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MIMO-OFDM 시스템에서 다중사용자 다이버시티 기술의 성능분석

장기* · 서희종**

An Analysis of Multiuser Diversity Technology in the MIMO-OFDM System

Ke Zhang* · Hee-Jong Suh**

요 약

본 논문에서는 OFDM과 MIMO 기술의 응용을 기술하고, 이 기술이 고속인 무선이동통신에 적합함을 설명하였다. OFDM 변조기, 복조기와 MIMO-OFDM 시스템을 블록화하여 설명하였다. MIMO-OFDM 시스템에서 다이버시티 기술을 연구하고 성능을 분석하였다. 이 성능분석을 위해서 모의실험을 하였다.

ABSTRACT

In this paper, we introduce the combination of OFDM(Orthogonal Frequency Division Multiplexing) and MIMO(Multiple-Input Multiple-Output) technology, and explain that this combination seems to be very preferable when designing very high-rate wireless mobile systems. The application of OFDM, with the block diagrams of an OFDM modulator and demodulator and a MIMO-OFDM system, are described. The several diversities are studied at the receiver, analyzed the performances of diversity in OFDM-MIMO system and simulated results.

키워드

OFDM, MIMO, Modulator, Demodulator, OFDM-MIMO System
OFDM, MIMO, 변조기, 복조기, OFDM-MIMO 시스템

Ⅰ. Introduction

Recently, OFDM(: Orthogonal frequency division multiplexing) has become a popular technique for transmission of signals on wireless channels. Also, Multiple-Input Multiple-Output(: MIMO) is one of the most promising technologies for assisting fading and improving link reliability without sacrificing bandwidth efficiency. The combination of OFDM and MIMO seems to be the key technology in high-rate wireless mobile systems.

OFDM has been adopted in several wireless standards such as digital audio broadcasting (DAB), digital video broadcasting standard (DVB-T), the IEEE 802.11a local area network (LAN) standard and the IEEE 802.16a metropolitan area network (MAN) standard [1]. It was also used in the asymmetrical digital-subscriber line (ADSL)

* 북경석유화공학원 교수(hjsuh@jnu.ac.kr)
** 교신저자 : 전남대학교 전자통신공학과
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・Corresponding Author : Hee-Jong Suh
Dept. Electronic Communication, Chonnam Nat'l University,
Email : hjsuh@jnu.ac.kr

standard, where it was referred to as Discrete Multitone modulation. OFDM was also being pursued for dedicated short-range communications (DSRC) for road side to vehicle communications and as a potential candidate for mobile wireless systems.

The wireless communications system design is increasing spectral efficiency and improving link reliability. And a radio channel suffers from fading and interference [2]. The use of multiple antennas at both ends of a wireless link promises significant improvements in terms of spectral efficiency and/or link reliability. MIMO technology had become very popular since it can improve link reliability without sacrificing bandwidth efficiency [3-5].

In a very high data rate MIMO communication system, the radio channel introduces severe intersymbol interference. In this case, single-carrier based MIMO systems require highly complex equalization techniques such as a vector-maximum likelihood sequence estimator (MLSE) or a multichannel equalizer. However, multicarrier based MIMO systems, e.g. MIMO-OFDM, permits simple equalization processes by turning the frequency selective fading channel into a set of parallel at fading channels [6]. Essentially, the equalization in a MIMO-OFDM system is done by inverting a constant matrix for each OFDM tone.

The combination of OFDM and MIMO seems to be very promising when aiming at the design of very high-rate wireless mobile systems [7]. While multiple antennas at the transmitter and receiver elevate channel capacity, i.e. the achievable transmission rate, OFDM converts the wideband frequency selective radio channel into a set of parallel flat-fading channels, thus simplifying signal processing required at the receiver [8].

In this paper, we described the block diagrams of an OFDM modulator and demodulator and a MIMO-OFDM system. The several diversities are studied at the receiver, analyzed the performances of diversity in OFDM-MIMO system, and we did simulation by Matlab [12-14].

The paper is organized as follow: in Section II the OFDM and MIMO technologies are described. The OFDM-MIMO system model is outlined in Section III. The Performance of Diversity in system is studied, and analyzed by the simulation results in Section IV. Finally, conclusions are in Section V.

