal.

Step1:Antenna scan form -90° to 90°

Fig 3.2 is a simple diagram of directional antenna. It is a two-dimensional beam pattern of directional antenna. The shadow areas are beam pattern of antenna. The beam pattern has mainlobe and sidelobe in antenna pattern. The mainlobe is that portion of the pattern which has maximum intended radiation. The goal of smart antenna system is to steering the mainlobe to arrival-of-angle. On this paper, Rotate the antenna angle of five degree each form -90° to 90°, and in every adjustment, it have to calculate the correlation value. Finally, getting the power angular spectrum about the signal arrival of received end will show in Fig 3.4.

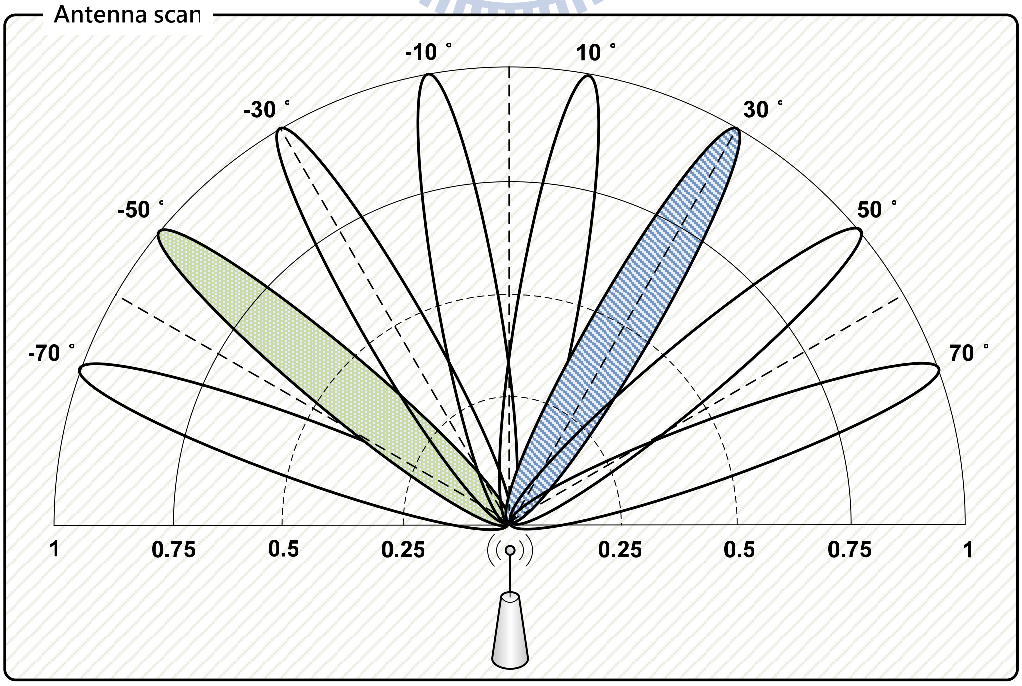


Fig.3.2 Smart antenna scan form -90° to 90°

Step2: Cross-correlation and auto-correlation

Cyclic shift is a common technique of OFDM transmitted system. It is be used to prevent uninterentional beamforming when the same signal or scalar multiples of one signal are transmitted through different spatial stream or transmit chains. The cyclic shift is applied to each OFDM symbol in the packet separately.

Correlation is a mathematical tool used in signal processing for analysing functions or series of values, such as time domain signals. Correlation is the mutual relationship between two or more random variables. Autocorrelation is the correlation of a signal with itself. This is unlike cross-correlation, which is the correlation of two different signals.

The following is a correlation matrix that it is performed by calculating the parallel cross-correlation of the received signal $R_i(k)$ and the known short training sequence $Q(k)$ to be reference. Fig 3.3 will show the correlation value how to generate by proposed cross-correlation and auto-correlation architecture. There are some parameter will to introduce. The parameter K is the time scalar point. And the parameter B is a buffer of the short training sequence. The parameter L is a correlation window. Define an L×B matrix of $Q(k)$ which consist of $Q_1(k) \sim Q_L(k)$.

$$Q(k)=\begin{bmatrix} Q_1(k) \\ Q_2(k) \\ Q_3(k) \\ \vdots \\ Q_{L-2}(k) \\ Q_{L-1}(k) \\ Q_L(k) \end{bmatrix}=\begin{bmatrix} L-STS(1) & L-STS(2) & L-STS(3)\cdots & \cdots & \cdots L-STS(B-2) & L-STS(B-1) & L-STS(B) \\ L-STS(16) & L-STS(1) & L-STS(2)\cdots & \cdots & \cdots L-STS(B-3) & L-STS(B-2) & L-STS(B-1) \\ L-STS(15) & L-STS(16) & L-STS(1)\cdots & \cdots & \cdots L-STS(B-4) & L-STS(B-3) & L-STS(B-2) \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ L-STS(4) & L-STS(5) & L-STS(6)\cdots & \cdots & \cdots L-STS(B+1) & L-STS(B+2) & L-STS(B+3) \\ L-STS(3) & L-STS(4) & L-STS(5)\cdots & \cdots & \cdots L-STS(B) & L-STS(B+1) & L-STS(B+2) \\ L-STS(2) & L-STS(3) & L-STS(4)\cdots & \cdots & \cdots L-STS(B-1) & L-STS(B) & L-STS(B+1) \end{bmatrix}$$

The parallel cross-correlation with each $Q_L(k)$ indicates the correlation power is $CP_{i,L}(k)$.

$$\begin{aligned} CP_{i.L}(k) &= p_i\left[R_i(k-B+1), R_i(k-B+2), R_i(k-B+3), \ldots R_i(k)\right] \\ &= \left|\sum_{L=0}^{B} R_i(k-B+1) * Q_L(k-B+1)\right| \end{aligned}$$

Auto-correlation is use to finding repeating patterns in a signal, such as determining the presence of a periodic signal which has been buried under noise. The parallel auto-correlation is correlation of a signal with correlation buffer1 and correlation buffer2, the autocorrelation power is $AP_{i,L}(k)$.

$$\begin{aligned} AP_{i.L}(k) &= p_i\left[R_i(k-B+1), R_i(k-B+2), R_i(k-B+3), \ldots R_i(k)\right] \\ &= \left|\sum_{L=0}^{B} R_i(k-B+1) * R_i(k-B+1)\right| \end{aligned}$$

Use the cross-correlation to generate the reference value about the relative of received signals, and use auto-correlation values is represent the signal strength on receiver end. Sum of two correlation values will generate a new value $Power_k$. $Power_k$ is a reference value to describe the relatively of received environment. It will be the equal ratio between cross-correlation and auto-correlation value.

