Efficient PLU Pre-Processing Algorithm with Adaptive Modulation and Coding For MIMO-OFDM Receiver

M.Bakyalakshmi, C.Susil Kumar

Abstract: **Modern wireless communication applications are characterized by the need for advanced signal processing techniques such as Multiple-Input Multiple-Output (MIMO) technology for achieving high throughput and diversity and Orthogonal Frequency Division Multiplexing (OFDM) for achieving robustness to multipath fading. The implementation of such techniques at the transceiver level typically involves the design of algorithms with high processing complexity.**

This paper introduces techniques that increase the throughput, reduces preprocessing delay and thereby increases the overall spectral efficiency of any wireless communication system. Generally preprocessing is done at the receiver in order to estimate the channel response. There are several preprocessing techniques such as Geometric mean decomposition (GMD), uniform channel decomposition (UCD), Singular Value Decomposition (SVD) Decomposition, and QR Decomposition. In an efficient preprocessed adaptive modulation and coding (AMC) design for MIMO–OFDM receiver systems, we propose PLU channel decomposition replacing the widely used QR decomposition. The PLU Decomposition algorithm is used to achieve a better matching of the processing rate of MIMO-OFDM receivers to the real-time processing deadlines imposed by the structure of the incoming data packets. The PLU decomposition algorithm is an attractive algorithm for MIMO-OFDM receiver because of its lower complexity, achieving the optimal operation point and it eliminates the need for buffering even for high number of antennas. Based on the Channel State Information acquired at the receiver, the AMC selector determines the modulation and coding pair for each sub carrier, which is then sent back to the transmitter. The modulation and encoding techniques for each subcarrier derived from the result of preprocessing is updated frame-by-frame to match the time-varying channel conditions, in order to take full advantage of the OFDM systems. The simulation results show that the proposed method is found to have lower computational complexity and better bit error rate performance than that of other conventional decomposition schemes.

Keywords: AMC, MIMO, OFDM, PLU, QR

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I. INTRODUCTION

THE performance of wireless communication can be drastically improved when using multiantenna transmission techniques. Specifically, multiantenna techniques can be used to increase the antenna gain and directionality (beamforming), to improve link robustness (space division coding), or to improve spectrum efficiency (space division Multiplexing).

Orthogonal frequency division multiplexing (OFDM) has fascinated a great deal of attention due to its resilience to RF interference, high spectral efficiency [1][2]. The combination of MIMO and OFDM has emerged as a promising choice for future high data rate wireless communications to achieve high capacity and high robustness without excessive complexity equalization, and thus MIMO-OFDM has been proposed for Wi-Fi, WiMax and 4G communication systems [3][4].

MIMO technology for WiFi or WiMax offers the potential to take advantage of spatial diversity in an communication channel to increase the bandwidth without sacrificing larger portions of radio spectrum [5].The general form of MIMO system consists of n_t transmit and n_r receiver antennas is shown in Fig.1

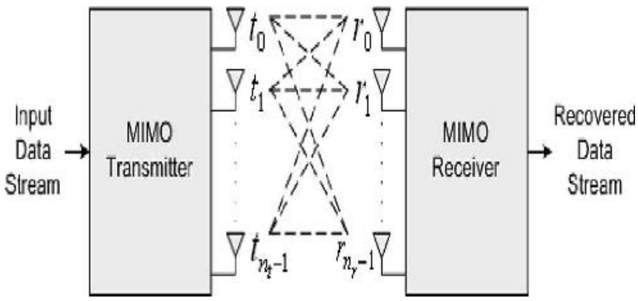


Fig.1. MIMO system overview

Among the techniques of MIMO design, MIMO channel decomposition is one of the most important essentials since it governs how a mutually independent MIMO channel is decomposed into independent and scalarized sub channel gains. The optimization of processing at the receiver is of vital importance as it can reduce the symbol processing delays and related data buffering requirements and thus reduce complexity and cost of a MIMO-OFDM receiver. The various decomposition schemes are suggested with a compromise between performance and complexity [6] [7]. Among these schemes, the most popular scheme is Singular value decomposition (SVD).

