# Simulation and Performance Analysis of INTERLEAVE DIVISION MULTIPLE ACCESS in Advance Wireless Communication System

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***Abstract*-- This paper outlines a survey on interleave-division multiple-access (IDMA) technique which exploits the interleaving as only means of user separation instead of by different signatures as in a conventional code-division multiple-access (CDMA) scheme. IDMA scheme can achieve near single user performance in situations with very large numbers of users while maintaining very low receiver complexity. This technique inherits many advantages from CDMA, such as diversity against fading and mitigation of the worst-case user interference problem.**

**This paper presents an overview of IDMA and discusses the main features and areas of application as the future air interface access schemes for IMT-2000/UMTS.**

***Index Terms*—Multiple Access, IMT 2000, Interleaver.**

## I. INTRODUCTION

Recently, extensive investigations have been carried out into the implantation and applications of interleave-division multiple-access (IDMA) system as an air interface multiple access scheme. Emerging requirements for higher rate data services and better spectrum efficiency are the main drivers identified for the third generation mobile radio systems. It appears that IDMA is emerging as the strongest candidate for the third generation wireless personal communication systems. A lot of research and development (R&D) projects in the field of IDMA have been going on all over the world. It then seems that IDMA will be an appropriate answer to the question: “What will the multiple access scheme for IMT-2000 / UMTS be?”

The paper is organized as follows. Multiple access schemes along with IDMA are introduced in Section 2. IDMA concepts and elements are explained in Section 3. Current issues related to IDMA scheme are presented in Section 4. Finally conclusions are given in Section 5.

## II. CONCEPT OF IDMA

The performance of conventional CDMA systems [3] is limited by multiple access interference (MAI), as well as inter symbol interference (ISI). Also, the complexity of CDMA multiuser detection has always been a serious concern. The problem can be seen from the angle of computational cost as well complexity of multiuser detection algorithms. The use of signature sequences for user separation is a characteristic feature for a conventional CDMA system. Interleaving is usually placed between forward error correction (FEC) coding and spreading and is traditionally employed to combat the fading effect. The possibility of employing interleaving for user separation in CDMA systems is briefly mentioned in [3] but the receiver complexity is considered as a main obstacle. In a performance improvement achieved by assigning different interleavers to different users in a CDMA system is demonstrated. In [4], [5], [6], multiuser detection in narrowband applications with a small number of users is investigated.

A conventional random waveform CDMA (RWCDMA) system (such as IS-95) involves separate coding and spreading operations. Theoretical analysis shows that the optimal multiple access channel (MAC) capacity is achievable only when the entire bandwidth expansion is devoted to coding. This suggests combining the coding and spreading operations using low-rate codes to maximize coding gain. But separation of users without spreading operation is not feasible in CDMA.

<u>*Possible Solution for User Separation*</u>

Now the question arises that what should be the strategy for distinguishing the different users. The possible solutions includes narrow band coded-modulation scheme using trellis code structures [4], and to employ chip-level interleavers [3][4][5][6].

Improvement in CDMA scheme by assigning different interleavers to different users [5] [6] has already been reported. So the possible solution to this problem is to employ chip-level interleavers for user separation. This principle has been considered previously and its potential advantages have been demonstrated [7] showing the possibility of employing interleaving for user separation in coded systems. For wideband systems, the performance improvement by assigning different interleavers to different users in conventional CDMA has been demonstrated in [3]. Ref. [9] studied a chip interleaved CDMA scheme and a maximal-ratio-combining (MRC) technique for ISI MACs. It clearly demonstrated the advantages of introducing chip-level interleavers. An interleaver-based multiple access scheme has also been studied in [10][11] for high spectral efficiency, improved error performance and low receiver complexity.

## III. INTRODUCTION TO IDMA

This paper presents an asynchronous interleave-division multiple-access (IDMA) scheme for spread spectrum mobile communication systems, in which users are distinguished by different chip-level interleavers instead of by different signatures as in a conventional CDMA system incorporating the principle explained in [2][11]. The scheme considered is a special case of CDMA in which bandwidth expansion is entirely performed by low-rate coding. For convenience, it may be referred as interleave-division multiple-access (IDMA) [10][11]. This scheme inherits many advantages from CDMA such as dynamic channel sharing, mitigation of cross-cell interferences, asynchronous transmission, ease of cell planning, and robustness against fading. It also allows a low complexity multiple user detection techniques applicable to systems with large numbers of users in multipath channels. In this paper, an effort has been made to study of proposed IDMA scheme by different researchers. A very low-cost chip-by-chip iterative detection algorithm is explained with complexity independent of user number and increasing linearity with the path number. The advantages of using low-rate coded systems are demonstrated analytically. We will show that the proposed IDMA scheme can achieve performance close to the capacity of a multiple access channel.