$$Power_k = CP_{i.L}(k) \times 50\% + AP_{i.L}(k) \times 50\%$$

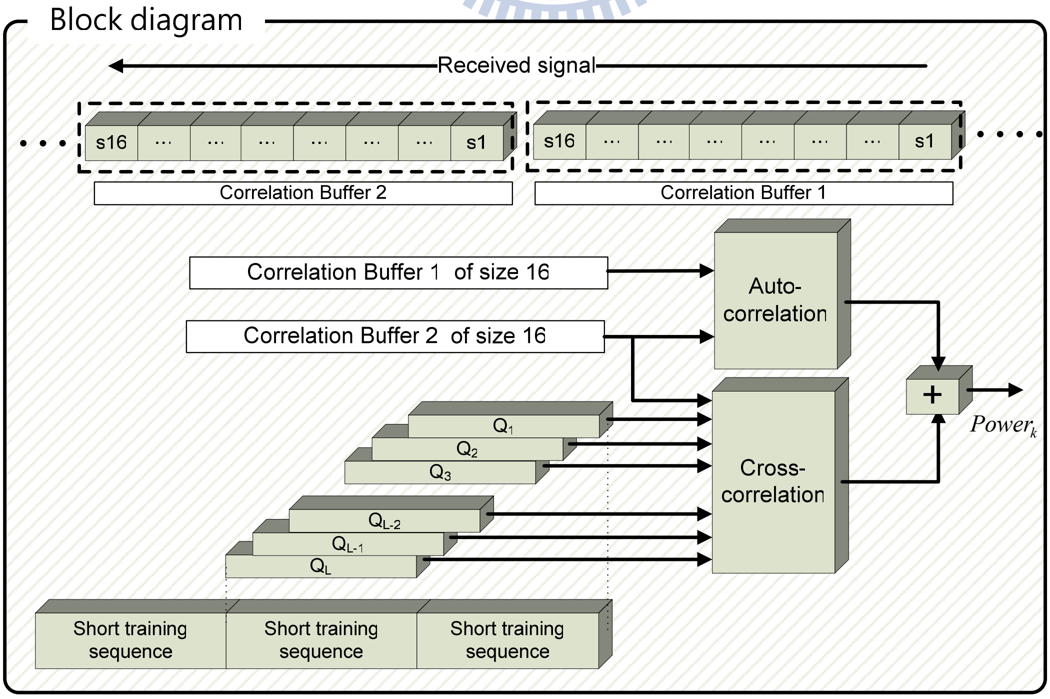


Fig.3.3 Auto-correlation and cross-correlation block diagram

Every receiver antenna scans frequency is once time per 5 degree form -90 degree to 90 degree, and then it can get the power of angular spectrum in Fig.3.4. For example, if the arrival angle coming on receiver end is -50 degree and 30 degree. The Fig 3.4 is the power angular spectrum of these arrivals of angle. By this spectrum, it can find that if the antenna angle is more closed the arrival angle, the antenna can received the more strength signal, and if the antenna angle is far away the arrival of angle, it has be less power of power angular spectrum.

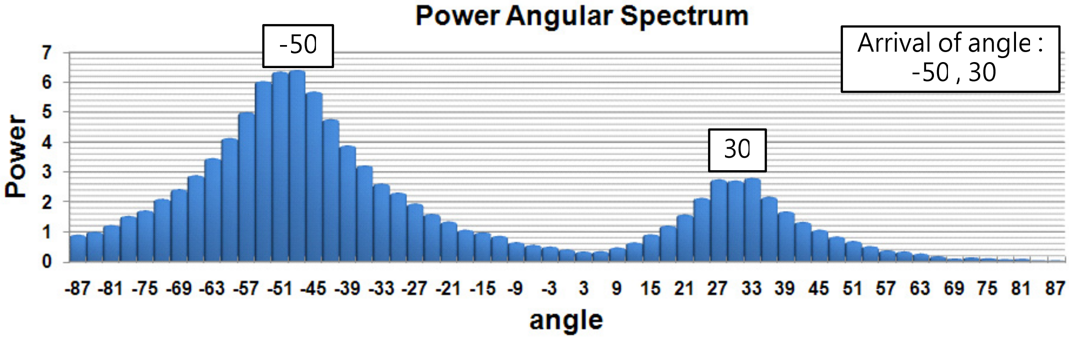


Fig.3.4 Example of power angular spectrum

Step3: Calculate the angle of interest signal

By auto-correlation and cross-correlation value and power angular spectrum, there are some information can be used. On this paper, we proposed a method to estimate the arrival of angle. In Fig 3.4, separate the spectrum of higher power can find some possible cases in this power angular spectrum. In the other word, when getting a power angular spectrum, it's well to know where the angle of power is larger and where the angle of power is small. Defined a ratio φ as a angle estimation threshold. After a lot of simulation results, we can statistic the performance that if set φ is 0.5, it will find the arrival of angle accurately. After setting the threshold, there exist some remain power of spectrum. Group remain of the spectrum, it can be find the number of group possible areas.

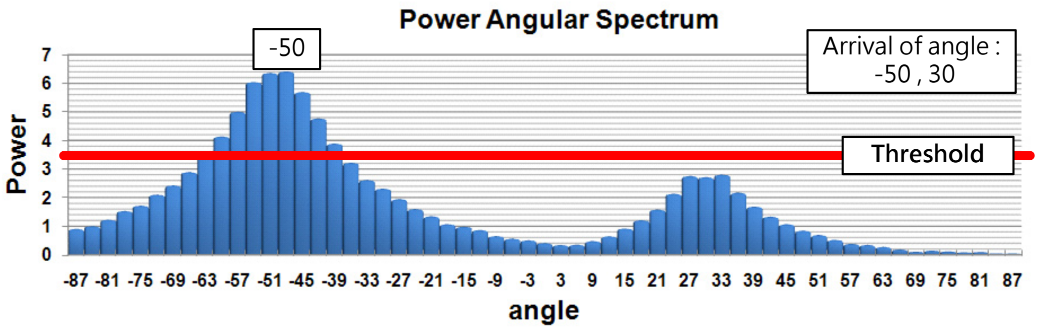
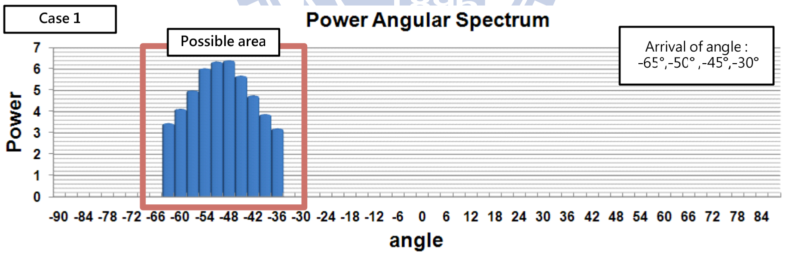
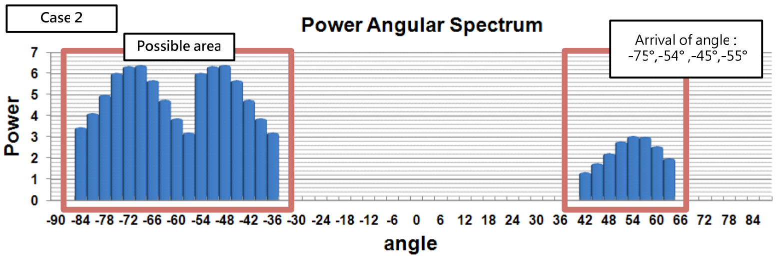


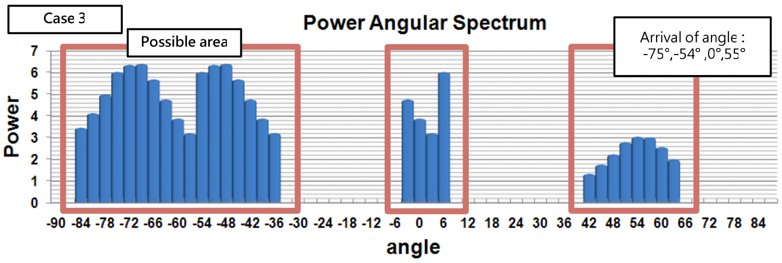
Fig.3.5 setting the threshold

In Fig 3.5, setting the threshold and in Fig 3.6 (a) is after setting the threshold. It is a new power angular spectrum after the set threshold and filtering the low possible in front method. There are some cases in power angular spectrum to find the arrival of angle. It will show as follows on Fig 3.6 (a) ~ (e) and table I.

The possible areas represent the more possible of arrival angle. It should to selecting the arrival of angle form possible area. On this paper, choose the max angle of the possible area and delete the neighborhood of max angle. Repeat this action, until to find the number of signal. Following table I will introduce the detail of choosing algorithm.