In the SVD, extremely widespread eigen values will suffer from two problems:

1. The large fading gain variation results in difficulties in coding and bit loading on each sub channel to attain the prescribed system bit error rate (BER).
2. The smallest eigen values limits the overall system performance.

The generalized Singular-value decomposition (GSVD) allows to use a single transformation for two different channels at one of the ends, but for each virtual parallel channel it yields a different gain for each user. Adapting SVD to this scenario is challenging since the decomposition requires multiplying by a channel–dependent matrix at the encoder which prevents from using this decomposition for MIMO-OFDM systems [8].The

Geometric mean decomposition and Uniform channel decomposition have these problems:

1. Both the GMD and UCD have equal sub channel gains, bringing about low BER by using constant modulation and equal power allocation.
2. Another problem of GCD and UCD is that error propagation occurs at the decoder due to imperfect channel estimates [9].

The most widely used QR-based decomposition schemes fails.

1. It requires the individual streams to be simultaneously decodable at all the receiver implies that the rate per stream is governed by the smallest of the corresponding diagonal elements.
2. The preprocessing delay for the QR decomposition is large.
3. It needs data buffering for the higher number of antennas.

The existence of large preprocessing delays has a huge impact on the performance of the system. As a result of these difficulties, we propose the PLU decomposition algorithm, which reduce the symbol processing delay and also it eliminates the need for data buffering for the higher number of antennas. The PLU decomposition with the adaptive modulation scheme increases the data transmission rate. With the fixed modulation on channels with varying signal-to-noise ratio is that bit-error-rate probability performance is changing with the channel quality. Based on the channel state information, adaptive modulation and coding will select the modulation. Thus PLU decomposition method combined with adaptive modulation and coding effectively improves the spectral efficiency.

II. System Model

We consider a spatial multiplexing MIMO-OFDM system with N_t transmit and N_r receive antennas, where Nt = Nr = N . Although Nr can be larger than Nt, we assume Nt = Nr for simple description. Then the received signal can be represented in discrete time as

$$r(k) = H(k)s(k) + n(k) \tag{1}$$

where r(k) € C^{N}_{Rx} received signal vector for OFDM subcarrier k (where C is the set of complex numbers), s(k) € L^{N}_{Tx} is the vector of modulated signals departing from the transmitter at OFDM subcarrier k (where L is the constellation corresponding to any modulation scheme such as Quadrature Amplitude Modulation), n(k) € $C^{N}_{RX}{}^{x\,N}_{TX}$ is the MIMO channel transfer function at subcarrier k that consists of the MIMO sub channels fading gains.[10].

Receiver processing for MIMO-OFDM can be viewed as sequence of computational kernels (algorithms) connected in a pipelined fashion shown in Fig.2. This model consists of computation can be adapted to the processing architecture.

