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IRREGULAR REPETITION CODE HYBRID ARQ IN WIRELESS SYSTEM

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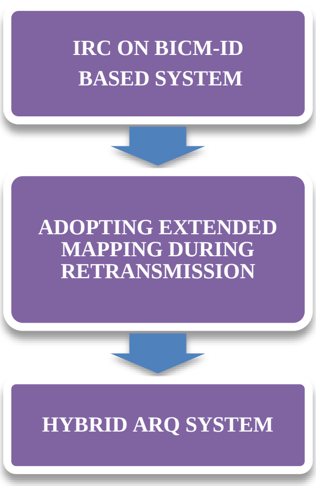
Graphical abstract



Abstract

Error control consists of error detection and error correction in the communication system. The purpose of this research work is to reduce error in the wireless communication system by using the advantages of both error correction techniques which are forward error correction (FEC) and automatic repeat request (ARQ). Thus, error can be corrected without retransmission and also via retransmission(s) when needed. Combination of FEC and ARQ is known as Hybrid ARQ. In this paper, Hybrid ARQ system is designed using three components which are the irregular repetition code (IRC) as a simple code, bit-interleaved coded modulation with iterative decoding (BICM-ID) as a simple Turbo processing and ARQ. The HARQ system is enhanced by the extended mapping (EM) adopted in the mapping system. The performance of the systems is evaluated in the additive white Gaussian noise (AWGN). The results show the Hybrid ARQ with extended mapping (Hybrid ARQ-EM) outperforms Hybrid ARQ with standard mapping (Hybrid ARQ-SM). Hybrid ARQ-EM achieves low bit error rate BER (10^{-5}) at low signal-to-noise ratio SNR which only 3.03dB close to the theoretical limit. The proposed system Hybrid ARQ-EM achieves 52 percent gain enhancement of SNR gap from the theoretical limit compared to Hybrid ARQ-SM. Hybrid ARQ-EM gives better performance although in worse channel condition.

Keywords: Hybrid ARQ, turbo process, extended mapping, BICM-ID

1.0 INTRODUCTION

Hybrid ARQ systems have been widely used in various wireless communications systems including 3G, Long Term Evolution (LTE) and/or Worldwide Interoperability for Microwave Access (WIMAX) systems [1]. In Fifth Generation (5G), capability of Hybrid ARQ of improving the transmission system was studied in [2]. Hybrid ARQ compromises of error control coding and ARQ scheme. The combination improves the recovering of the corrupted information bits during transmission with FEC scheme, while ARQ schemes send the feedback information to the transmitter if error cannot be corrected. It can increase the reliability in the transmission system where the enhancement of retransmission system performance shows the space for improvement.

Several methods have been used to enhance the Hybrid ARQ system performance using various error correcting code [3], then vary the modulation or mapping technique in [4]-[5] and type of equalizer [6].

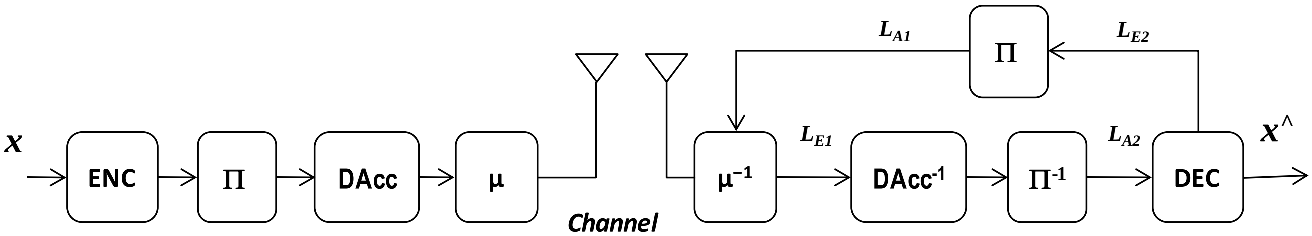


Figure 1 The proposed Hybrid ARQ based IRC with BICM-ID system model

In term of FEC, many researchers mostly used convolutional code as error correcting code in the transmission system [7]-[9]. Convolutional code efficiency in error control mechanism is formerly known for error correction and thus, it has been used in Turbo code development [10]. The efficient of concatenated convolutional code make the transmission system achieves near to theShannoncapacity. It builds a strongcodesthat have a random long enough to perform as a good error control mechanism [11]-[13].