## IV. Transmitter and Receiver Structure of IDMA scheme

### 1) *IDMA MECHENISM*

In conventional CDMA, signature sequences are used for user separation [6] while in IDMA, every user is separated with individual interleaver, orthogonal in nature. The block diagram of IDMA scheme is shown for K users in figure 1. Data from user *k* is first encoded by a rate-*R* binary forward error control (FEC) code followed by spreader. Each user has been assigned common signature sequence $s_k$ with length S. The elements in $s_k$ are called *chips*. The spreader for user *k* spreads a coded bit to a chip sequence (i.e., it transmits either $s_k$ or – $s_k$ to represent one bit). The spreading operation results bandwidth expansion since a single chip alone can carry one bit of information. Then interleaving is done on each of the data related to individual user. The redundancy from interleaving is introduced mainly to distinguish different users. From a coding theory point of view, however, this is a good choice since it introduces redundancy with coding gain.

The principle of iterative multi user detection (MUD) which is a promising technique for multiple access problem (MAI), is illustrated in the lower part of Fig. 1. The turbo processor involves an elementary multi-user detector (EMUD) and a bank of *K* decoders (DECs). The EMUD partially resolves MAI without considering FEC coding. The outputs of the EMUD are then passed to the DECs for further refinement using the FEC coding constraint. The DECs outputs are fed back to the EMUD to improve its estimates in the next iteration. This iterative procedure is repeated a preset number of times (or terminated if a certain stopping criterion is fulfilled). After the final iteration, the DECs produce hard decisions on the information bits.

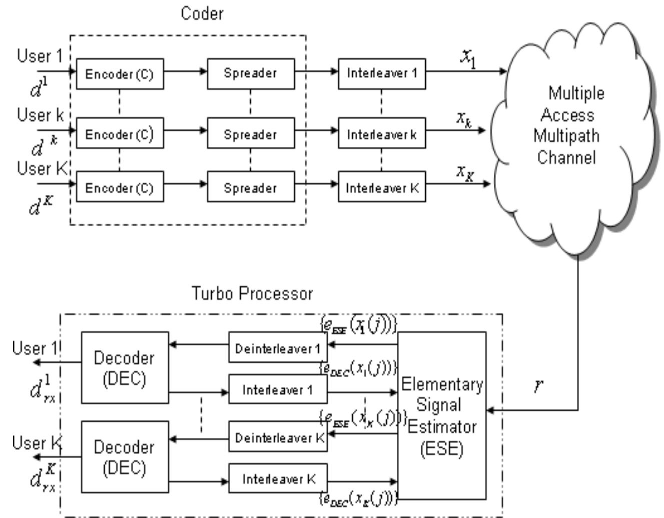



Figure 1. IDMA Transmitter and Iterative MUD Receiver

In the turbo processor, each DEC handles the data for a particular user only and ignores the others. Therefore, the DEC complexity per user is independent of the user number *K*. The task of the EMUD, on the other hand, is to find a joint solution considering all users. The complexity involved (mainly for solving a size *K*x*K* correlation matrix) is $O(K^2)$ per user by the well-known iterative minimum mean square error (MMSE) technique [13] in CDMA while in IDMA, it is independent of user. This can be a major benefit when *K* is large.

### 2) *IDMA and Multiuser Detection*

The upper part of Figure 1 shows the transmitter structure of an IDMA system [27]. The coder block of a low-rate code *C* is employed to produce a coded sequence $c^{(K)}$ = { $c^{(K)}$, j=1, 2, ..*J*□}, where *J* is the frame length, followed by a chip level interleaver $\Psi^{(m)}$ that maps $c^{(K)}$ to $x^{(K)}$ ={ $x^{(K)}$, j=1, 2, ..*J*}.