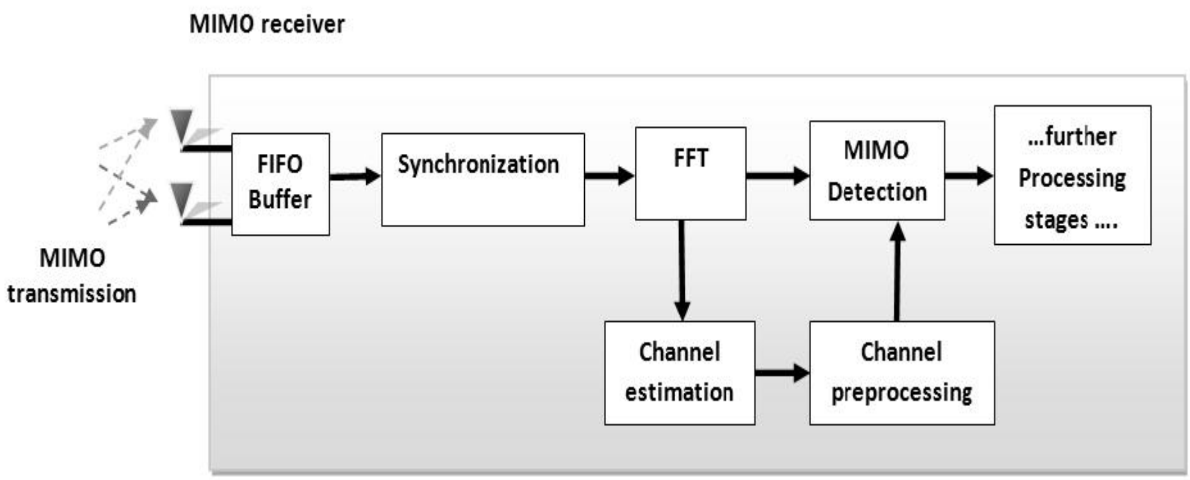


Fig. 2. Typical MIMO-OFDM receiver

The channel estimation takes place at the receiver by using the preprocessing algorithm. Here, the channel matrix **H** can be decomposed as **H = LU**, where **L** and **U** are the lower and upper $N \times N$ triangular matrices, respectively [11].

Based on the channel state information acquired at the receiver the AMC selector determines the modulation and coding pair for each sub carrier, which is then sent back to the transmitter. The modulation and encoding techniques for each subcarrier derived from the result of preprocessing is updated frame-by-frame to match the time-varying channel conditions, in order to take full advantage of the OFDM systems.

III. PROPOSED PREPROCESSING ALGORITHM

The MIMO-OFDM receiver design uses a preprocessing algorithm in the channel estimation, in order to reduce the preprocessing delay.

A. PLU Decomposition Algorithm

PLU decomposition is a key function of the linear equation required for the MIMO demodulation. In addition, once LU decomposition is performed, the inversion of any nonsingular matrix **A** can be easily obtained since $\mathbf{A}^{-1} = (\mathbf{LU})^{-1} = \mathbf{U}^{-1}\,\mathbf{L}^{-1}$. Here, the inversion of upper (or lower) triangular matrix **U** can be performed by directly solving **XU = I**, which leads to easy backward substitution [11]. The Fig 4 presents the pseudo-code for LU decomposition based on the pivoted LU LAPACK code [12]. In PLU, row permutations are not optimized because such a task is dependent on the target platform details.

The PLU pseudo-code has been arranged so that the algorithm operates on each column of the channel transfer matrix in succession (line 2: loop j).

Each iteration of j (lines 3 to 24) can be performed after the Corresponding jth column is estimated by the MIMO channel estimation process (line 2)[12].Thus PA = LU, where L is lower triangular and U is upper triangular. It is also called as PLU factorization. We propose PLU channel decomposition replacing the widely used QR decomposition to accomplish a better matching of the processing rate of MIMO-OFDM receivers[13].

The pre-processing kernel is some form of matrix factorization of H(k) such as QR- or LU-decomposition[14]. The PLU decomposition algorithm is an attractive algorithm for MIMO-OFDM receiver because of its lower complexity, achieving the optimal operation point and it eliminates the need for buffering even for high number of antennas. The AMC controller then updates the transmission mode at the transmitter shown in fig 3.Here the channel state information is obtained from the channel estimator at the receiver[15][16][17].

Receiver processing for MIMO-OFDM can be viewed as a sequence of computational kernels (algorithms) connected in a pipelined fashion. The channel estimation kernel involves estimation of the MIMO channel matrix per OFDM subcarrier[18].

In this way channel state is estimated and different modulation and coding scheme is used for different subcarriers. Then the adaptively modulated signals are then coded.

The cost of solving the linear equations is approximately 2/3 n^3 floating point operations if the matrix A has size n. This makes it twice as fast as algorithm based on the QR decomposition, which cost about 4/3 n^3 floating point operations. For this reason, the LU decomposition is preferred [19][20].