Instead of the concatenated codes applied in Turbo code to gain the high performance, a simple Turbo process is introduced by Tuchler as stated in [14]. A BICM-ID system reduces the complexity of Turbo processing in Turbo code. BICM-ID based system is widely used by researchers as in [15]-[18]. Various coding can be implemented in BICM-ID based system such as convolutional code, Reed Solomon code and also the simplest code; repetition code. In [19]-[20], they found that the simple code of irregular repetition code (IRC) with simple Turbo processing gives good result to achieve Turbo-like performances.

This paper proposed Hybrid ARQsystem considering the combination of BICM-ID with extended mapping. In the BICM-ID, IRC will be applied because it has low complexity coding compared to convolutional code. Then, the system is enhanced with the ARQ scheme if error cannot be corrected by error correcting code. In addition, Doped-Accumulator (DAcc) is implemented to eliminate error floor in the system [21], hence the spectrum efficiency can be improved.

This paper is organised as follows. In Section 2, the general description of the proposed system models which BICM-ID and Hybrid ARQ scheme are presented and some of its characteristics are discussed in order to improve the FEC method. Section 3 presents numerical results and comparisons with simulations using Matlab software where two analyses have been done which are EXtrinsic Information Transfer (EXIT) chart and BER analysis. The simulation results investigate the BER performances for several cases in different technique which are BICM-ID with/without retransmission, different modulation and mapping technique and also the effect of doped-accumulator to the system design. Section 4concludes the paper.

2.0 THE PROPOSED HYBRID ARQ

2.1 IRC with BICM-ID Based System

The hybrid ARQ system proposed in this paper is applied IRC based on BCM-ID system. Iterative decoding process is the heart of BICM-ID system and it plays an important role in turbo process. During the iterative process, some parameters can raise to infinity unless there is a concern in the decoding algorithm. Limitations imposed on these parameters give worse effects on the BER performance especially at high noise environment. Hence, the optimum performance of BICM-ID can be achieved by considering the component codes, the interleaver design and the number of decoding iterations [13].

Figure 1 shows the proposed transceiver system with DAccoptimization for Hybrid ARQ system model. The information bit is encoded by IRC encoder (ENC) for repetition times, $d_v$which take different values in one block of information. In case of irregular degree allocation, the repetition time, d_{vi} and degree distribution a_i(i.e. a ratio value to the total length of the block) have to be considered. The length of IRC coded block is given as [20],

$$K = \sum_i a_i \, d_{vi} \times N \qquad (1)$$

which is equal to the random interleaver length, where $N$is the information length and i index represents the number of divided length.

The encoded information is bit interleaved by π and doped accumulated before it mapped the information at the mapper μ. In this paper, extended mapping technique is applied during retransmission process. Then the modulated signal transmitted to the AWGN channel and the discrete time of the received signal $y(q)$ is expressed as

$$y(q) = x(q) + n(q) \quad (2)$$

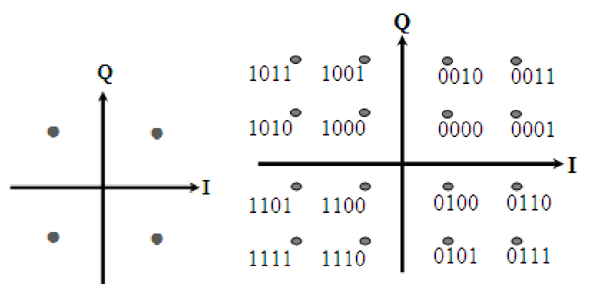
where$q$is the symbol timing index, $x(q)$ is the transmitted modulated signal and $n(q)$ is the zero mean complex AWGN component with variance,σ_N^2. At the receiver part, the received signal goes to demapperμ^{-1}.For initial process, there is no *a priori* LLR from decoder is assumed. The extrinsic log likelihood ratio (LLR) of demapperL_{E1} is deinterleved and forwarded to IRC decoder as *apriori*LLRL_{A2}.For the d_{vi}bits connected to a variable node, the extrinsic LLR is updated by summing up the LLR for the $(d_{vi}-1)$bits to produce extrinsic LLR of the *j*-th IRC coded bit as [20],

