

# An Efficient High-Throughput for Hard and Soft SC-FDMA MIMO Detectors

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**ABSTRACT:** This paper introduces a novel low-complexity multiple-input multiple-output (MIMO) detector tailored for single-carrier frequency division-multiple access (SC-FDMA) systems, suitable for efficient hardware implementations. The proposed detector starts with an initial estimate of the transmitted signal based on a minimum mean square error (MMSE) detector. Subsequently, it recognizes less reliable symbols for which more candidates in the constellation are browsed to improve the initial estimate. An efficient high-throughput VLSI architecture is also introduced achieving a superior performance compared to the conventional MMSE detectors with less than 28% added complexity. The performance of the proposed design is close to the existing maximum likelihood post-detection processing (ML-PDP) scheme, while resulting in a significantly lower complexity, i.e., and times fewer Euclidean distance (ED) calculations in the 16-QAM and 64-QAM schemes, respectively

## I. INTRODUCTION

Very large scale integration (VLSI) is the process of creating an integrated circuit (IC) by combining thousands of transistors into a single chip. The microprocessor is a VLSI device. Before the introduction of VLSI technology most ICs had a limited set of functions they could perform. An electronic circuit might consist of a CPU, ROM, RAM and other glue logic. VLSI lets IC designers add all of these into one chip. The first semiconductor chips held two transistors each. Subsequent advances added more transistors, and as a consequence, more individual functions or systems were integrated over time. The first integrated circuits held as ten diodes, transistors, resistors and capacitors, making it possible to fabricate one or more logic gates on a single device known retrospectively as small-scale integration (SSI), improvements in technique led to devices with hundreds of logic gates, known as medium-scale integration (MSI). Further improvements led to large-scale integration (LSI), i.e. systems with at least a thousand logic gates.

## II. LITERATURE REVIEW

### 2.1 A FAST RECURSIVE ALGORITHM FOR OPTIMUM SEQUENTIAL SIGNAL DETECTION IN A BLAST SYSTEM

Jacob Benesty, Yiteng Arden Huang and Jingdong Chen (July 2003)

Bell Laboratories layered space-time (BLAST) wireless systems are multiple-antenna communication schemes that can achieve very high spectral efficiencies in scattering environments with no increase in bandwidth or transmitted power. The most popular and, by far, the most practical architecture is the so-called vertical BLAST (V-BLAST). The signal detection algorithm of a V-BLAST system is computationally very intensive. If the number of transmitters is  $M$  and is equal to the number of receivers, this complexity is proportional to  $M^4$  at each sample time. In this paper, we propose a very simple and efficient algorithm that reduces the complexity by a factor of  $M$ .

## **2.2 A PRACTICAL MMSE-ML DETECTOR FOR A MIMO SC-FDMA SYSTEM**

Hoondong Noh, Myoungseok Kim, JaesangHamandChungyongLee(Dec 2009)

We propose a new minimum mean square error (MMSE) based maximum likelihood (ML) detector for a single carrier frequency division multiple access system. By utilizing the distance between decision line and MMSE soft-output, the proposed detector reduces the resources required to check superfluously accurate reliability of received symbol.

The proposed detector provides almost same bit error rate with the conventional MMSE-ML detector while requiring significantly low computational complexity below 10% as SNR varies.

## **2.3 ASIC IMPLEMENTATION OF SOFT-INPUT SOFT-OUTPUT MIMO DETECTION USING MMSE PARALLEL INTERFERENCE CANCELLATION**

ChristophStuder,SchekebFateh and Dominik Seethaler (July 2011)

Multiple-input multiple-output (MIMO) technology is the key to meet the demands for data rate and link reliability of modern wireless communication systems, such as IEEE 802.11n or 3GPP-LTE. The full potential of MIMO systems can, however, only be achieved by means iterative MIMO decoding relying on soft-input soft-output (SISO) data detection.

In this paper, we describe the first ASIC implementation of a SISO detector for iterative MIMO decoding. To this end, we propose a low-complexity minimum mean-squared error (MMSE) based parallel interference cancellation algorithm, develop a suitable VLSI architecture, and present a corresponding four-stream 1.5 mm detector chip in 90 nm CMOS technology. The fabricated ASIC includes all necessary pre-processing circuitry and exceeds the 600 Mb/s peak data rate of IEEE 802.11n. A comparison with state-of-the-art MIMO detector implementations demonstrates the performance benefits of our ASIC prototype in practical system-scenarios.