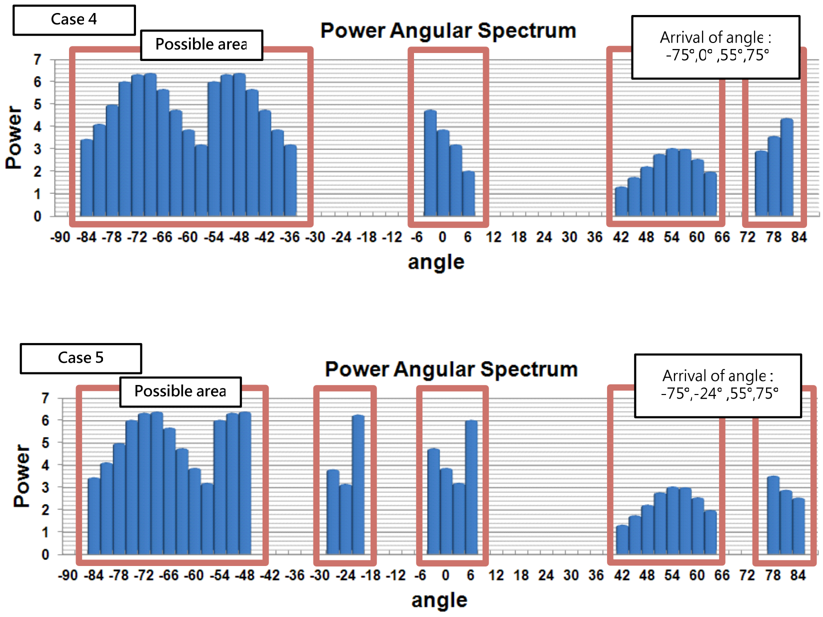


Fig.3.6 (a) ~ (e) Five case about the choosing algorithm

TABLE I

CHOOSING ALGORITHM

case	Situation	Solution strategy
1	Possible regions=1	Only have one region in the power angular spectrum which that it means four arrival of angle will have large probability in this area. Use the find max and delete neighbour that it can find four arrival of angles on this possible area.
2	Possible regions=2	Compare the number of the two areas that it can consider the large numbers has more probability of arrival angle. Such that it can use this ratio to guess the arrival of location. If twice ratio of small area number is less then large number of area. It can be determine the small number of possible area only have one arrival angle, large number of possible area have three arrive of angles.
3	Possible regions=3	Because the possible region number is three such that the max number of possible area must have the two arrival of angle. Choose the max power of this area and delete the surround of the max power of this area, it can be find the sub maximal of this area.
4	Possible regions=4	Choosing the maximal of every possible area that can get four arrivals of angle.
5	Possible regions>4	Possible region is large four such that it means every arrival of angle will not closely. Choosing the four maximal of possible areas to be the arrival of angles.

Step4: Update and rotate the antenna angle

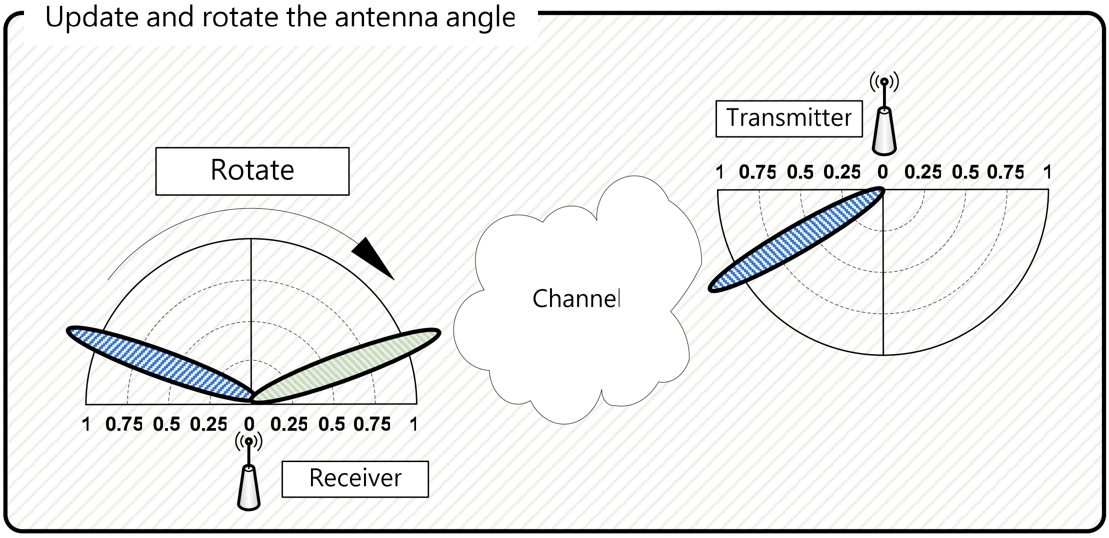


Fig.3.7 Update and rotate the antenna angle

After determine the arrival of angle, rotate the receiver antenna to steering the arrival of angle. This action will make the receiver end have higher quality of signal then untargeted angle.

Fig3.8 is a figure about MSE of angle. Obviously, it can see that if did not adjust the antenna of angle, it will have large errors of angle. The average angle of MSE is 60 degrees inaccuracy. If rotate the receiver antenna, used to steer the arrival of angle, it can be have the less errors of angle and received the large strength of signal power. It will be improve the system performance on this algorithm.

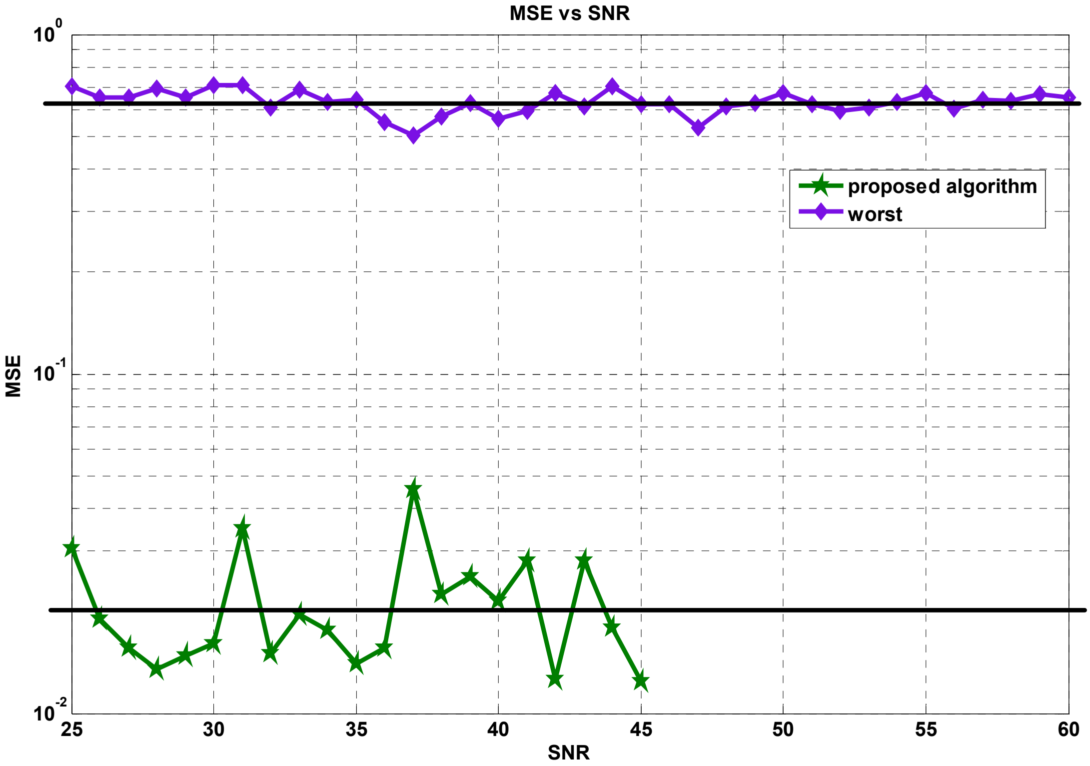


Fig.3.8 MSE of smart antenna methods for 64QAM modulated 4×4 MIMO OFDM systems

Chapter 4
Analysis Digital Beamforming

The goal of digital beamforming system is use a weighting vector to adjust the signal that let the small quality of interference signal and large quality of interested signal. In order to do this, use an AOA estimation to estimation the signal of arrival delay, by this delay time information to estimate the angle of arrival. If determine the arrival of angle, it can derive the signal arrival delay and use this delay to calculate the weighting vector. Finally, it can cancel the interference to improve the system performances.