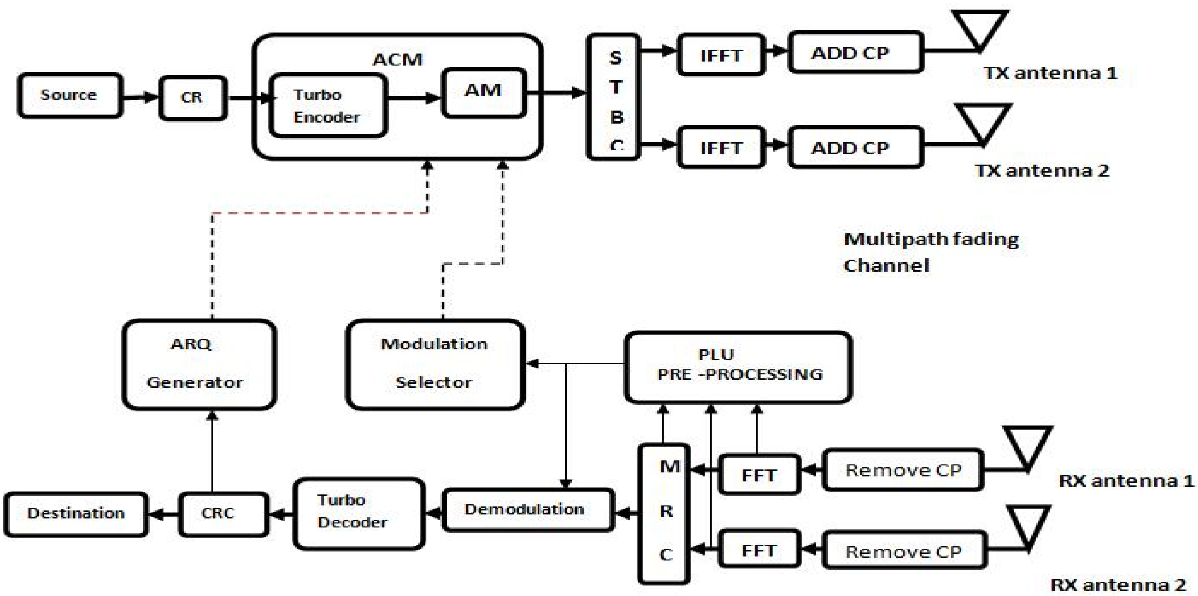


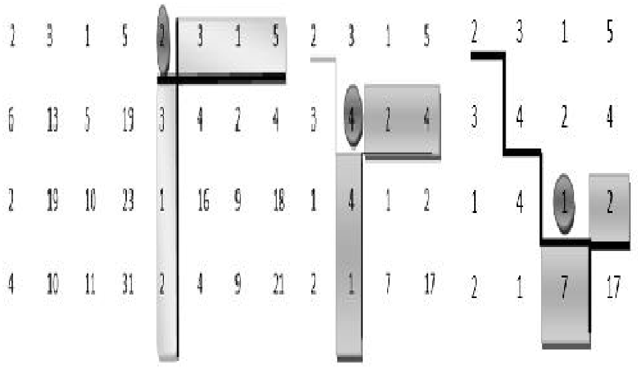
Fig 3 : Adaptive MIMO-OFDM System

PLU Algorithm (column by column pipeline design)

Outputs: in place LU decomposition A, row perm. Ipiv

```
Ipiv = [1 ⋯ min(N_RX, N_TX)]     // initialize pivot indices
   for j= 1, ⋯, min(N_RX, N_TX)
         // get j^th column from channel estimator
            a_j =h_j        //Perform accumulated (trailing sub matrix) updates
   for k=1, 2, ⋯, j-1
           exchange (a_kj , a_ipiv(k) j )
          if (k < min(N_RX, N_TX))       // undo row pivot affecting computations
         b = a_k      // avoid permuting A
        for  m= j, j-1, ⋯, k+1
           exchange  (b_m, b_ipiv(m))
         end          // perform computations
         for m= k+1, k+2, ⋯, N_RX
            a_nj = a_nj - b_n * a_kj
           end
      end
  end   // estimate row to be exchanged for current column
      for k = 1, 2, ⋯, j
          exchange(a_kj, a_ipiv(k) j)
      end     // compute elements of a_j
if (j < N_RX)
   for   m= j+1, j+2,  .., N_RX
           a_mj = a_mj / a_jj
         end
      end
end
```