II. Tchnologies in Mobile System

2.1 OFDM

OFDM converts a frequency-selective channel into a parallel collection of frequency flat subchannels. The subcarriers have the minimum frequency separation required to maintain orthogonality of their corresponding time domain waveforms, yet the signal spectra corresponding to the different subcarriers overlap in frequency. Hence, the available bandwidth is used very efficiently.

OFDM uses adaptive bit loading techniques, where different sized signal constellations are transmitted on the subcarriers.

The transmitted signals arrive at the receiver after being reflected from many objects. Sometimes the reflected signals add up in phase and sometimes they add up out of phase causing a "fade". This causes the received signal strength to fluctuate constantly. Also, different subchannels are distorted differently. An OFDM receiver has to sense the channel and correct these distortions on each of the subchannels before the transmitted data can be extracted. OFDM is effective in correcting such frequency selective distortions.

OFDM has many advantages over other transmission techniques. One such advantage is high spectral efficiency (measured in bits/sec/Hz). Each of the frequencies is an integer multiple of a fundamental frequency. This ensures that even though the subchannels overlap they do not interfere with each other. This results in high spectral efficiency.

OFDM modulation divides a broadband channel into many parallel subchannels. This makes it a very efficient scheme for transmission in multipath wireless channels. The use of an FFT/IFFT pair for modulation and demodulation make it parallel subchannels. This makes it a very efficient scheme for transmission in multipath wireless channels. The use of an FFT/IFFT pair for modulation and demodulation make it computationally efficient as well. The use of IFFT and FFT for modulation and demodulation results in computationally efficient OFDM modems. The block diagram of an OFDM modulator and demodulator are shown in Fig. 1.

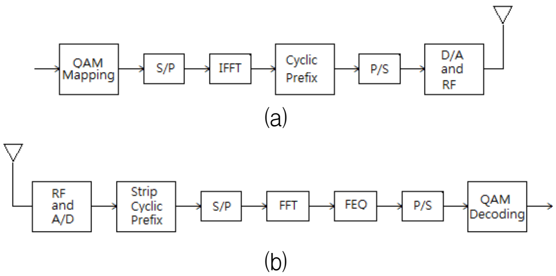

Fig. 1 OFDM (a) Modulator and (b) Demodulator

2.2 MIMO

MIMO systems can be defined simply as having multiple transmitting and receiving antennas. A MIMO system takes advantage of the spatial diversity that is obtained by spatially separated antennas in a dense multipath scattering environment. MIMO systems may be implemented in a number of different ways to obtain either a diversity gain to combat signal fading or to obtain a capacity gain. Let us assume that the number of transmitting antennas is M, and the number of receiving antennas is N. We will first look at the capacity of different antenna systems in order to see the dramatic increases in capacity obtained by using MIMO systems.

Multiple-Input, Multiple-Output (MIMO)- Same signal transmitted by each antenna

The MIMO system can be viewed in effect as a combination of the Multiple-Input Single-Output (MISO) and Single-Input Multiple-Output (SIMO) channels. In this case, it is possible to get approximately an MN-fold increase in the SNR yielding a channel capacity equal to

$$C = \cong B \cdot \log_2(1 + MN \cdot SNR_0) \tag{1}$$

Thus, we can see that the channel capacity for the MIMO system is higher than that of MISO or SIMO. However, we should note here that in all four cases the relationship between the channel capacity and the SNR is logarithmic. This means that trying to increase the data rate by simply transmitting more power is extremely costly.

Multiple-Input, Multiple-Output (MIMO)- Different signal transmitted by each antenna

Our assumption here is that N, M, so that all the transmitted signals can be decoded at the receiver. The big idea in MIMO is that we can send different signals using the same bandwidth and still be able to decode correctly at the receiver. Thus, it is like we are creating a channel for each one of the transmitters. The capacity of each one of these channels is roughly equal to

$$C_{single} \cong B \cdot \log_2(1 + \frac{N}{M} \cdot SNR_0) \tag{2}$$

But, since we have M of these channels (M transmitting antennas), the total capacity of the system is

$$C \cong M \bullet B \bullet \log_2(1+\frac{N}{M} \bullet SNR_0) \qquad (3)$$

Thus, as we can see from (3), we get a linear increase in capacity with respect to the number of transmitting antennas. So, the key principle at work here, is that it is more beneficial to transmit data using many different low-powered channels than using one single, high-powered channel.