In the narrow band system, the time arrival delay is a signal phase delay. Use a weighting vector to compensation the phase shift. Section 4.1 will introduce the digital beamforming block and section 4.2 will introduce how to detect the channel impulse and adjust the phase in order to improve performance. All of these are analysis in MIMO-OFDM system.

4.1 Digital beamforming block

Fig 4.1 is a block diagram of digital beamfomring. There are some block functions under the digital beamforming. The functions are AOA estimation, weighting calculate, weighting update. AOA estimation is used to estimate the time delay (phase shift) of received signal. Use a detector to detect the channel impulse response. If detect skew, it can use a phase shifter to adjust the received signal. It will let the signal arrived simultaneously. If detector detects signal arrival at the same time, then bypass the signal to next stage. To get the arrival of angle that uses this information to calculate weighting to update the signal.

Consider a method of weighing, if cancel all interference by placing nulls at interference angles of arrival, it will automatically maximize the SIR. The weighting calculates is always to do this. However, it is not a simple thing to achieve this goal, because the received signal is a mix of all transmitter data. The multipath and AWGN noise will affect the data relatively more. Sections 4.3 will analysis this method.

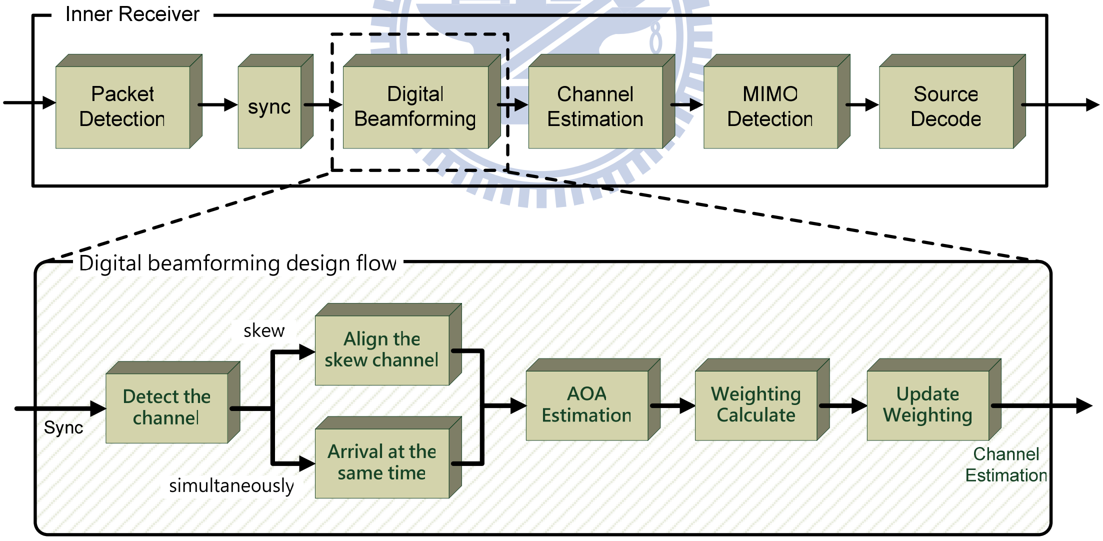


Fig.4.1 Digital beamforming block diagram

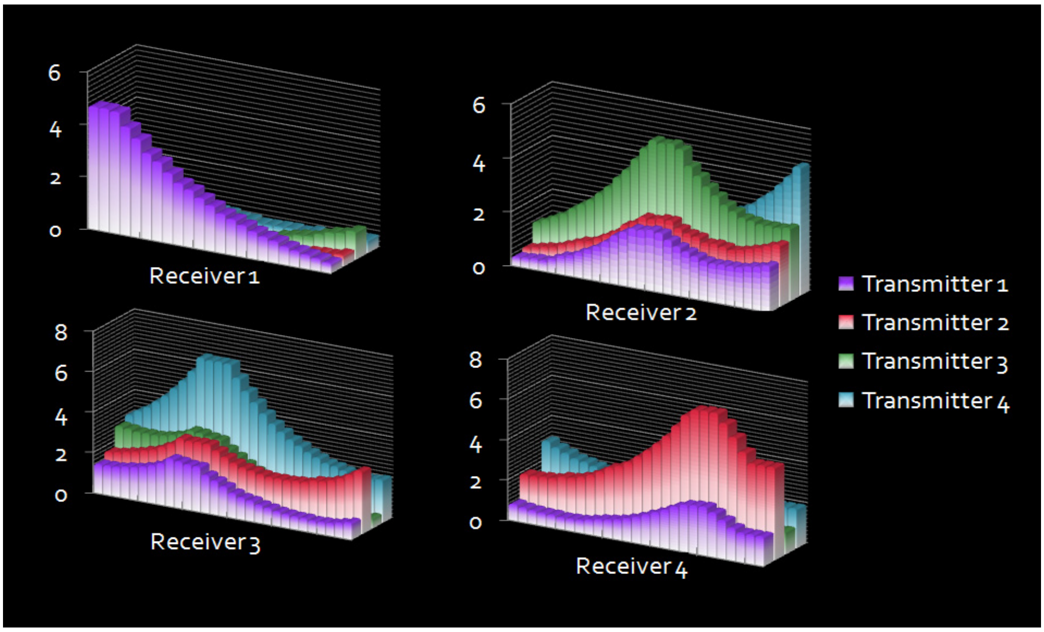


Fig.4.2 The transmitter signal on receiver end on Digital beamforming system

4.2. Analysis digital beamforming

On the digital beamforming system, every signal on receiver ends has signal delay and phase shift. After adjusting the signal delay, use MIMO detection to detect and demodulate the channel. MIMO detection includes the zero forcing, Minimum Mean Square Error (MMSE), K-best, Maximum likelihood detection (MLD)…etc, these methods are used to detect the channel in MIMO-OFDM system.

On the receiver end, we use a simple channel impulse response detector to detect the channel. Use cross-correlation to achieve it. If detect the signals from every transmitter which it arrive at the same time, it means that the signal arrival same time. This is a special case of digital beamfoming [6]. In this case, it will have the best performance on digital beamforming system. Fig 4.3(a) will present the signals on receiver end are arrive at the same time.

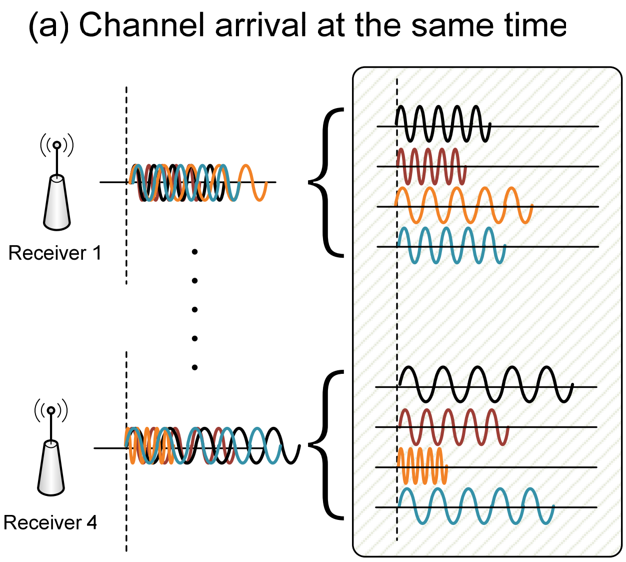

(a) Channel arrival at the same time

Fig.4.3 (a) Channel environment

Another case is when signals pass the multipath of every transmitter that they are not arrival at the same time. These signals will arrival in different time. It will cause the MIMO detection function to demodulate channel hardly. It is very important to avoid this thing before the signal haven pass in MIMO-detection function block. Use a phase shifter to adjust the signal when this situation occurs.

First, design a channel impulse response to detect the signal. We appear that if use cross-correlation with signals and the ideal short training sequence, we can find the cross-correlation value of each time slot is different.