We follow the convention of CDMA and call the basic elements in $c^{(K)}$ and $x^{(K)}$ "chips". Coder block can be either the same or different for different users. It can be an FEC code, or a spreading sequence (spreading is also a special form of coding), or a combination of the two [11]. From a performance point of view, it is advantageous to use a low-rate FEC code [9][10] that can provide an extra coding gain.

The key principle of IDMA is that the interleavers { $\Psi^{(K)}$ } should be different for individual users. We assume that the interleavers are generated independently and randomly. For simplicity, we first consider time-invariant single-path channels with real channel coefficients and BPSK signaling.

After sampling at chip rate, the received signal from *K users* can be written as

$$r_j = \sum_{1}^{m} h^{(K)} x_j^{(K)} + n_j \qquad (1)$$

$j = 1, 2, \ldots, J$, where $x_j^{(K)}$ is the $j$th chip transmitted by the $K$th user, the channel coefficient for the $K$th user and $\{n_j\}$ samples of a zero-mean additive white Gaussian noise (AWGN) with variance $\sigma^2 = N0/2$.

In the lower part of Figure 1, showing the receiver section of IDMA system, the iterative multiuser detector employs a low-cost chip-by-chip detection strategy and avoids conventional MAP. The receiver consists of Elementary Signal Estimator (ESE) and an *a posteriori* probability (APP) decoder (DEC). The ESE exchanges information with the DEC in a turbo-type manner [8]. The DEC also produces hard decisions $\{d_{rx}^K\}$ on information bits $\{d^K\}$ in the final iteration.

The receiver operation is based on the received signal $r\{r_j, j = 1,\ldots, J\}$, the channel coefficients $h[h^{(1)},\ldots,h^{(k)},\ldots,h^{(K)}]$. Finding an optimal solution is usually prohibitively complicated. We now consider a sub-optimal approach by first separating the conditions, i.e., $r$, $h$ and $C$, and then combining the results using an iterative process. This greatly reduces the complexity involved.

Specifically, the constraint of *Coder* is ignored in the ESE. The output of the ESE is defined by the logarithm likelihood ratio (LLR)

$$\{e_{ESE}(x_K(j))\} = \log\left[\frac{p(r_j \mid x_K(j) = +1, h)}{p(r_j \mid x_K(j) = -1, h)}\right] \quad \forall K, j \qquad (2)$$

1) The DEC consists of $K$ local APP decoders. The $k$th local APP decoder performs an APP decoding of *Coder* for the $k$th user using $e_{ESE}$, after appropriate deinterleaving, as its input. Its output is the so-called extrinsic LLR [8]. Initialize
2) $e_{DEC}(x_k(j)) = 0$
3) Set $E((x_k(j)) = \tanh\left(\frac{e_{DEC}(x_k(j)}{2}\right)$
4) $Var(x_k(j))$=1-E$((x(j))^2$
5) $Find\ E(r(j)) = \sum h_k . E\,(x_k(j))$
6) Variance of the equation is given by Var(r(j))$\Leftarrow \sum_{k'=1}^{k} h_k^2\ Var(x_k(j)) + \sigma^2$
7) Finally find Elementary Signal Estimator Function as
8)

$$e_{ESE}((x_k(j)) \Leftarrow 2h_k . \frac{r(j) - E(r(j)) + h_k E(x_k(j))}{\mathrm{Var}(\mathrm{r(j)}) - \mathrm{h}_\mathrm{k}^2 \mathrm{Var}(\mathrm{x_k(j)})}$$

$$\{e_{DEC}(x_K(j))\} = \log\left[\frac{p_r(x_K(j) = +1 \mid e_{ECE}(x_K(j)), Coder)}{p_r(x_K(j) = -1 \mid e_{ECE}(x_K(j)), Coder)}\right] - e_{ECE}(x_K(j)) \quad \forall K, j \qquad (3)$$

The APP decoding in the DEC is a standard function [8] so we will not discuss it in detail. In the following, we will focus on the ESE.

## V. Issues in IDMA

There are many burning issues in the field of research in Interleave Division Multiple Access which includes optimum signaling schemes, coding technique, interleaver design, and detection techniques etc.

### 1) *Signaling schemes in multipath fading channels*

In the [13], L. ping has studied the IDMA scheme with BPSK and QPSK modulation schemes. In both the scheme, the improvement in BER has been observed. Benefit including low-cost MUD for system for large users, high spectral efficiency and near limit performance, has been observed. QPSK scheme is always preferred to BPSK in multipath fading channels.