## **2.4 A LOW-COMPLEXITY HIGH-THROUGHPUT ASIC FOR THE SC-FDMA MIMO DETECTORS**

K. Neshatpour, M. Mahdavi, and M. Shabany (May 2012)

A novel low-complexity detection scheme is proposed for the multiple-input multiple-output (MIMO) single-carrier frequency division-multiple access (SC-FDMA) systems, which is suitable for ASIC implementations. The proposed detection scheme makes an initial estimate of the transmitted signal based on a minimum mean square error (MMSE) frequency domain equalizer (FDE) detector and finds symbols with higher error probability among them and browse more candidates for them in the constellation to improve their initial estimate. Based on this approach, architecture is introduced that achieves superior bit error rate (BER) performance compared to the conventional MMSE FDE.

The performance of the proposed design is close to the existing maximum likelihood-post detection processing (ML-PDP) scheme, while achieving a significantly lower complexity, i.e., 450× less Euclidean distance (ED) calculations in 16-QAM. The ASIC implementation of the proposed architecture, the first ASIC for SC-FDMA detectors to-date, achieves a 3× higher throughput than the best design reported to-date.

## **2.5 PERFORMANCE EVALUATION OF MIMO SC-FDMA SYSTEM WITH FDE RECEIVER**

W. Bai, D. Yan, Y. Xiao, and S (Nov 2009)

SC-FDMA (Single carrier frequency division multiple access) has been adopted as the uplink transmission scheme in 3GPP LTE (3rd Generation Partnership Project Long Term Evolution). MIMO (Multiple-input multiple-output) SC-FDMA, which combines the advantages of spatial and frequency diversities with FDE (frequency domain equalizers), has drawn great attention recently.

This paper proposes MIMO FDE receivers for MIMO SC-FDMA system including linear MIMO FDE and layered FDE receivers. Simulation Results show that IFDMA system with linear MMSE FDE receivers can achieve a much better performance than that of LFDMA system while LFDMA system with layered MMSE FDE receivers can achieve approximate or better BER performance than that of IFDMA system when the number of transmit and receive antennas is large to gain enough spatial diversity.

## **2.6 PRACTICAL SOFT-SIC DETECTION FOR MIMO SC-FDMA SYSTEM WITH CO-CHANNEL INTERFERENCE**

Z. Pan, G. Wu, S. Fang, and D (Oct 2010)

The single-carrier frequency division multiple access (SC-FDMA) is employed in the 3GPP Long Term Evolution (LTE) standard as the uplink transmission scheme. In this paper, we propose a novel successive interference cancellation (SIC) detector for multiuser detection in multiuser Multiple Input Multiple Output (MIMO) SC-FDMA system with co-channel interference (CCI). Compared to conventional SIC receiver, the proposed scheme can overcome the error propagation problem in the interference cancellation process via soft-decision output combined with channel decoder.

we also study the impact of the channel estimate error on the receiver and investigated it via simulation. Simulation results show that the proposed algorithm is significantly superior to the conventional frequency domain linear equalization based receiver in terms of bit error rate (BER) performance even the channel state information is imperfect at the receiver.

## **2.7 AN ITERATIVE MIMO-DFE RECEIVER WITH MLD FOR UPLINK SC-FDMA**

B. Dhivagar, K. Kuchi, and K. Giridhar (Feb 2013)

Single carrier frequency division multiple access (SC-FDMA) based systems such as long term evolution (LTE) uplink experience severe inter symbol interference (ISI) in highly frequency selective channels. The conventional linear receivers such as the linear minimum mean square error (LMMSE) based receiver fail to address this issue, thereby degrading the performance of the system.

This paper proposes a new iterative multiple input multiple output decision feedback equalizer (MIMO-DFE) which does not require the estimation of any parameters for cancelling ISI. It also derives a closed form expression for the residual noise covariance after equalization which is used for maximum likelihood detection (MLD) across streams. Simulations show that the proposed receiver yields significant performance gains especially in the high signal-to-noise-ratio (SNR) regime with only a modest increase in computational complexity.

## **2.8 EFFICIENT EQUALIZATION HARDWARE ARCHITECTURE FOR SC-FDMA SYSTEMS WITHOUT CYCLIC PREFIX**

R. Ferdian, K. Anwar, and T. Adiono (Oct 2012)

Single carrier frequency domain multiple access (SC-FDMA) system achieves better spectral efficiency when cyclic prefix (CP) is not transmitted. However, the chained turbo equalization (CHATUE) algorithm, an equalizer required to both equalize the multipath fading effect and cancel the inter-block interference of SC-FDMA without CP, requires high computational complexity due to the non-circulate structure of the past and the future interference matrices.