$$L_{E2}(j) = \sum_{J=1,J\neq j}^{d_{vi}} L_{A2}(J) \qquad (3)$$

The extrinsic LLR of decoder $L_{E2}$is feed back to the demapper by passing through interleaver as *apriori*LLR L_{A1}. The process is repeated until the iteration is set to discontinue when no more relevant gains in *extrinsic* LLR can be achieved. After that, the decoder makes the decision based on the *a posteriori* information when no more improvement value of mutual information and the iterative process is then terminated.The decoded signal x^ is measured for BER performance.

2.2 Extended Mapping

The implementation of standard mapping technique in huge data transmission system required higher order modulationto utilize the bandwidth more efficiently by increasing the number of bit and labeling pattern. Figure 2(a) depicts the constellation point coordinate structure for 4-Quardrature Amplitude Modulation (QAM) and Figure 2(b) shows that number of labeling pattern is increased for 16-QAM. However, the consequence of increasing the number of constellation point resulting to poor BER performance due to higher noise level.



(a) 4-QAM **(b)** 16-QAM

Figure 2 Standard mapping diagram

Extended mapping is introduced to employ higher order modulation with the minimum number of constellation point for the purpose of reducing the error rate in the mapping process [22]-[23].The technique provides higher possibility to enhance the detection scheme in the system where the possibility of error can be corrected is higher [24]-[25].In extended mapping, error can be reduced once it maintains the same constellation point with more than a symbol. For extended mapping with 2^M-QAM, there are $l_{map} = 2^M$ bits allocated to one signal point in the constellation.

Figure 3 shows an extended mapping of 4-QAM with l_{map}=4 whereit is 2-bits extended of 4-QAM with 4-bits assignment. Therefore, there are 16 patterns; each constellation point has four labeling patterns. The coded bit sequence is bit interleaved, and segmented into l_{map}bit segments, and then each segment is mapped on to one of the 2^Mconstellation points for modulation. Since l_{map}>M with extended mapping, more than one labels having different bit patterns in the segment are mapped on to each constellation point.

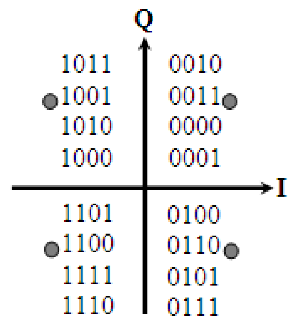


Figure 3 Extended Mapping 4-QAM (2-bits extended)

The spectrum efficiency, R for the IRC code using extended mapping can be expressed as [20];

$$R = \frac{l_{map}}{\sum_i (a_i \cdot d_{vi})} \qquad (4)$$

where$l_{map}$is referred as the index number of mapping technique. It is shown that higher spectrum efficiency can be achieved when extended mapping technique is applied in BICM-ID based system [24].For the demapping purpose,the demapper calculates the extrinsic LLR of the bit $x(q)$from the received signal y by

$$L_{E,dem}((y(q)|x_w(q)) = \ln \frac{\sum_{v=1,v\neq w}^{m} \Pr(y(q)|x_w(q)=+1)}{\sum_{v=1,v\neq w}^{m} \Pr(y(q)|x_w(q)=-1)}, \qquad (5)$$

where it can be simplified into

$$L_{E,dem}[y(x_w(q)] = \ln \frac{\sum_{s\epsilon S_0} \exp\left\{\frac{-|y-s|^2}{\sigma_N^2}\right\} \prod_{v=1,v\neq w}^{l_{map}} \exp(-x_v(s) L_{A,dem}(x_v(s)))}{\sum_{s\epsilon S_1} \exp\left\{\frac{-|y-s|^2}{\sigma_N^2}\right\} \prod_{v=1,v\neq w}^{l_{map}} \exp(-x_v(s) L_{A,dem}(x_v(s)))} \qquad (6)$$

in whichs_0, s_1 indicates the set of labels in mapping symbol having bit $x_w(q)$being 0 and 1, respectively. $L_{A,dem}(x_v[s])$is the *a priori* LLR fed back from the decoder corresponding to the *v*-th bit position in the labelallocated to the signal point *s*.