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Ⅲ. The Combining System Model

MIMO-OFDM combines OFDM and MIMO techniques thereby achieving spectral efficiency and increased throughput. A MIMO-OFDM system transmits independent OFDM modulated data from multiple antennas simultaneously [9-10]. At the receiver, after OFDM demodulation, MIMO decoding on each of the subchannels extracts the data from all the transmit antennas on all the subchannels. The block diagram of a MIMO-OFDM system is shown in Fig. 2.

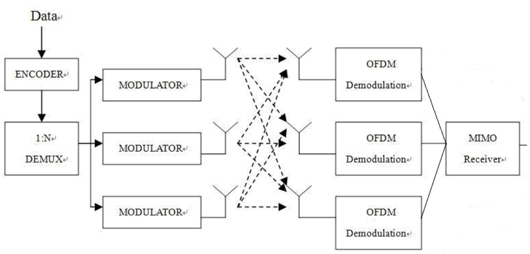

Fig. 2 MIMO-OFDM Transmitter and receiver

They transmit independent data (say x_1, x_2, ... x_n) on different transmit antennas simultaneously and in the same frequency band. At the receiver, a MIMO decoder users $M \geqq N$ antennas. Assuming N receive antennas, and representing the signal received by each antenna as we have:

$$\begin{aligned} r_1 &= h_{11}x_1 + h_{12}x_2 + ... + h_{1n}x_n \\ r_2 &= h_{21}x_1 + h_{22}x_2 + ... + h_{2n}x_n \\ &\cdots \\ r_n &= h_{n1}x_1 + h_{n2}x_2 + ... + h_{nn}x_n \end{aligned} \qquad (4)$$

As can be seen from the above set of equations, in making their way from the transmitter to the receiver, the independent signals $\{x_1,\ x_2,\ ...\ x_n\}$ are all combined. Traditionally this "combination" has been treated as interference. However, by treating the channel as a matrix, we can in fact recover the independent transmitted streams $\{x_i\}$. To recover the transmitted data stream $\{x_i\}$ from the $\{r_i\}$ we must estimate the individual channel weights, construct the channel matrix H. Having estimated H, multiplication of the vector r with the inverse of H produces the estimate of the transmitted vector x. This is equivalent to solving a set of n linear equations in n unknowns.

Ⅳ. Performance Analysis of Diversity in OFDM-MIMO System

This section is concerned with performance of diversity technology in OFDM-MIMO system. As mentioned above, diversity is one of the most effective ways to combat deep fades. Assume that the receiver is provided with multiple replicas of the same information bearing signal, and denote by p the probability that the instantaneous SNR is below the receiver threshold on a single diversity branch (p denotes the probability of outage for that specific threshold in this case). If the receiver is provided with L replicas that fade independently, then the probability that all the branches are at, or below the threshold at the same time is equal to pL. Diversity Combining Techniques are as follows.

There are many methods for combining the different diversity branches at the receiver, the most important of which and most widely used are: Maximal Ratio Combining (MRC), Equal Gain Combining (EGC) and Selective Combining (SC) [11]. Let us assume at this point that we have L receivers (diversity branches), and let us denote by $i=1,\cdots L$, the instantaneous received symbol energy-to-noise ratio on the ith diversity branch. As we saw in class, with Rayleigh fading has an exponential pdf.

$$f_{\gamma_e}(x)=\frac{1}{\gamma_e}e^{x/\overline{\gamma_e}} \qquad (5)$$

where γ_e is the average received branch symbol energy-to-noise ratio.

4.1 Selective Combining

With selective combining, the diversity branch yielding the highest SNR is always selected. Thus, the output of the selective combiner is

$$\gamma_s^{sc}=\max\{\gamma_{1,\dots}\gamma_{\mathrm{L}}\} \qquad (6)$$

If the branches experience independent fading, it can be shown that the cdf function of is [3]:

$$F_{\gamma_s}^{sc}(x)=P_\gamma[\gamma_1\le x,\cdots\gamma_L\le x]=[1-e^{-x/\overline{\gamma_c}}]^L \qquad (7)$$

The probability of outage that we discussed in class is in fact equal to $F_{\gamma_s}^{sc}(x)$. Figure 3 shows the probability of outage for selective combining. Note that the largest diversity gain is obtained when going from L= 1 to L= 2, and diminishing returns are obtained with increasing L.

sc is impractical for systems that use continuous transmission because it requires monitoring of all diversity branches. If such monitoring is performed, then it is better to use MRC which is optimal.