This paper proposes efficient hardware architecture based on systolic architecture for practical implementation. The main idea is to minimize the number of required processing elements by utilizing efficient resources sharing method while exploiting concurrency of the processing. A new computation method using masking matrices is introduced to obtain interference matrix from its corresponding circulate channel matrix. The results with fixed point computation show that the computational complexity can be significantly reduced up to 96% for practical implementation without significant degradation in bit-error-rate (BER) performances.

## **III. PROPOSED SYSTEM**

### **3.1 INTRODUCTION**

The 3rd generation partnership project (3GPP) defined long term evolution (LTE) to meet the requirements of the 4G wireless communication. LTE combines multiple-input multiple-output (MIMO) technology with orthogonal frequency division-multiple access (OFDMA) technology in the downlink and single carrier-frequency division multiple access (SC-FDMA) in the uplink to achieve peak data rates of 300 Mbps and 75 Mbps, respectively. LTE-Advanced (LTE-A), which is an evolution of LTE, supports single-user spatial multiplexing of up to eight layers in the downlink and four layers in the uplink targeted to achieve peak data rates of 1 Gbps and 500 Mbps, respectively. The

SC-FDMA utilizes a discrete Fourier transform-spread OFDM (DFT-S-OFDM) modulation with similar performance compared to the OFDM.

### 3.2 BLOCK DIAGRAM

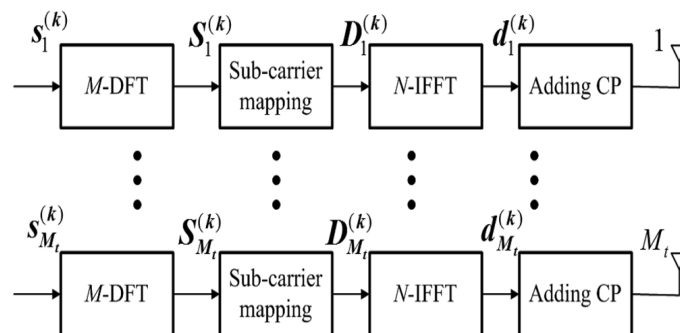


Fig 3.1: Block diagram for MIMO SC-FDMA transmit antenna

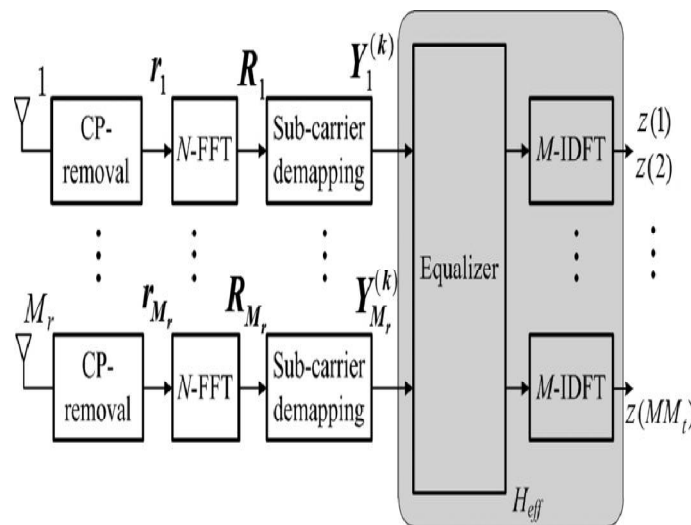


Fig 3.2: Block diagram for MIMO SC-FDMA receiver antenna

### 3.3 FDMA

Frequency Division Multiple Access or FDMA is a channel access method used in multiple-access protocols as a channelization protocol. FDMA gives users an individual allocation of one or several frequency bands, or channels. It is particularly commonplace in satellite communication. FDMA, like other Multiple Access systems, coordinates access between multiple users. Alternatives include TDMA, CDMA, or SDMA. These protocols are utilized differently, at different levels of the theoretical OSI model. FDMA is distinct from frequency division duplexing (FDD). While FDMA allows multiple users simultaneous access to a transmission system, FDD refers to how the radio channel is shared between the uplink and downlink for instance, the traffic going back and forth between a mobile-phone and a mobile phone base station. Frequency- the other hand, is an access method in the data link division multiplexing (FDM) is also distinct from FDMA. FDM is a physical layer technique that combines and transmits low-bandwidth channels through a high-bandwidth channel. FDMA, on layer.