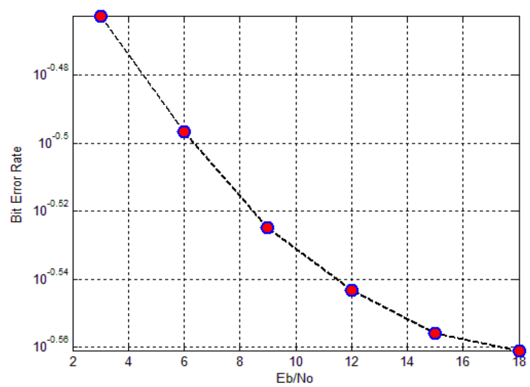



Figure 2. Tree Based Interleaver scheme with variation in user count

The scope of applying other modulation scheme to IDMA needs to be performed, still.

### 2) *Detection techniques in iterative IDMA receivers*

In the [15] IDMA scheme the results with different multiuser detection techniques. The three detector techniques discussed here which includes chip extrinsic information (CEI), a posteriori probability information (APPI), bit extrinsic information (BEI)

**1. CEI (*chip extrinsic information):***

The chip extrinsic information is extrinsic at the chip level, in the sense both L($b_k$(1)) and the elementary signal estimator are subtracting from each other, that is they are extrinsic. This gives better results in the sense of BER at the expense of memory. This detector requires more memory to store the elementary signal estimator values.

$$e_{DEC}(x_k(\pi_k(j)) = L_{APP}(b_k(1)) + L(b_k(1)) - e_{ESE}(x_k(\pi_k(j)), j = 1,2...S \quad (4)$$

**2. APPI (*a posteriori probability information):***

This detector removes the necessity of storing the value of the elementary signal estimator, but the bit error rate is comprised. This needs less memory at the expense of the bit error rate.

$$e_{DEC}(x_k(\pi_k(j)) = L_{APP}(b_k(1)) + L(b_k(1)),\ j = 1,2 \ldots S. \quad (5)$$

**3. BEI *(bit extrinsic information):***

This is so called because the feed back is done at the bit level rather than at the chip level. The memory required for this detector is less when compared to both the APPI and CEI, but there is reduction in the BER.

$$e_{DEC}(x_k(\pi_k(j)) = L_{APP}(b_k(1)),\ j = 1,2 \ldots S. \quad (6)$$

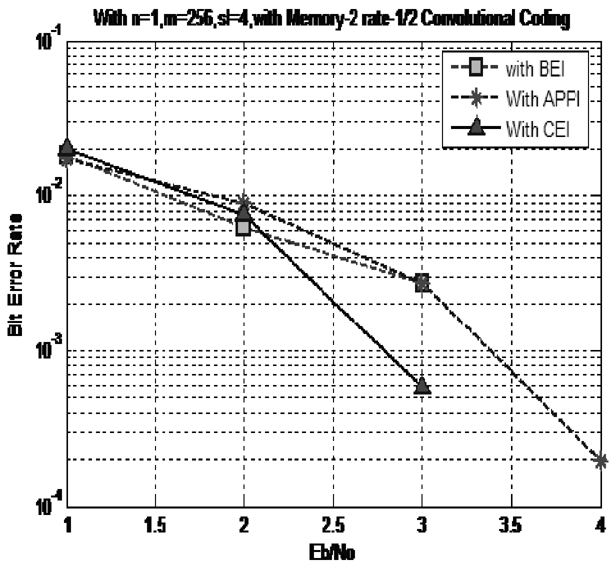



Figure 3. Simulation of IDMA scheme with different detection techniques

*3) Optimum coding Technique*

In [13], Ping has worked with turbo-hadamard codes and in [18],[19] space time code has been reported.