Second, find the maximal of the correlation value, and compensate the signal. The compensation method is use a shifter to shift the signals that it will adjust the signal arrival simultaneously. Fig 4.3(b) is signal arrival skew, and Fig 4.3(c) is after shifting the signal.

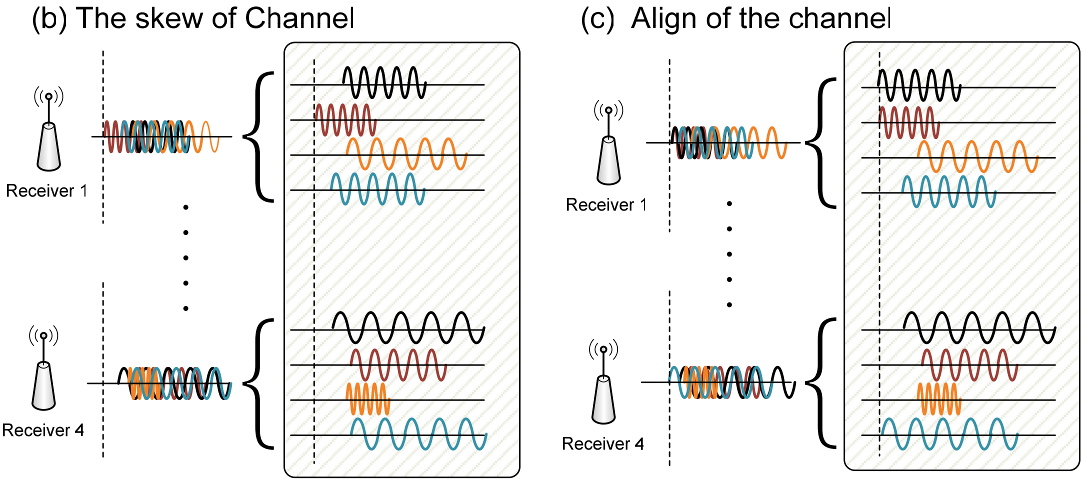


Fig.4.3 (b) (c) Channel environment

4.3. Weighting calculate

4.3.1. AOA estimation

When the receiver end receives the signals from transmitter ends, estimate the arrival of angle in order to find the transmitter possible angular locations [7]. The goal of AOA estimation is to define a function that gave an indication of the angles of arrival based upon maxima vs. angle. This function is a pseudo spectrum $p(\theta)$ and the unit can be in energy or in watts. There is some AOA estimation like Capon [8], Max entropy [9],[10], and MUSIC [11]…etc. In this paper, assume we have been detecting the AOA in receiver end.

4.3.2. Weighting calculate

One criterion which can be applied to enhancing the received signal and minimizing the interference signal is based upon maximizing the SIR [12]. If known the arrival of angles, the array vector matrix is given by

$$a=\begin{array}{c}\begin{array}{cccc}\mathrm{a}(\theta_1) & \mathrm{a}(\theta_2) & \mathrm{a}(\theta_3) & \mathrm{a}(\theta_4)\end{array}\\ \begin{bmatrix}1 & 1 & 1 & 1\\ e^{-jkdsin\theta_1} & e^{-jkdsin\theta_2} & e^{-jkdsin\theta_3} & e^{-jkdsin\theta_4}\\ e^{-j2kdsin\theta_1} & e^{-j2kdsin\theta_2} & e^{-j2kdsin\theta_3} & e^{-j2kdsin\theta_4}\\ e^{-j3kdsin\theta_1} & e^{-j3kdsin\theta_2} & e^{-j3kdsin\theta_3} & e^{-j3kdsin\theta_4}\end{bmatrix}\end{array}\text{.............................. (1)}$$

By the channel estimation, use the estimation channel to calculate the weighting vector. The estimation channel can be written as a channel matrix H and the weighting vector can be written the matrix w, it will show as follows:

$$H=\begin{bmatrix}H_{11} & H_{12} & H_{13} & H_{14}\\ H_{21} & H_{22} & H_{23} & H_{24}\\ H_{31} & H_{32} & H_{33} & H_{34}\\ H_{41} & H_{42} & H_{43} & H_{44}\end{bmatrix}\text{.. (2)}$$

$$w=\begin{bmatrix}w_{11} & w_{12} & w_{13} & w_{14}\\ w_{21} & w_{22} & w_{23} & w_{24}\\ w_{31} & w_{32} & w_{33} & w_{34}\\ w_{41} & w_{42} & w_{43} & w_{44}\end{bmatrix}\text{.. (3)}$$

The received signal is given as:

$$R_k=a_{11}(H_{11}\otimes S_1)+a_{12}(H_{12}\otimes S_2)+a_{13}(H_{13}\otimes S_3)+a_{14}(H_{14}\otimes S_4)\text{.... (4)}$$

By (1), (2), (3), (4) The total output is given as:

$$Y_k=w*R=\begin{bmatrix}w_{11} & w_{12} & w_{13} & w_{14}\\ w_{21} & w_{22} & w_{23} & w_{24}\\ w_{31} & w_{32} & w_{33} & w_{34}\\ w_{41} & w_{42} & w_{43} & w_{44}\end{bmatrix}*\begin{bmatrix}R_1\\ R_2\\ R_3\\ R_4\end{bmatrix}$$

$$=\begin{bmatrix}w_{11}*a_{11}*\overline{H_{11}}+w_{12}*a_{12}*\overline{H_{12}}+w_{13}*a_{13}*\overline{H_{13}}+w_{14}*a_{14}*\overline{H_{14}}\\ w_{21}*a_{21}*\overline{H_{21}}+w_{22}*a_{22}*\overline{H_{22}}+w_{23}*a_{23}*\overline{H_{23}}+w_{24}*a_{24}*\overline{H_{24}}\\ w_{31}*a_{31}*\overline{H_{31}}+w_{32}*a_{32}*\overline{H_{32}}+w_{33}*a_{33}*\overline{H_{33}}+w_{34}*a_{34}*\overline{H_{34}}\\ w_{41}*a_{41}*\overline{H_{41}}+w_{42}*a_{42}*\overline{H_{42}}+w_{43}*a_{43}*\overline{H_{43}}+w_{44}*a_{44}*\overline{H_{44}}\end{bmatrix}\text{........................ (5)}$$

The output array will hope the desire signals have large signal quality and the interference signals have null gain. There is a strategy to do. When receiver end receive the signal R, we can estimate array of angle (1) and CIR (2). Set the condition to calculate the weighting vector matrix. In receiver 1, wanted the signal form transmitter 1 will be large then others. Set the condition as follows:

$$w_{11}*a_{11}*\overline{H_{11}}+w_{12}*a_{12}*\overline{H_{12}}+w_{13}*a_{13}*\overline{H_{13}}+w_{14}*a_{14}*\overline{H_{14}}=1 \text{ .... } (6)$$

$$w_{21}*a_{21}*\overline{H_{21}}+w_{22}*a_{22}*\overline{H_{22}}+w_{23}*a_{23}*\overline{H_{23}}+w_{24}*a_{24}*\overline{H_{24}}=0 \text{ .... } (7)$$

$$w_{31}*a_{31}*\overline{H_{31}}+w_{32}*a_{32}*\overline{H_{32}}+w_{33}*a_{33}*\overline{H_{33}}+w_{34}*a_{34}*\overline{H_{34}}=0 \text{ .... } (8)$$

$$w_{41}*a_{41}*\overline{H_{41}}+w_{42}*a_{42}*\overline{H_{42}}+w_{43}*a_{43}*\overline{H_{43}}+w_{44}*a_{44}*\overline{H_{44}}=0 \text{ .... } (9)$$

Combine (6), (7), (8), (9). These conditions can be recast in matrix form as

$$w*(\overline{AH})=\overline{u_1}^{T} \text{ .... } (10)$$

Where the w is weighting matrix, A is steering vector matrix, H is estimated cannel impulse response matrix.