FDMA also supports demand assignment in addition to fixed assignment. Demand assignment allows all users apparently continuous access of the radio spectrum by assigning carrier frequencies on a temporary basis using a statistical assignment process. The first FDMA demand-assignment system for satellite was developed by COMSAT for use on the Intelsat series IVA and V satellites **Disadvantage:**

Crosstalk may cause interference among frequencies and disrupt the transmission.

- In FDMA all users share the satellite transponder or frequency channel simultaneously but each user transmits at single frequency.
- FDMA can be used with both analog and digital signal.
- FDMA requires high-performing filters in the radio hardware, in contrast to TDMA and CDMA.
- FDMA is not vulnerable to the timing problems that TDMA has. Since a predetermined frequency band is available for the entire period of communication, stream data a continuous flow of data that may not be packetized can easily be used with FDMA.
- Due to the frequency filtering, FDMA is not sensitive to near-far problem which is pronounced for CDMA.
- Each user transmits and receives at different frequencies as each user gets a unique frequency slots.

FDMA is distinct from frequency division duplexing (FDD). While FDMA allows multiple users simultaneous access to a transmission system, FDD refers to how the radio channel is shared between the uplink and downlink for instance, the traffic going back and forth between a mobile-phone and a mobile phone base station. Frequency-division multiplexing (FDM) is also distinct from FDMA. FDM is a physical layer technique that combines and transmits low-bandwidth channels through a high-bandwidth channel. FDMA, on the other hand, is an access method in the data link layer.

FDMA also supports demand assignment in addition to fixed assignment. Demand assignment allows all users apparently continuous access of the radio spectrum by assigning carrier frequencies on a temporary basis using a statistical assignment process. The first FDMA demand-assignment system for satellite was developed by COMSAT for use on the Intelsat series IVA and V satellites.

#### **Main techniques:**

- Multi-channel per-carrier (MCPC)
- Single-channel per-carrier (SCPC)

These are the two main techniques for the FDMA systems. FDMA also supports demand assignment in addition to fixed assignment. Demand assignment allows all users apparently continuous access of the radio spectrum by assigning carrier frequencies on a temporary basis using a statistical assignment process.

#### **3.3.1 SINGLE CARRIER MAPPING**

- Single-carrier FDMA (SC-FDMA) is a frequency-division multiple access scheme. It is also called Linearly precoded OFDMA (LP-OFDMA). Like other multiple access schemes (TDMA, FDMA, CDMA, OFDMA), it deals with the assignment of multiple users to a shared communication resource. SC-FDMA can be interpreted as a linearly precoded OFDMA scheme, in the sense that it has an additional DFT processing step preceding the conventional OFDMA processing.
- SC-FDMA has drawn great attention as an attractive alternative to OFDMA, especially in the uplink communications where lower peak-to-average power ratio (PAPR) greatly benefits the mobile terminal in terms of transmit power efficiency and reduced cost of the power amplifier. It has been adopted as the uplink multiple access scheme in 3GPP Long Term Evolution (LTE), or Evolved UTRA (E-UTRA).
- The performance of SC-FDMA, in relation to OFDMA has been the subject of various studies. Although the performance gap is not much, SC-FDMA's additional advantage of low PAPR makes it a favorite especially for uplink wireless transmission in future mobile communication systems where transmitter power efficiency is of paramount importance.

The transmission processing of SC-FDMA is very similar to that of OFDMA. For each user, the sequence of bits transmitted is mapped to a complex constellation of symbols (BPSK, QPSK or M-Quadrature amplitude modulation). Then different transmitters are assigned different Fourier coefficients. This assignment is carried out in the mapping and demapping blocks. The receiver side includes one demapping block, one IDFT block, and one detection block for each user signal to be received. Just like in OFDM, guard intervals called cyclic prefixes with cyclic



repetition are introduced between blocks of symbols in view to efficiently eliminate inter-symbol interference from time spreading caused by multi-path propagation among the blocks.

### 3.4 DETECTOR

In electronics, a detector is an older term for an electronic component in a radio receiver that recovers information contained in a modulated radio wave. The term dates from the first three decades of radio. Unlike modern radio stations which transmit sound an audio signal on the radio carrier wave, the first radio transmitters transmitted information by wireless telegraphy, using different length pulses of radio waves to spell out text messages in Morse code. So radio receiving equipment didn't have to extract a sound wave from the incoming radio signal, but only "detect" the presence or absence of the radio signal, to produce clicks in the receiver's earphones representing the Morse code symbols.