4.2 Maximal Ratio Combining

With maximal ratio combining, the diversity branches are weighted by their respective complex fading gains and combined. MRC gives an optimal performance. As we have seen in class, the output of the MRC combiner, γ_s^{mrc} has the following cdf:

$$F_{\gamma_s}^{sc}(x)=1-e^{-mx/\overline{\gamma_c}}\times\sum_{i=0}^{L}\frac{1}{i!}(-mx/\overline{\gamma_c})^i \qquad (8)$$

Where m is the fading index.

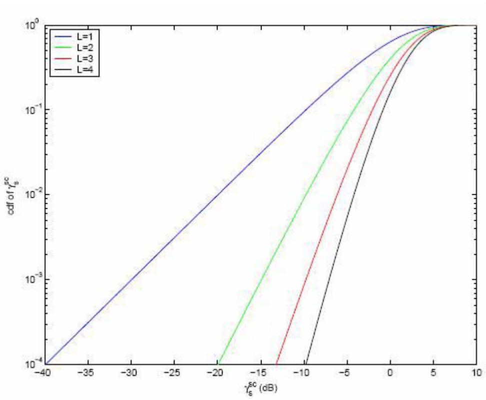

Fig. 3 cdf γ_s^{sc} of (probability of outage) for selective combining

4.3 Equal Gain Combining

Equal gain combining is similar with MRC with the only difference that the diversity branches are not weighted. As it is noted in [10], the cdf and pdf of the output of the EGC combiner, γ_s^{egc} cannot be obtained in closed form for $L>2$. EGC is useful for modulation techniques having equal energy symbols such as M-PSK.

Besides the plots for the cdf of the combiners for MRC and SC, we also performed extensive MATLAB simulations to see the performance of antenna diversity systems when 16-QAM is used. Fig. 4 shows the performance of dual diversity systems in terms of probability of symbol error. As we can see, MRC has superior performance and is closely followed by EGC. As expected, SC has the worst performance.

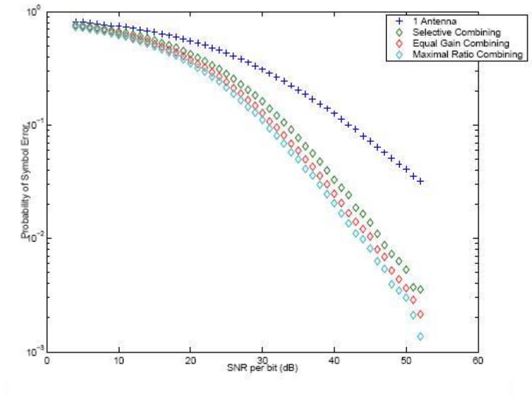

Fig. 4 Dual antenna diversity for 16-QAM

Fig. 5 shows the effects of diversity according to the number of multiple access user when m is equal to 3. As user number is increased, interval between curves is decreased by degrees. It is shown that, with no diversity, data service is available to less than 5 users. With, however, diversity, data service is reachable up to 20 users.

Fig. 6 show BER performance related to fading figure m and the number of multiple access user at E_b/N_0=18 dB. As fading is deeper(m decrease), improvement of diversity decrease. Also even though user increases, slope of curve is not large. But, it is shown that in the case of m=3, improvement of diversity is large, and sensitive to user.

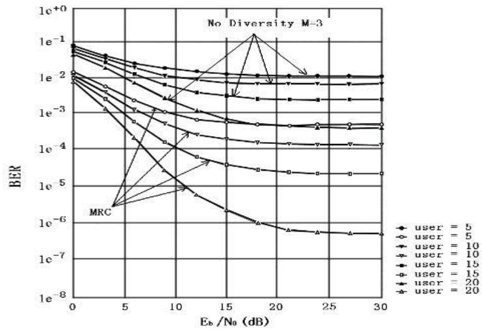

Fig. 5 Error rates for MIMO-OFDM system according to MRC diversity and user(L=2, m=3)

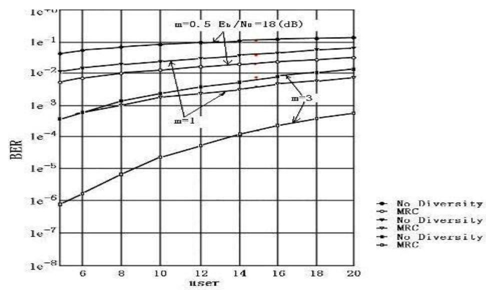

Fig. 6 Error rates for MIMO-OFDM signal not using and using maximal ratio diversity according to user and fading index m (L=2)