$\overline{u_1},\overline{u_2},\overline{u_3},\overline{u_4}$ is Cartesian basis vector. $\overline{u_1}=\begin{bmatrix}1\\0\\0\\0\end{bmatrix},\overline{u_2}=\begin{bmatrix}0\\1\\0\\0\end{bmatrix},\overline{u_3}=\begin{bmatrix}0\\0\\1\\0\end{bmatrix},\overline{u_4}=\begin{bmatrix}0\\0\\0\\1\end{bmatrix}$ .... (11)

Use the equation $w=\overline{u_1}^{T}(\overline{AH})^{-1}$ to calculate the weighting. Assume the interested signal arrival at one degree, and we should design a weighting vector that let the signal have large energy on this degree, the interference angle have less energy. In Fig 4.5, it can tell us the array factor of received end. Low power is interference signal and the large power is interest signals.

4.3.3. Update weighting

According the weighting vector, the receiver signals can multiple the weighting and summation it to be new signals. Fig 4.4 is the architecture of the weighting calculates. It can use a weighting vector to update the signals. In Fig4.5 will present the weighting vector affect the array factor. In Fig 4.5 it will be found that the interest signals have large energy and the interference signals have less energy. If the weighting vector can cancel the interference signal, it will improve performance a little.

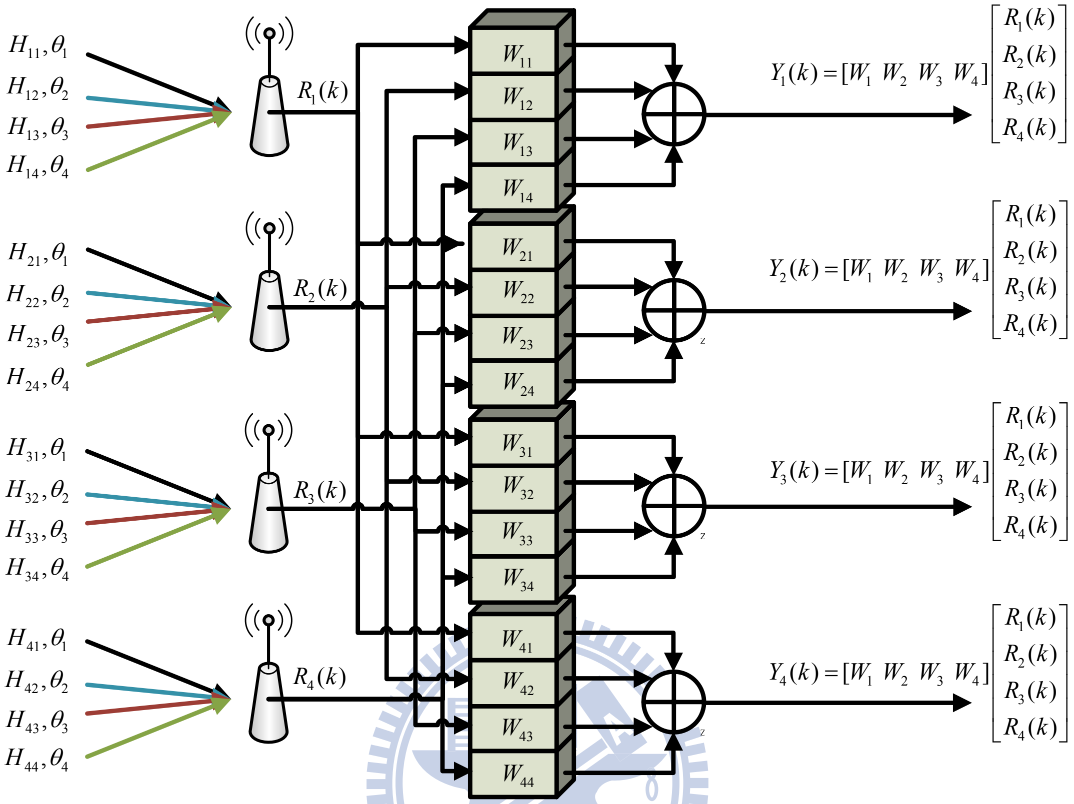


Fig.4.4 weighting calculate

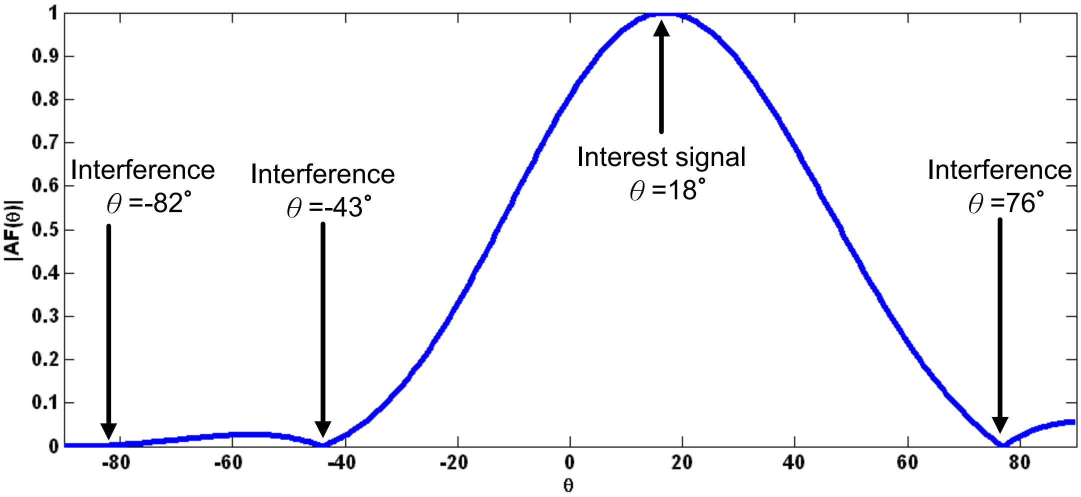


Fig.4.5 Side lobe cancelation

In section 5, we will show the BER, PER and other performance in digit beamforming system.

Chapter 5

Simulation Results

MATLAB is chosen as simulation language, due to its ability to mathematics, such as matrix operation, numerous math functions, and easily drawing figures. A MIMO-OFDM system based on IEEE 802.11n Wireless LANs, TGn Sync Proposal Technical Specification, is used as the reference simulation platform. The major parameters are shown in TABLE II.

TABLE IIII

SIMULATION PARAMETERS

Parameter	***Value***
Number of antennas	4Tx and 4Rx
Signal bandwidth	20 MHz
Carrier frequency	2.4 GHz
Number of subcarrier	52
Subcarier modulation	64 QAM
Packet size	1024 (Bytes)
FEC coding rate	2/3
Channel Model	TGn D type
Number of taps and RMS delay spread	8 , 50 nsec
MIMO Detection	K-best sphere decoder
K-best K value	12

5.1 Smart antenna performance

The proposed smart antenna detection algorithms have to rotate the antennas to steer the arrival angle. From the simulation results, we can see that the un-rotate the antenna is the worst of performance. But if use the proposed algorithm, we can rotate the antenna to steering the estimation of AOA, it can improve the performance. The best case is antenna to steering the AOA perfectly. On this paper, compare the performance with it.

Fig 5.1 shows the performance of the optimal, proposed algorithm and worst algorithm. All of these are simulate in 4 transmit antennas and 4 receive antennas. On this figure, when antenna is not rotate anymore, it is the worst case of smart antenna system because the receivers get the less energy of signal. With the proposed algorithm, the performance has obviously improved. In Fig 5.2, see the PER, the proposed algorithm with smart antenna approaches the best method within 2.17 dB. But compare to not rotate the antenna system, it will better than 21dB.