2.3 Hybrid ARQ

Hybrid ARQ is a system that combines the FEC and ARQ in one transmission system. Hybrid ARQ is categorized in two types which are Hybrid ARQ Type-

I or known as chase combining and Hybrid ARQ Type-II formerly as incremental redundancy method. Many researchers consider integrating BICM-ID to achieve high performance of hybrid ARQ system [26]-[27]. The transceiver with ARQ system design may operates with FEC and then repeats the transmission for error transmitted block received after negative acknowledgment sent in the error control scheme.

In this paper, the proposed Type-I hybrid ARQ system is design concatenated with extended mapping during the retransmission part as shown in Figure 4. Implementation of extended mapping is expected to reduce error in the conventional method of retransmission system. The receiver uses maximum-ratio combining to combine the received bits with the same bits from previous transmissions. Since all transmissions are identical, chase combining can be seen as additional repetition coding.

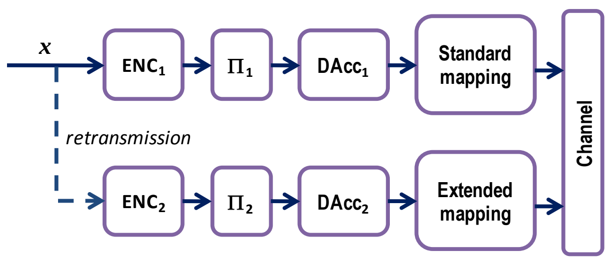


Figure 4 The Proposed HYBRID ARQ extended mapping system

The proposed HYBRID ARQ retransmits the information and uses the mutual information LLR value of both received blocks to update and exchange the mutual information received.The retransmission will be requested and pass to transmitterwhen negative acknowledgment (NACK) is indicated. In this work, the system stores the transmitted information, so that the new mapping scheme is repeated in the retransmission process. Standard mapping is replaced by the extended mapping scheme while retransmission is requested.

3.0 RESULTS AND DISCUSSION

The analysis of the proposed system is simulated based on Figure 1 with MATLAB software for AWGN channel. We assumed IRC with the node degree distribution $d_{v1} = 8\ (a_1 = 0.65)$and $d_{v2} = 3\ (a_1 = 0.35)$, and extended mapping with $l_{map}=4$. DAcc with doping ratio, *P=20* is considered in the performance analysis. The performance is evaluated and compared between standard mapping and extended mapping using EXIT chart and BER analysis. EXIT chat analysis is applied to analyze the matching between decoder and demapper[28]-[30].The simulation parameters are also summarized in Table 1.

Table 1 Parameter design for Hybrid ARQ system

No.	Parameter / Performance metrics	
1	Channel	AWGN
2	Mapping	Standard: 4-QAM, 16-QAM Extended: EM 4-QAM
3	Frame Length	10,000 bits
4	Doping Ratio	*P=20*
5	Coding	IRC : Degree distribution:(a_1=0.65a_2=0.35) Repetition time : (dv_1=8dv_2=3)
6	Interleaver	Random Interleaver
7	ARQ	Stop-n-Wait

Figure 5 shows the EXIT chart analysis for IRC with demapper curve for standard mapping and extended mapping technique without the DAcc. We can see that, EM 4-QAM intersect at the nearest of (1.0,1.0) point compare to standard mapping which means that better error rate performance is achieved. Although higher iteration is required to achieve the lowest BER, the error floor still cannot be avoided at this point.