The device that did this was called a detector. A variety of different detector devices, such as the coherer, electrolytic detector, and magnetic detector, were used during the wireless telegraphy era.

### 3.5 DFT

In mathematics, the discrete Fourier transform (DFT) converts a finite list of equally spaced samples of a function into the list of coefficients of a finite combination of complex sinusoids, ordered by their frequencies, that has those same sample values. It can be said to convert the sampled function from its original domain often time or position along a line to the frequency domain.

The DFT is the most important discrete transform, used to perform Fourier analysis in many practical applications. In digital signal processing, the function is any quantity or signal that varies over time, such as the pressure of a sound wave, a radio signal, or daily temperature readings, sampled over a finite time interval often defined by a window function. In image processing, the samples can be the values of pixels along a row or column of a raster image.

The DFT is also used to efficiently solve partial differential equations, and to perform other operations such as convolutions or multiplying large integers. Since it deals with a finite amount of data, it can be implemented in computers by numerical algorithms or even dedicated hardware. These implementations usually employ efficient fast Fourier transform (FFT) algorithms; so much so that the terms "FFT" and "DFT" are often used interchangeably. Prior to its current usage, the "FFT" initialism may have also been used for the ambiguous term "finite Fourier transform".

The transmission BER is the number of detected bits that are incorrect before error correction, divided by the total number of transferred bits including redundant error codes. The information BER, approximately equal to the decoding error probability, is the number of decoded bits that remain incorrect after the error correction, divided by the total number of decoded bits the useful information. Normally the transmission BER is larger than the information BER. The information BER is affected by the strength of the forward error correction code.

The BER may be evaluated using stochastic Monte Carlo computer simulations. If a simple transmission channel model and data source model is assumed, the BER may also be calculated analytically. An example of such a data source model is the Bernoulli source.

#### 3.5.1 BIT ERROR RATE

In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that have been altered due to noise, interference, distortion or bit synchronization errors.

The bit error rate (BER) is the number of bit errors per unit time. The bit error ratio is the number of bit errors divided by the total number of transferred bits during a studied time interval. BER is a unitless performance measure, often expressed as a percentage.

The bit error probability  $p_e$  is the expectation value of the bit error ratio. The bit error ratio can be considered as an approximate estimate of the bit error probability. This estimate is accurate for a long time interval and a high number of bit errors.

In a communication system, the receiver side BER may be affected by transmission channel noise, interference, distortion, bit synchronization problems, attenuation, wireless multipath fading, etc.

The BER may be improved by choosing a strong signal strength unless this causes cross-talk and more bit errors by choosing a slow and robust modulation scheme or line coding scheme, and by applying channel coding schemes such as redundant forward error correction codes.

The transmission BER is the number of detected bits that are incorrect before error correction, divided by the total number of transferred bits including redundant error codes. The information BER, approximately equal to the decoding error probability, is the number of decoded bits that remain incorrect after the error correction, divided by the total number of decoded bits the useful information. Normally the transmission BER is larger than the information BER. The information BER is affected by the strength of the forward error correction code.

The BER may be evaluated using stochastic Monte Carlo computer simulations. If a simple transmission channel model and data source model is assumed, the BER may also be calculated analytically. An example of such a data source model is the Bernoulli source.

#### IV. RESULTS AND DISCUSSION

The proposed detector starts with an initial estimate of the transmitted signal based on a minimum mean square error (MMSE) detector. Subsequently, it recognizes less reliable symbols for which more candidates in the constellation are browsed to improve the initial estimate. An efficient high-throughput VLSI architecture is also introduced achieving a superior performance compared to the conventional MMSE detectors with less than 28% added complexity. The performance of the proposed design is close to the existing maximum likelihood post-detection processing (ML-PDP) scheme.

#### V. CONCLUSION

The architecture of a practical receiver was implemented and tested in an FPGA and ASIC platform for MIMO SC-FDMA systems, resulting in a superior BER performance compared to the MMSE detector and lower complexity compared to current reported designs. The BER performance of the proposed detection scheme is close to ML-PDP while the reduction in the complexity is significant in large constellation sizes. A soft decoding MIMO detector with reasonable complexity was also implemented for a MIMO SC-FDMA coded system, result in significant enhancement in the performance.

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