Fig 4. Pseudo code for proposed PLU algorithm



$$\underset{A}{\begin{pmatrix} 2 & 3 & 1 & 5 \\ 6 & 2 & 13 & 19 \\ 2 & 19 & 10 & 23 \\ 4 & 10 & 11 & 31 \end{pmatrix}} = \underset{L}{\begin{pmatrix} 1 & 0 & 0 & 0 \\ 3 & 1 & 0 & 0 \\ 1 & 4 & 1 & 0 \\ 2 & 1 & 7 & 1 \end{pmatrix}} \underset{U}{\begin{pmatrix} 2 & 3 & 1 & 5 \\ 0 & 4 & 2 & 4 \\ 0 & 0 & 1 & 2 \\ 0 & 0 & 0 & 3 \end{pmatrix}}$$

Fig 5: Example on the PLU decomposition

IV. SIMULATION RESULTS

This algorithm is evaluated using the Network Simulator 2. An OFDM – MIMO systems with 8 transmit and receive antennas was simulated in NS2. The simulation was done with no preprocessing (using STBC codes), with QR preprocessing and with PLU preprocessing; with and without AMC.

The simulation parameters considered are

NUM_DATA _SUBCARRIER = 841
MAX_OFDM_SYMBOLS = 100
NUM_SUBCARRIERS = 1024
FFT size = 512
No of subcarrier used = 421
No of sub channel = 15
No of subcarrier per sub channel = 28
No of data subcarrier per sub channel per symbol = 24

Table 2 compares the preprocessing delays between QR and PLU decomposition algorithms. It also shows improvement in throughput since processing delay is reduced and time is utilized for data transfer.

In Fig. 6 we can observe the throughput performance for a Non-Adaptive system corresponding to each modulation type in Table 2. For simulation 1, the combination parameters are: STBC 4x2, turbo code 1/3 and QPSK modulation; the maximum throughput is 160kbps with a starting point at SNR equal to -9dB. This means that a system that uses a fixed

modulation
Scheme without preprocessing can achieve a maximum throughput of 160 kbps within a relatively low SNR range; nonetheless, if we compare it with the other systems using different modulation schemes, 160 kbps results in the lowest maximum throughput among all the systems. The highest maximum throughput among all systems is achieved using the fixed 64 QAM. Nevertheless, there is a price to pay since the system uses a fixed 64 QAM, it must guarantee sufficient SNR in order for it to operate properly. On the other hand, the throughput performance of the AMC System, shown in fig. 7, increases gradually because the MIMO scheme, the channel coding, and the modulation scheme change with the increase of the SNR. This improvement in the trade-off between SNR and throughput leads to a better average data