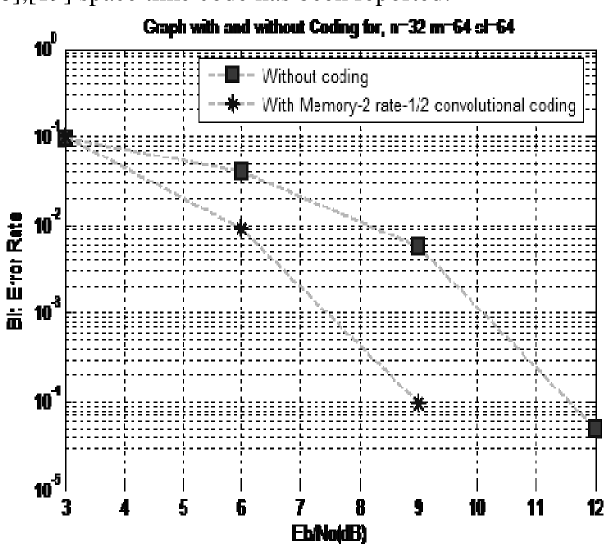



Figure 4. Simulation of IDMA scheme with coded and un-coded status

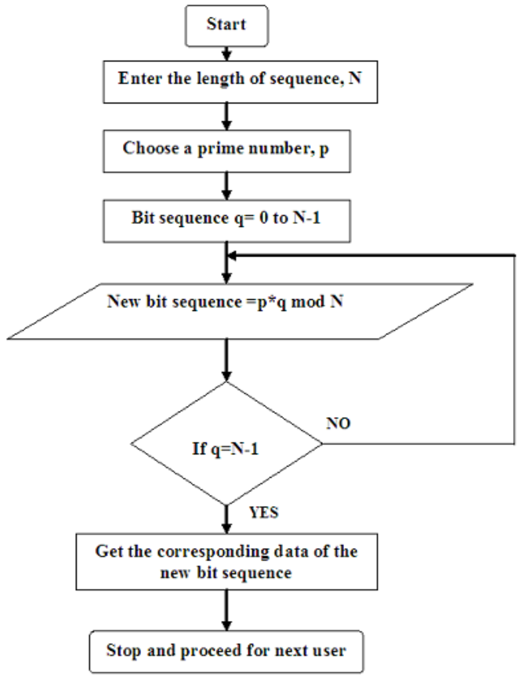
With simple convolution/repetition codes, overall throughputs of 3 bits/chip with one receive antenna and 6 bits/chip with two receive antennas are observed for systems with as many as about 100 users. More sophisticated low-rate codes can also be used for further performance enhancement, as illustrated by comparison between low-rate and high-rate coded IDMA systems. With space time coding, the detection complexity is very moderate, and grows only linearly with the number of transmit antennas. Thus, systems with a large number of transmit antennas can be processed.

The basic principle of the scheme in Figure 1, is the use of repetition coding together with random interleaving and iterative detection. The repetition coding is a simple way to achieve diversity, since each bit has N replicas transmitted from N antennas with different fading coefficients. At the receiver side, the information about a bit is collected from N samples. Such a technique has been studied before, e.g., the delay diversity scheme [28]. The work in this paper shows that such a simple scheme can achieve performance close to the theoretical limit (as a result of the iterative detection strategy). This scheme is applicable to any number of transmit antennas and is simpler and more flexible than other the schemes. It also appears that a codeword difference matrix in an interleaver-based code has a large probability of being full rank after random interleaving. The theoretical analysis of this problem remains open and is a subject of current investigations. (For a preliminary discussion see [26].) It will also be interesting to discover if careful design can lead to better performance for the interleaver-based code, and how much improvement can be achieved. We are currently working on this issue.

*4) Variation in Interleaver Design*

In IDMA systems, different interleavers are assigned to different users. In theory, the user-specific interleavers can be generated independently and randomly. If this is the case, the base station (BS) has to use a considerable amount of memory to store these interleavers, which may cause serious concern when the number of users is large. Also, during the initial link setting-up phase, there should be messages passing between the BS and mobile stations (MSs) to inform each other about their interleavers. Extra bandwidth resource will be consumed for this purpose if the interleavers used by the BS and MSs are long and randomly generated. With this method, the interleaver assignment scheme is simplified and memory cost is greatly reduced without sacrificing performance. This method not only reduces the amount of information exchanged between the BS and MSs, but also greatly reduces the memory cost. Here, the only the power interleaver $\phi$ is needed to be stored. Let the power interleaver be $\pi_1 \equiv \phi$. After completing the detection cycle for user 1, the interleaver can be updated from $\pi_1 \equiv \phi$ to $\phi(\pi) = \phi^2$. This procedure continues recursively.

Numerical results show that the new interleaver generation method, so-called 'power-interleavers', can take the place of random-interleavers without performance loss.




