Front-End MIMO Transceivers in CDMA

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ABSTRACT

The main limitation of using multiple antenna architecture is the complexity and high cost of the hardware in the RF section. One solution to reduce the extra hardware cost and RF circuit imperfection is the utilization of a single RF front-end in a MIMO system. This article discusses the different alternatives to realize single RF front-end transceivers, including the antenna selection technique, code-division multiplexing, and the parasitic antenna method. The implementation technique for each approach is presented, and a performance study has been conducted. The practical limitations of a single RF front-end design alternative are also discussed.MIMO system can transfer the data upto 100 Mbps.

General Terms

Antenna Selection, Receiver, Transmitter, Parasitic Antenna,

Keywords

CDMA, MIMO, Antenna,.

1. INTRODUCTION

Multiple-input multiple-output (MIMO) wireless communication systems are designed to either provide maximum diversity to increase transmission reliability, or achieve maximum multiplexing gain to support a high data rate . It is known that the channel capacity of a MIMO system can be much higher than that of a single-input single-output (SISO) system. This performance of a MIMO system is quantified with the spatial multiplexing gain.

In this implementation, the receiver descrambles signals that are transmitted simultaneously from multiple antennas. Accordingly, it is possible to send parallel independent data streams and achieve overall system capacities that scale with min(N_r, N_t), where N_r and N_t are the number of receiving and transmitting antennas. On the other hand, if the signal copies are transmitted from multiple antennas or received at more than one antenna, the multiple antenna systems can provide a gain that can improve the reliability of a wireless link. This gain is called the diversity gain. This is achieved by space-time codes, which are capable of delivering a diversity order of N_rN_t. Furthermore, MIMO systems can be used to provide both diversity and multiplexing gain simultaneously; however, there may need to be a fundamental trade-off between them. The multiple-antenna front-end architecture design traditionally results in greater complexity and higher hardware costs in the radio frequency (RF) section. The hardware complexity and costrise with the increase in the number of antennas RF circuit mismatches and coupling also grow with the number of antennas; consequently, these factors limit the use of high numbers of antennas at the transceiver. To overcome this issue, one solution may be the utilization of a single RF front-end in a MIMO system, where a single RF path is used instead of multiple parallel RF paths. This results in an RF section that has lower complexity and cost, a simpler RF design, a compact size, and reduced power consumption. To realize a single RF front-end path, orthogonal transmission of multiple RF streams over a single front-end must be recognized. There are different alternatives to realizing orthogonal transmission systems that result in a single RF front-end MIMO system. The concept of a single RF front-end is investigated for both the transmitter and receiver sides. The current common designs are the antenna selection technique, code-division multiplexing (CDM) and the parasitic antenna approach. According to the antenna selection theory, in a MIMO system with N_t transmitting and N_r receiving antennas, L_t and K_r antennas and RF blocks are used instead of N_t and N_r, respectively. The antenna selection technique has been investigated for diversity and spatial multiplexing. On the other hand, the concepts of CDM have been mostly investigated for the receiver side of a MIMO system, whereas the investigation of the parasitic antenna approach targeted the transmitter, in order to realize a single RF front-end MIMO system. This article is organized as follows. First, the different alternatives for the design a single RF front-end MIMO system are introduced. This is followed by a performance study of the different approaches, and the implementations of the various approaches for the realization of single RF front-end MIMO systems are described. Finally the experimental results are presented.