Index	Mod	Rate	n=Rep	J	Data Block size (bytes)	Encoded data block size (bytes) = 48*n*M/B	Beta Ped-B (dB)	Beta veh-A (dB)
1	**QPSK**	1/2	1	10	6	12	2.46	2.54
2	**QPSK**	1/2	2	10	12	24	2.28	2.26
3	**QPSK**	1/2	3	10	18	36	2.27	2.26
4	**QPSK**	1/2	4	10	24	48	2.18	2.12
5	**QPSK**	1/2	5	10	30	60	2.05	2.07
6	**QPSK**	1/2	6	10	48	72	2.00	2.06
7	**QPSK**	1/2	8	10	54	96	2.03	2.02
8	**QPSK**	**1/2**	9	10	60	108	2.04	2.01
9	**QPSK**	**3/4**	1	6	9	12	2.56	2.50
10	**QPSK**	**3/4**	2	6	18	24	2.43	2.43
11	**QPSK**	**3/4**	3	6	27	36	2.46	2.44
12	**QPSK**	**3/4**	4	6	36	48	2.41	2.39
13	**QPSK**	**3/4**	5	6	45	60	2.41	2.41
14	**16-QAM**	**1/2**	1	5	12	24	7.45	7.48
15	**16-QAM**	**1/2**	2	5	24	48	7.14	7.14
16	**16-QAM**	**1/2**	3	5	36	72	7.00	6.92
17	**16-QAM**	**3/4**	1	3	18	24	8.93	8.93
18	**16-QAM**	**3/4**	2	3	36	48	8.87	8.87
19	**16-QAM**	**3/4**	3	3	54	72	8.85	8.90
20	**64-QAM**	**1/2**	1	3	18	36	11.31	11.43
21	**64-QAM**	**1/2**	2	3	36	72	11.11	11.16
22	**64-QAM**	**3/4**	1	2	27	36	14.71	14.68
23	**64-QAM**	**3/4**	2	2	54	72	14.59	14.55
24	**64-QAM**	**5/6**	1	2	30	36	14.71	14.68
25	**64-QA,**	**5/6**	2	2	60	72	15.29	15.27

Table 1: EESM Beta Values for Different modulation Technique

SNR necessary to guarantee such a maximum throughput is the highest among all the systems; about 5dB. Therefore, if a rate.

MIMO Preprocessing Scheme	Code rate	Modulation	Average Throughput	Preprocessing Delay
STBC 4x2	1/3	QPSK	160 Kbps	NA
QR	1/3	QPSK	320 Kbps	2.34 ms
PLU	1/3	QPSK	445 Kbps	1.68 ms
QR	1/2	QPSK	480 Kbps	2.34 ms
PLU	1/2	QPSK	666 Kbps	1.68 ms
QR	1/3	16 QAM	680 Kbps	2.34 ms
PLU	1/3	16 QAM	944 Kbps	1.68 ms
QR	1/2	16 QAM	960 Kbps	2.34 ms
PLU	1/2	16 QAM	1280 Kbps	1.68 ms
QR	1/2	64 QAM	1440 Kbps	2.34 ms
PLU	1/2	64 QAM	1536 Kbps	1.68 ms

Table 2: Comparison of throughput and preprocessing delay between QR and PLU with AMC

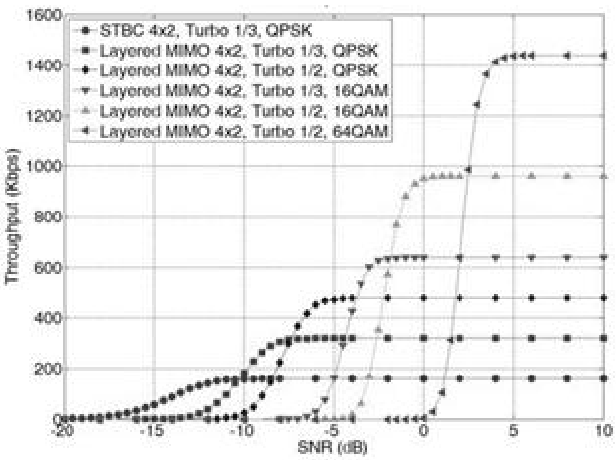


Fig 6: SNR vs Throughput (Fixed modulation)

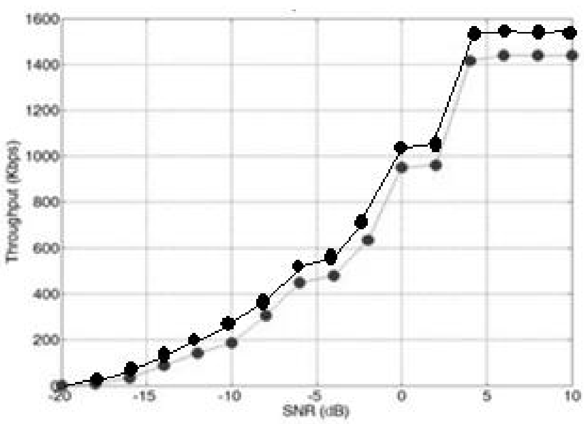


Fig 7: SNR vs Throughput (Adaptive modulation and coding with QR preprocessing and PLU processing)

V. CONCLUSION

In this paper, we proposed a system that combines AMC and MIMO schemes with PLU preprocessing method. The PLU preprocessing method improves the throughput of a MIMO – OFDM system by reducing the preprocessing delay, especially for large number of antennas. This, combined with adaptive modulation and coding, effectively improves the spectral efficiency.