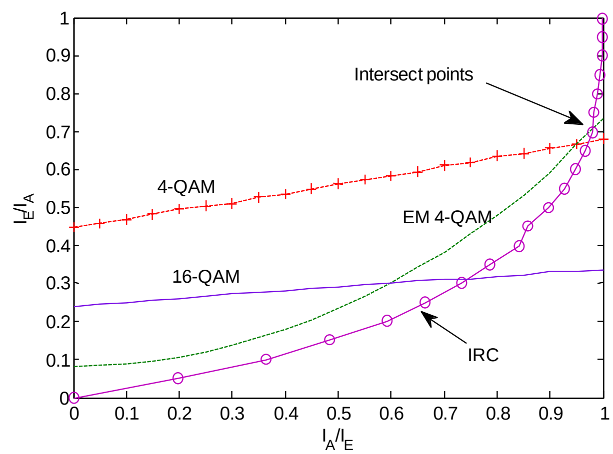


Figure 5 EXIT curves for different mapping technique without DAcc at SNR = 0.5 dB

Figure 6 shows the EXIT chart analysis for IRC with demapper curve for standard mapping and extended mapping technique with the DAcc when *P=20*to overcome the error floor problem. It is clearly shows that with DAcc, all the ending point is pushed to the mutual information of(1.0,1.0) point. IRC is well matched with EM 4-QAM compared to standard mapping where sharper BER cliff is expected at SNR= 0.5 dB.

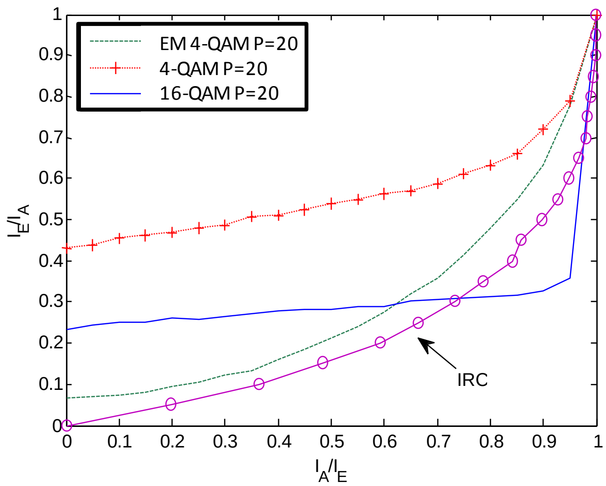


Figure 6 EXIT curves for different mapping technique with DAcc

Figure 7 shows BER performance of Hybrid ARQ-EM and Hybrid ARQ-SM. For the Hybrid ARQ-SM system, 16-QAM mapping is used. Meanwhile, EM4-QAM is used when decoder send NACK to retransmit the information inHybrid ARQ-EM. Both transmissions usingDAcc with doping rate *P=20*. It shows that retransmission using EM 4-QAM improves the BER performanceby 3.5dB SNR gain compared to 16-QAM. It is well matched with the EXIT chart in Figure 6 where BER cliff of EM 4-QAM occurred at 0.5dB.

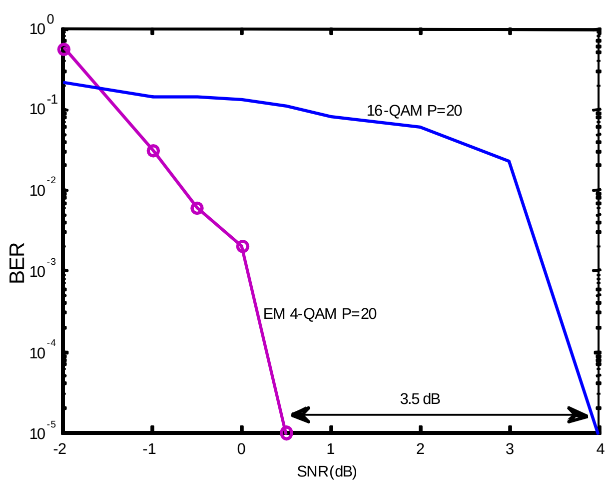


Figure 7 BER of HYBRID ARQs with DAcc

Table 2tabulates the BER performance for both Hybrid ARQ systems referring to the theoretical limit of Shannon capacity. Theoretical limit in decibel of IRC is at -2.53 dB using equation (4) and followed by equation (7);

$$SNR\_\{lim\} = 10 \log (2^R - 1) \quad (7)$$

Table 2 BER performances

Hybrid ARQ with DAcc	Turbo Cliff (dB)	Theoretical limit (dB)	SNR Gain (dB)
EM4-QAM	0.5	-2.53	3.03
16-QAM	4.0	-2.53	6.53

For this system, EM4-QAM obtains 3.03 dB away from the limit and the Turbo Cliff occurred at 0.5 dB. System with 16-QAM shows a major SNR gains around 6.53 dB from the limit at BER 10^{-5}. As a result, the use of EM4-QAM during retransmission is significant to achieve system close to the Shannon limit and hence, higher spectrum efficiency can be achieved.