2. SINGLE RF FRONT-END MIMO ARCHITECTURES

2.1 ANTENNA SELECTION

A simpler RF front-end MIMO system can be achieved using the antenna selection technique at the transmitter and/or receiver. By using this approach, some of the available antennas are selected, and the MIMO system uses fewer RF chains than the number of transmitter and/or receiver antennas. Accordingly, the complexity

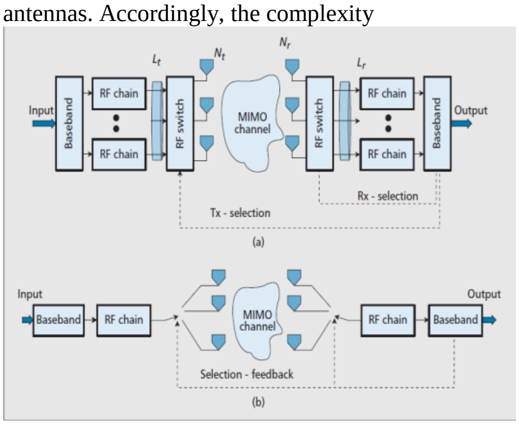

Fig 1:-Antenna selection Technique a) General concept b) single antenna selection system.

and cost are reduced, and the system performance is largely maintained. The antenna selection systems in both the receiver and transmitter are presented in Fig. 1. The received signal-to-noise ratio (SNR) values must be known for both the receiver and transmitter sides in this technique. Although implementation of antenna selection in the receiver is very straightforward, antenna selection in the transmitter requires a feedback path from the transmitter to the receiver. A common criterion for antenna selection is maximization of the channel capacity.

$$C_{select} \leq \sum_{i=1}^{L_r} log_2\left(1 + \frac{\sigma}{N_t}\beta_i\right)$$

where σ is the mean SNR, L_r is the number of selected antennas in the receiver, and β_i represents the squared norm of the *i*th row of H, which is the MIMO channel matrix with the rows ordered from the smallest to the largest. They are obtained by ordering a set of N_r of independent and identically distributed (i.i.d.) chi-square random variables with $2N_t$ degrees of freedom (DOF).It has been shown that most of the capacity of the MIMO system is retained with the antenna selection technique, provided that the number of selected antennas on one end should be at least as many as the number of available antennas on the other end. If one selects $L_t = L_r$ =1, the single RF transceiver can be realized for a MIMO system. The single antenna selection diagram is shown in Fig. 1. As it can be seen, the single antenna selection is very similar to the threshold detection technique in mobile communications.

2.2 CODE-DIVISION MULTIPLEXING

In CDM, the signals of different antennas must be multiplied by orthogonal codes and then added together, and a single RF front-end is used to down-convert the summed RF signals to baseband. In the baseband section, the signals are multiplied by the orthogonal codes, integrated and demultiplexed. This technique is depicted in Fig. 3. In the case of two receiving antennas, the first signal is multiplied by code and the second signal by $c_2(t)$ code in the symbol duration (T_s) and are then added together. These two codes are orthogonal; that is, $c_1(t)$ is equal to 1 between 0 and T_s, and $c_2(t)$ is equal to 1 between 0 and $T_s/2$ and to –1 between $T_s/2$ and T_s. Then, after summation, the total signal is down-converted using a single RF front-end. In the baseband section, the signal is multiplied by $c_1(t)$ and $c_2(t)$ and separated into different paths. In each path, an integrator can remove the effect of the other signal; however, the effect of the noise of both antennas is maintained in each path. The simulation result for BPSK modulation using two receiving antennas is illustrated in Fig.2. A separation of 3 dB can be observed between the conventional diversity system and this technique

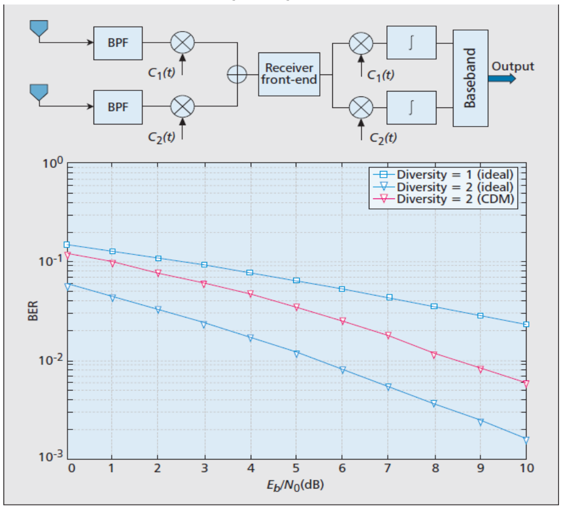

Fig 2:- Single Branch multi antenna receiver based on CDM; a) Functional Block Diagram;b)The BER Vs E_b/N_o for a single front end receiver using BPSK Modulation