REFERENCES

[1] R. van Nee et al., New high-rate wireless LAN standards, IEEE Commun. Mag.(1999) .

[2] G. Stuber, J. Barry, S. McLaughlin, Y. Li, M. Ingram, T. Pratt, Broadband MIMO_OFDM wireless communications, Proceedings of the IEEE 92 (2004) 271_294.

[3] G.L. Stuber, Broadband MIMO–OFDM wireless communications, Proc. IEEE (2004) 271–294.

[4] G.Foschini, "Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas."Bell Lab .Tech.J.pp.41-59,1996.

[5] R. U. Nanbar, H. Bolcskei and A. J. Paulraj, "Transmit optimization for spatial multiplexing in the presence of spatial fading correlation," *Proc.IEEE GLOBECOM, vol. 1, pp.131-135,2001*.

[6] J. K. Zhang, A. Kavi and K.M. Wong ,"Equal-diagonal QR decomposition and its application to precoder design for successive-cancellation detection," IEEE Trans. Inf. Theory, vol. 51,no. 1, pp. 154-172, 2005.

[7] Decomposing the MIMO Broadcast channel.

[8] Y. Jiang, J. Li and W. Hager, "Uniform channel decomposition for MIMO communication" *IEEE Trans. Signal Process., Vol. 53, no.10, pp. 3791-3803,2005.*

[9] D. Skraparlis, J.D. Kanellopoulos, "Design of preprocessing algorithm for efficient MIMO-OFDM receiver architectures", Physical Communication, 3, (2010), 37-47.

[10] T. H. Cormen, C. E. Leiserson, and R.L. Rivest, Introduction to Algorithms, 2nd ed. Cambridge, MA : MIT Press, 2001.

[11] Ji-Woong Choi, Byung Gueon Min and Jongsun Park, "Energy Efficient Hardware Architecture of LU Triangularization for MIMO Receiver", *IEEE Trans. Vol, 37, no. 8. 2010.*

[12] WiMAX Forum, System Evaluation Methodology Document, version1.7, Sept. 7, 2007.

[13] E. Anderson, Z. Bai, C. Bischof, S. Blackford, J. Demmel, J. Dongarra, J. DuCroz, A.Greenbaum, S. Hammarling, A. McKenny, D.Sorensen, LAPACK Users' Guide, Society for Industrial and applied Mathematics,1999.

[14] S. Chen, B. Mulgrew, and P. M. Grant, "A clustering technique for digital communications channel equalization using radial basis function networks," *IEEE Trans. Neural Networks*, vol. 4, pp. 570–578, July 1993.

[15] V. Tarokh, H. Jafarkhani, A.R. Calderbank, Space-time block coding for wireless communications: performance results, IEEE J. Select Areas Commun. 17 (1999), 451–460.

[16] S.T. Chung, A. Goldsmith, Adaptive multicarrier modulation for wireless systems, in: Asilomar Conference on Signals, Systems and Computers,November 2000.

[17] A. Pandharipande, Adaptive modulation for MIMO–OFDM systems, in: VTC Fall, 2004.

[18] Qingwen Liu, Shengli Zhou, Cross-layer combining of adaptive modulation and coding with truncated ARQ over wireless links, IEEE Trans. Wireless Commun. 3 (5) (2004) 1746–1755.
[19] http://en.wikipedia.org/wiki/LU_decomposition.
[20] G.w. Stewart, The decompositional approach to matrix computation,IEEE Educational Activities Department 2 (2000) 50_59. November 2000.

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