Flow chart of power Interleaver OR Clock wise interleaver

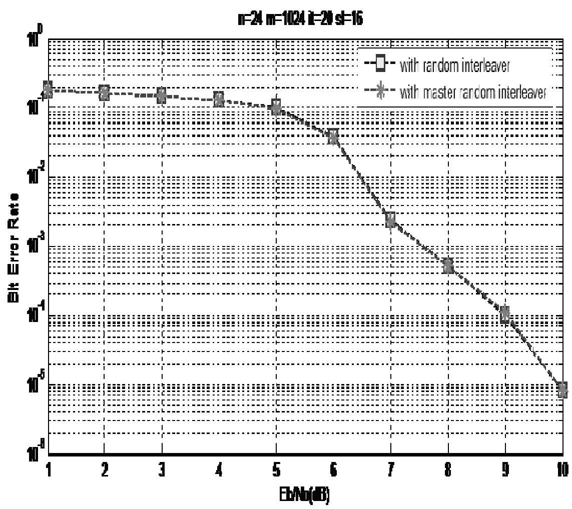
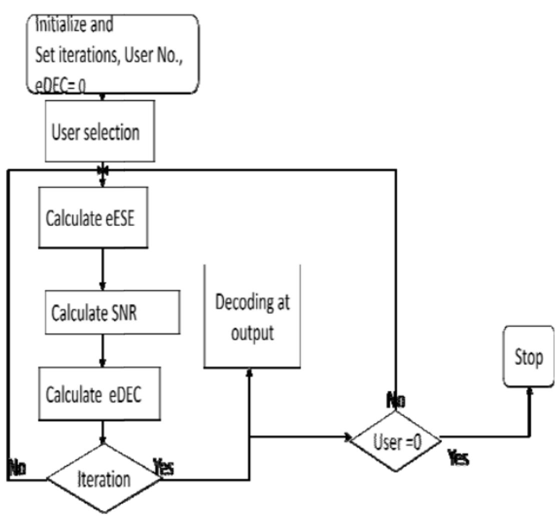



Figure 5. Comparison of random interleaver and master random interleaver for 24 users in IDMA scheme




Flow Chart for the Decoding Algorithm

Recently, PEG interleavers [29] have also been in literature which involves the PEG algorithm in generating random interleavers. So, it also counts for problem of huge memory requirement at transmitter and receiver section.

TABLE 1 : COMPARISON OF COMPUTATIONAL COMPLEXITY WITH TREE BASED INTERLEAVER AND MASTER RANDOM INTERLEAVER

| User Number | No. of times Interleaving in Tree Based Interleaver | No. of times Interleaving in Master Random Interleaver |
|---|---|---|
| 2 | 1 | 2 |
| 6 | 2 | 6 |
| 14 | 3 | 14 |
| 30 | 4 | 30 |
| 62 | 5 | 62 |
| 126 | 6 | 126 |

Tree Based Interleaver [30] is reported to be optimum interleaver in terms of computational complexity and memory requirements.

## VI. CURRENT TRENDS IN IDMA

The testing and improvements in IDMA scheme is being carried out by many researchers throughout the world. Simulation of IDMA scheme has been performed and is explained in [10, 11, and 12]. The problem of memory requirement for user specific interleavers at the receiver and transmitter end, is also explored in [15] and a suggestion has been explained regarding use of master interleaver and tree based interleaver [30]. The space time coding in IDMA system has been performed in [16] and near optimum results has been obtained.

IDMA can be considered as a special case of conventional CDMA. In IDMA, each data stream is first encoded by a (very) low-rate encoder. Conceptionally, the same encoder can be used for each data stream (i.e., even different users use the same encoder). For convenience, each data stream is referred to as a layer. We assume that the encoder is binary; hence the layers are binary as well. Subsequently the coded bits usually referred to as chips in this context, are interleaved.

## VII. CONCLUSIONS

The novel concept of IDMA can generate some fruitful results. The common advantages of conventional DS -CDMA are maintained, since IDMA is just a special form of DS-CDMA. As a consequence, existing CDMA systems may be enhanced by IDMA as well.

Still, there are many horizons open for further improvements and testing of IDMA systems such as in interleaving scheme for memory optimization, improvement in coding schemes, automatic repeat request, synchronization issues, and in modulation schemes.

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