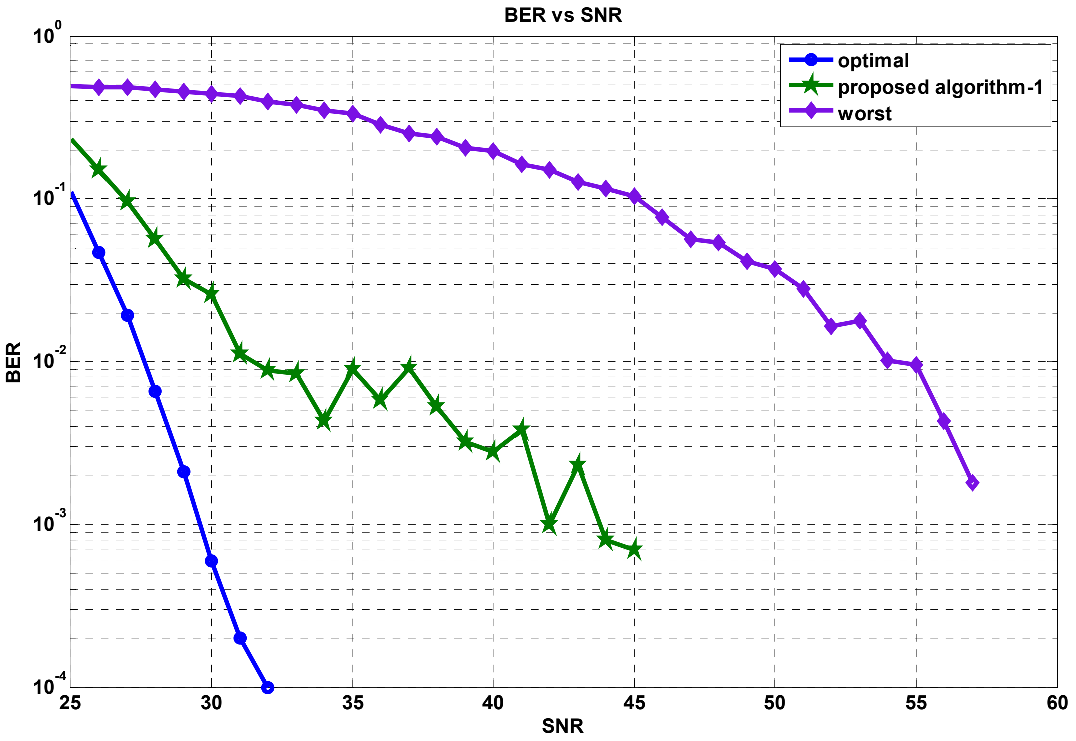


Fig.5.1 BER of smart antenna for 64QAM modulated 4×4 MIMO OFDM systems

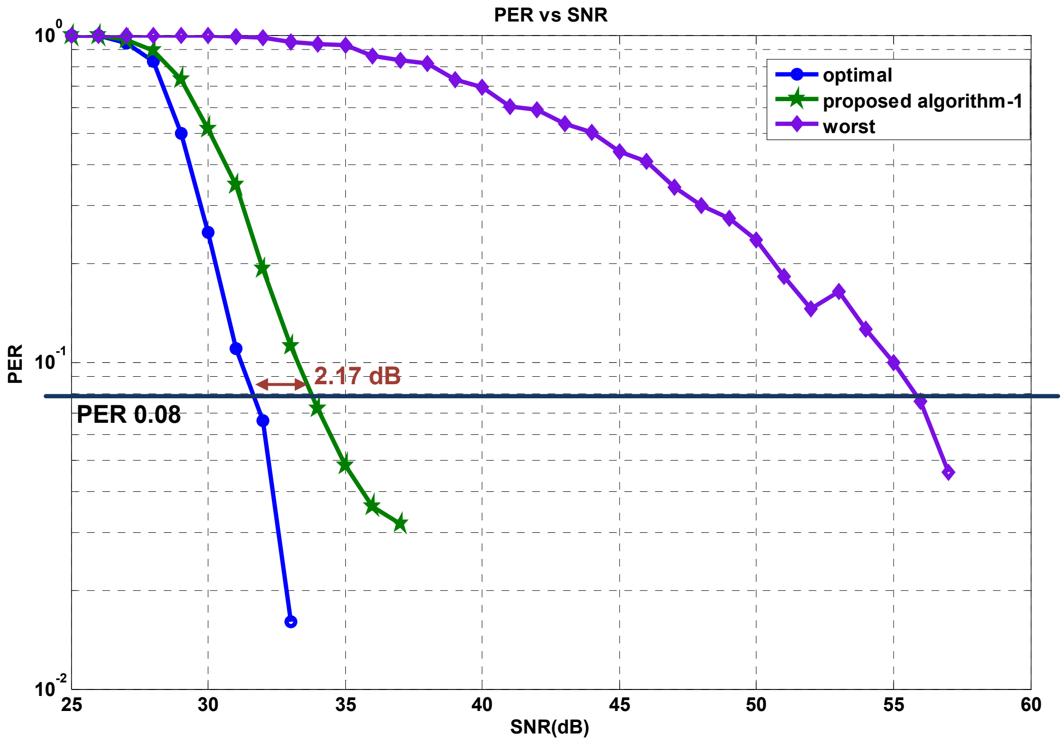


Fig.5.2 PER of smart antenna for 64QAM modulated 4×4 MIMO OFDM systems

TABLE IVII

COMPARISON WITH OTHER ALGORITHMS

	Ref [12]	Ref[13]	Ref[14]	Proposed Work
System Type	OFDM	MIMO/SDMA QPSK	MOMO-OFDM QPSK	MOMO-OFDM 64QAM
Assumption	Same scatter cluster have same delay	Channel information is perfectly know	Error free, zero-delay feedback channel	Random arrive of channel
Numbers of Antenna	1×2	10×3	2×2	4×4
FFT Size	64	N/A	128	64
Fading Channel	Cluster-based broadband fading channel (16 taps)	N/A	Rayleigh fading	IEEE TGn D (8 taps, rms:50 ns)
Performance loss	4 dB	5 dB	< 1 dB	1.03 dB

For the compare with other algorithms, there are some papers propose the algorithm similarity. The **TABLE VII** summarizes the performance condition and the performance. The proposed detection method can maintain performance within 1.03dB such that the method is suitable for practical system.

5.2 Digital beamforming performance

For analysis the digital beamforming system, it can separate two parts of the digital beamforming. One part is if the channel is skew, we alias the channel to let the signal form the transmitter arrival at the same time.

Fig 5.3, Fig 5.4 presents the performance of the channel arrival differently. When the channel arrival at the same time, it will be have best performance of PER. The star mark line is show the channel after alias. Obviously, we can see if we are not to do adjusting anymore, it will have the worst performance. If we align the channel, we can have the better performance then worst case. Observing from the Fig. 5.4, there is only near 1.03 dB SNR degradation for the channel arrival at the same time.

Fig 5.5 presents the performance after adding weighting vector. If adding the weighting vector to the received signals, the performance loss 10.2 dB. It is because the signals arrival simultaneous and cause the signal high relatively. If we use a weighting to summation four receiver end signals, it will broken the signal relative. It causes the performance loss seriously.