2.3 PARASITIC ANTENNA

The parasitic antenna array has been proposed as a solution for the disadvantages of the conventional digital beam forming (DBF) technique. In a conventional DBF, signals received by individual antenna elements are down-converted into baseband signals. These signals are digitized and fed onto a digital signal processing (DSP) chip in which the algorithms reside. However, RF circuit branches connected to the array elements, analog-to-digital converters (ADCs), and the baseband DSP chip consume a considerable amount of DC power. The functional block diagram of the parasitic antenna digital beam former is shown in Fig. 3a . In this structure, one central element is connected to the single RF front-end, and the surrounding parasitic elements realize the array. Beam steering is achieved by tuning the load reactances at parasitic elements surrounding the central active element. The loads may be realized with varactor diodes. The power consumption of this architecture is very small. Furthermore, the system has only one RF front-end. The small interelement spacing can be as small as 0.05λ. This technique is also known as electrical steerable parasitic array radiator (ESPAR) antennas.

3. SINGLE RF FRONT-END RECEIVER IMPLEMENTATION

3.1 ANTENNA SELECTION

Suboptimal algorithms are commonly used for implementation of the antenna selection algorithm. There are generally two types of suboptimal antenna selection algorithms. In the first implementation, the algorithm initially considers all antennas and then drops one antenna per step, where the removed antenna has the least impact on the channel capacity. In the faster implementation,

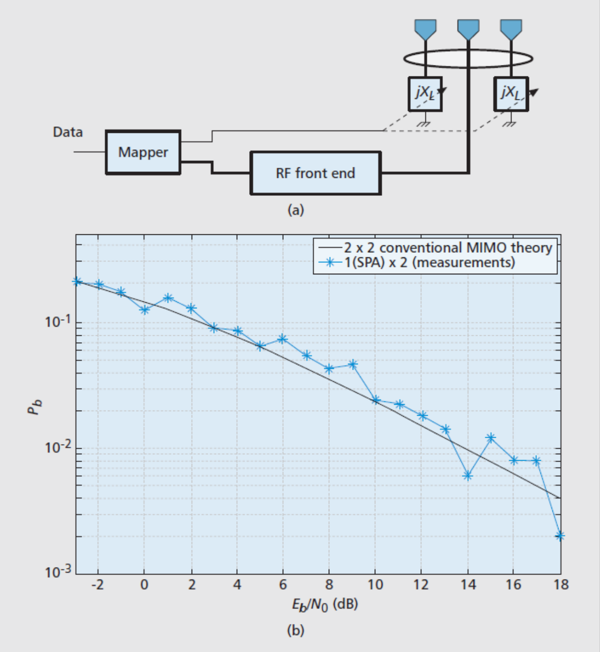

Fig 3 :- Single branch transmitter based on the parasitic antenna approach; a) Three element block diagram) The BER Vs E_b/N_0 for a single front end parasitic antenna using BPSK Modulation

the algorithm starts with zero antennas and adds one antenna per step, where the added antenna has the greatest effect on the channel capacity.

3.2 CODE-DIVISION MULTIPLEXING

An integrated circuit (IC) was designed and fabricated using the CDM technique to realize a single front-end receiver for two antennas. Figure 6a illustrates the different sections in the IC. First, the antenna signals are multiplexed using the CDM technique. The multiplexed signal then passes through a single RF front-end. After an ADC block, the match filters with corresponding codes are used to extract the individual signals from multiplexed signal. Figure 4b shows the die photo of the receiver at 5 GHz. The measurement results shows that this architecture reduces the chip area and power consumption and can be used in different multiple antenna schemes, while greatly reducing overall system complexity.