Ⅴ. Conclusions

In this paper, we mention the combination of OFDM and MIMO to be the key technology in next generation high-rate wireless mobile systems. After describing the application of OFDM, outline the block diagrams of an OFDM modulator/demodulator and a MIMO-OFDM system. Then, study several methods of diversity technology; analyze the performances of diversity in OFDM-MIMO system with simulation. The simulation results show that the amount of improvement is dramatically increased when the MRC diversity technology used. The system performance improvement is accomplished at the expense of increasing system complexity and cost. Therefore, the decision for one or another technology depends on the analysis of cost versus effectiveness.

References

[1] Elena Lopez-Aguilera, Eduard Garcia-Villegas, Ilker Demirkol, Josep Paradells Aspas, “An Alternative to IEEE 802.11ba: Wake-Up Radio With Legacy IEEE 802.11 Transmitters,” *IEEE Access*, vol. 7, 2019, pp. 48068-48086.

[2] J. John G. Proakis. “Digital Communications,” *McGraw Hill*, New York, 2000.

[3] D. Gesbert, M. Shafi, D. S. Shiu, P. Smith, and A. Naguib. “From theory to practice: An overview of mimo space-time coded wireless systems,” *IEEE Journal on Selected Areas in Communications*, vol. 21 no. 3, 2003, pp. 281-302.

[4] W. Keusgen, “On limits of wireless communications when using multiple dual-polarized antennas,” *10th International Conference on Telecommunications*, vol. 1, 2003, pp. 204-210.

[5] A. Angel. Lozano, F. Farrokh, R. Farrokhi, and R. Reinaldo , A. Valenzuela. “Lifting the limits on high-speed wireless data access using antenna arrays,” *IEEE Communications Magazine*, vol. 39 no. 9, Sept. 2001, pp. 156-162.

[6] A. N. Mody and G. L. Stuber, “Efficient training and synchronization sequence structures for MIMOOFDM systems,” *the 6th OFDM Workshop 2001*, Hamburg, Germany, 2001

[7] W. Mohr, “WWRF-the Wireless World Research,” Electronic & Communication Engineering Journal, Vol. 14, No. 6, 2002.

[8] G. G. Raleigh and J. M. Cioffi, “Spatio-Temporal Coding for Wireless Communication,” *IEEE Trans. Communications*, vol. 46, 1998, pp. 357–66.

[9] “Receiver implementation for a MIMO OFDM system,” *Proc. Globecom 2002*, vol. 1, pp. 716 -720.

[10] R. Blum, Y. (G.) Li, J. Winters, and Q. Yam, “Improved space–ime coding for MIMO-OFDM wireless communications,” *IEEE Trans. Communications*, vol. 49, Nov. 2001, pp. 1873–1878.

[11] Gordon L. Stuber, “Principles of Mobile Communication,” *Kluwer Academic Publishers*, 2001.

[12] Yanji and H. Suh, “A Comparison of Raptor Code Using LDGM and LDPC Code,” *J. of the Korea Institute of Electronic Communication Sciences*, vol. 8, no. 1, 2013, pp. 65-70.

[13] S. Chen and H. Suh, “An Effective Decoding Algorithm of LDPC Codes with Lowering Error Floors,” *J. of the Korea Institute of Electronic Communication Sciences*, vol. 9, no. 10, 2014, pp. 1111-1116.

[14] H. Chen and H. Suh, “An Improved Bellman-Ford Algorithm based on SPFA,” *J. of the Korea Institute of Electronic Communication Sciences*, vol. 7, no. 4, 2012, pp. 721-726.

저자 소개

장기(Ge Zhang)

1984년 Beijing Normal Univ. 졸업(공학사)
2004년 여수대학교 대학원 전자통신공학과 졸업(공학석사)
2006년 전남대학교 대학원 전자통신공학과 박사입학
1993년 ~ 북경석유화공학원 교수
※ 관심분야 : 데이터통신시스템, 컴퓨터통신

서희종(Hee-Jong Suh)

1975년 한국항공대학 항공통신공학과 졸업(공학사)
1996년 중앙대학교 대학원 전자공학과 졸업(공학박사)
2006년 ~현재 전남대학교 전자통신공학과 교수
※ 관심분야 : 네트워크, 그래프이론