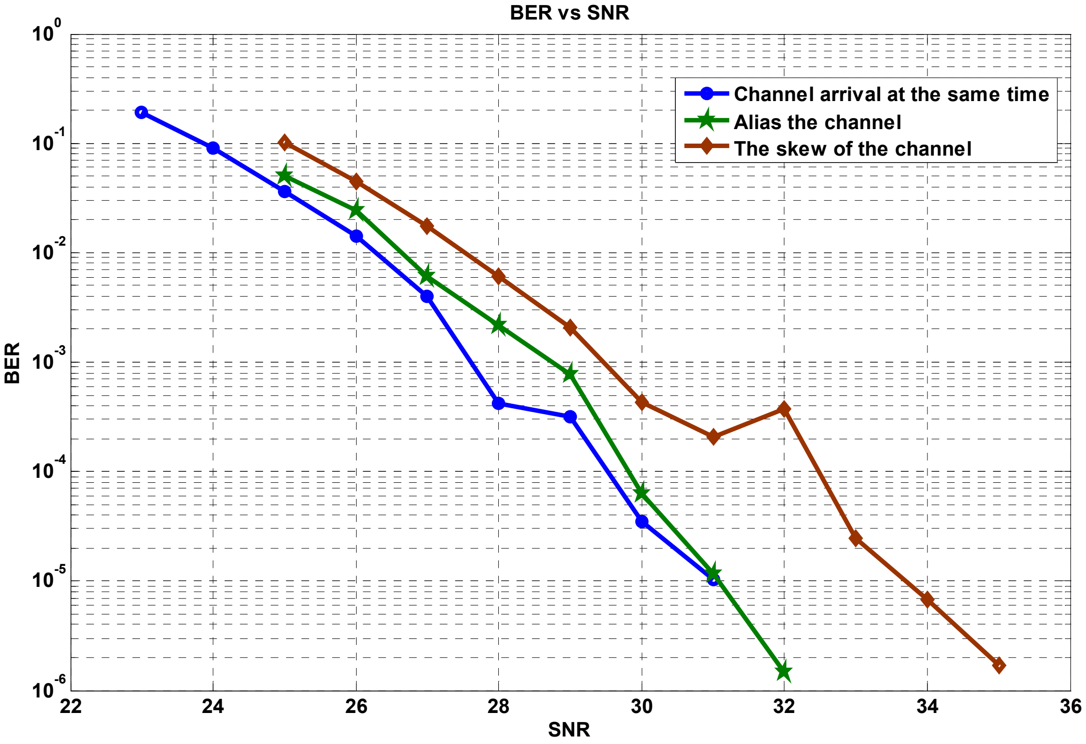


Fig.5.3 BER of digital beamforming for 64QAM modulated 4×4 MIMO OFDM systems

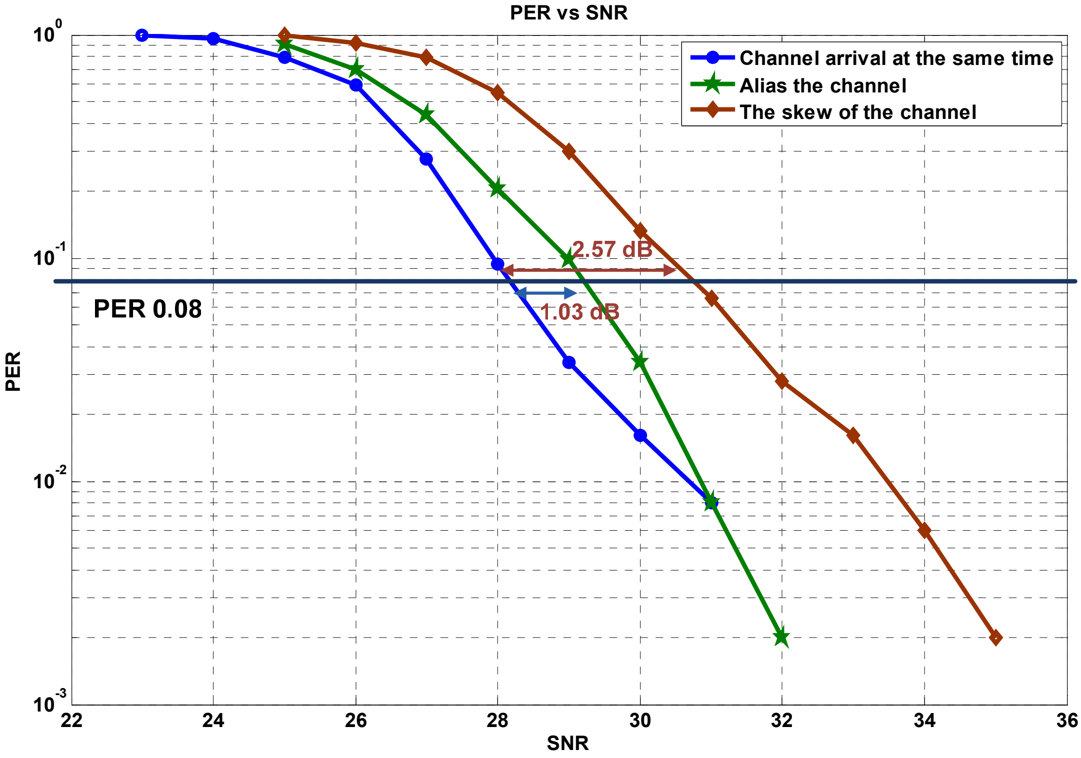


Fig.5.4 PER of digital beamforming for 64QAM modulated 4×4 MIMO OFDM systems

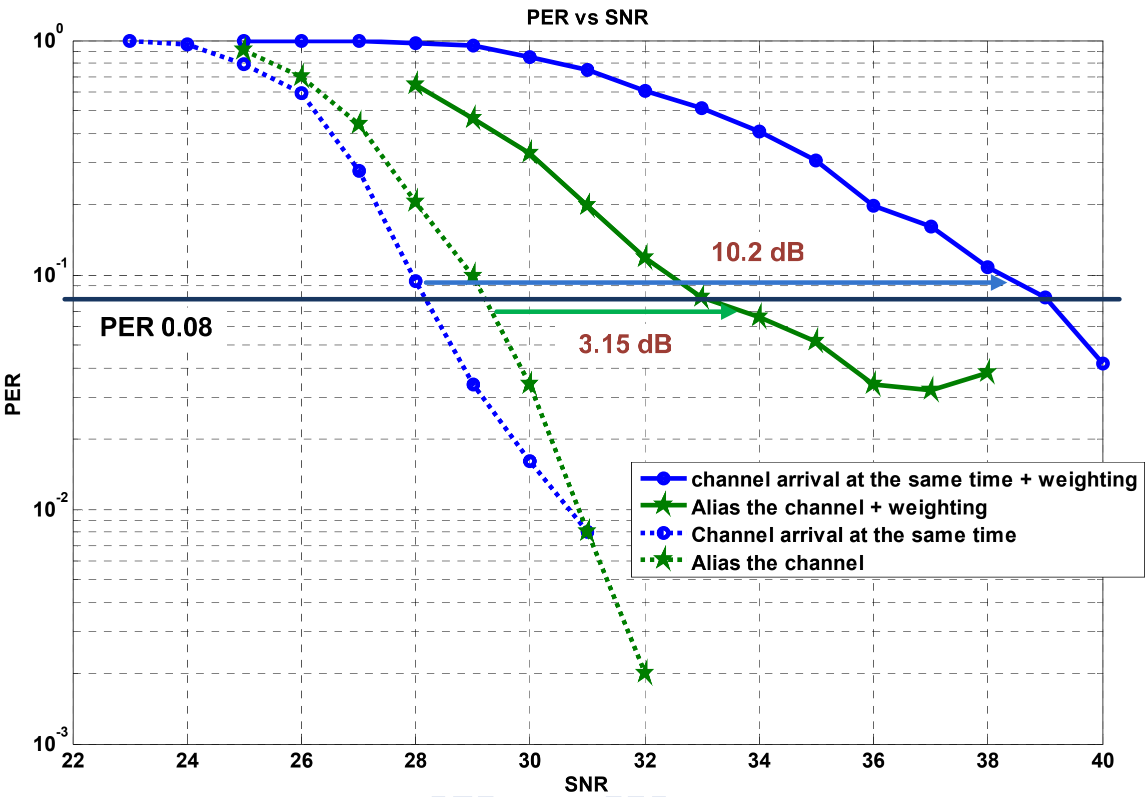


Fig.5.5 PER of digital beamforming after weighting update

Chapter 6
Conclusions

This work presents that smart antenna are similar with digital beamforming. They are suppress the interference signal and to strengthen the interested signal. On smart antenna system, we will easily to achieve it. Use the directional antenna to steering the signal is simple then uses DSP. If use directional antenna, it will be cost high then use a DSP to compute the signal. It is a tradeoff between of them. On the future, we use a DSP to achieve digital beamforming system, because there are too many signal information can improve the system performance. On this paper, we haven’t found the best weighting solution to improve the performance yet. But on the future, it is a future work to do.

Implement the channel impulse response detector to detect the channel arrival. Detector detects the channel arrival at the same time or not, when detect the channel is skew, use a switcher to switch the mode that to adjust the channel. It will be better 2.67 dB then not adjust the channel. All of these things will implement in hardware design.

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