3.3 PARASITIC ANTENNA

The parasitic antenna technique is used on the transmitter side for implementing MIMO/multiple-input single-output (MISO) transmitters for BPSK and quadrature phase shift keying (QPSK) modulation . Moreover, it has been implemented to realize a single RF front-end MIMO system for multiple phase shift keying (MPSK) modulation . The simplified schematic diagram of a three-element system for BPSK modulation is shown in Fig. 4a. As can be seen, an antenna element is connected to the RF frontend, and the other antennas are controlled using two load reactance. The mapper divides input data into two BPSK modulated streams. The first BPSK signal is up-converted to RF frequency. This RF modulated signal is used to drive the central element. The second BPSK signal is used to control the load reactance. The reactive loads are used to create a linear combination of spatial basis functions using spatially multiplexed signals. The spatially multiplexed signals are mapped to the spatial basis functions, where the desired beam pattern in the far field becomes a combination of the individual signals.

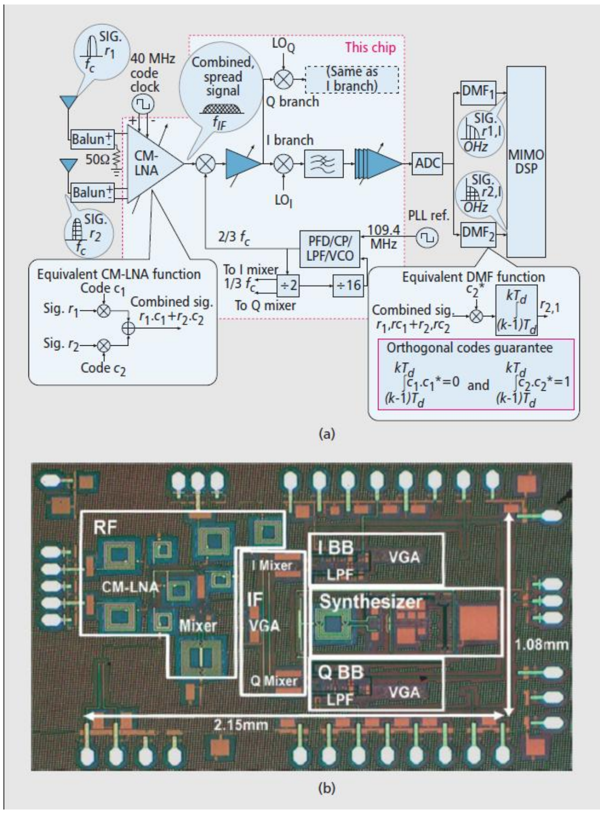

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Fig 4 :-The 5 GHz IC for two antenna single front end receiver; a)Circuit; a) dia photo

On the receiver side, the equivalent channel matrix is constructed. This matrix represents the receiver antenna responses to the spatial basis functions. The equivalent channel matrix is used for decoupling the two BPSK symbol Streams. The probability of bit error based on E_b/N_0 is shown in Fig. 3b for a three-element antenna using BPSK modulation

4. CONCLUSION

The different techniques that realize a single front-end MIMO transmitter, receiver and transceiver have been investigated. These techniques are antenna selection, CDM, and the parasitic antenna. Moreover, the simulation results are examined; and, the hardware performances are presented. These designs generally reduce complexity, cost, size, and power consumption in MIMO systems. However, they resulted in some drawbacks in system performance. As seen, the antenna selection technique may reduce the capacity, CDM technique needs more bandwidth and provides higher noise level and the parasitic antenna technique increases the system complexity. Indeed, the single RF front-end design techniques provide attractive design alternatives for many practical MIMO systems although there are some constraints for any implementation method.

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