4.0 CONCLUSIONS

In this paper, IRC with BICM-ID based for Hybrid ARQ system has been proposed. It has been shown that the Performance of Hybrid ARQ-EM system outperforms the Hybrid ARQ-SM system.The application of extended mapping technique at the retransmission process improves the Hybrid ARQ system performance. As a result, the proposed technique provides better BER performance where the SNR gain only 3.03 dB from the theoretical limit compared to system that using standard mapping technique. The proposed design describes the benefit of integration using extended mapping in retransmission scheme for Hybrid ARQ. Errors occur in the proposed system can be reduced and removed in higher percentage which achieves 52 % improvement of spectrum efficiency.

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References

[1] DahlmanE., Parkvall S., Skold J., and Beming P. 2008. 3G *Evolution- HSPA and LTE for Mobile Broadband,* 2nd ed., Academic Press.

[2] Sarret, M. G., Catania D., Frederiksen F., Cattoni A.F.,Berardinelli G. and Mogensen, P. 2014. Improving Link Robustness In 5G Ultra-Dense Small Cells By Hybrid ARQ. *Wireless Communications Systems (ISWCS), 2014 11th International Symposium.* 491-495.

[3] Cao L. and Shi T. 2004. Turbo Codes Based Hybrid ARQ With Segment Selective Repeat. *Electronics Letters*. 40(18): 1140-1141.

[4] SchreckenbachF., G¨ortzN., Hagenauer J., and Bauch G. 2003. Optimization Of Symbol Mappings For Bit-Interleaved Coded Modulation With Iterative Decoding. *IEEE Commun. Lett.* 7(12): 593–595.

[5] SzczecinskiL., DiopF.-K., BenjillaliM., CeronA., and FeickR. 2007. BICM in HARQ with Mapping Rearrangement: Capacity and Performance of Practical Schemes. *IEEE GLOBECOM'07*, Washington DC, USA.

[6] YeapBee L., HooiLiew T., Hámorský J., and Hanzo L. *2002. Comparative Study of Turbo Equalization Schemes Using Convolutional, Convolutional Turbo, and Block-Turbo Codes,* IEEE Transactions On Wireless Communications. 1(2).

[7] Hazilah Mad Kaidi, Muhammad Ibrahim 2011. Hybrid ARQ Type I Based on Convolutional Code. Jurnal Teknologi. 54(1): 45-54.

[8] Falahati, S., Ottosson, T., Svensson, A., Lin Zihuai, 1999. Convolutional coding and decoding in hybrid type-II ARQ schemes on wireless channels. *Vehicular Technology Conference, 1999 IEEE 49th*. 3(3): 2219-2224.

[9] Qingchun Chen, Wai-Ho Mow, Pingzhi Fan. 2006. Some New Results on Recursive Convolutional Codes and Their Applications.*Information Theory Workshop, 2006. ITW '06 Chengdu. IEEE*. 239-243.

[10] Berrou, C., Glavieux, A.,Thitimajshima, P. 1993. *Near Shannon limit error-correcting coding and decoding: Turbo-codes. 1*. Communications, 1993. ICC '93 Geneva. Technical Program, Conference Record, IEEE International Conference. 1064-1070.

[11] Breddermann, T.,Eschbach, B., Vary, P. 2012. Hybrid ARQ scheme for UMTS LTE based on insertion convolutional turbo codes.*Personal Indoor and Mobile Radio Communications (PIMRC), 2012 IEEE 23rd International Symposium*. 1919-1924.

[12] Al-Shaikhi, A., Ilow, J., Xin Liao. 2007. An Adaptive FEC-based Packet Loss Recovery Scheme Using RZ Turbo Codes," *Communication Networks and Services Research, 2007. CNSR '07. Fifth Annual Conference*. 263-267.

[13] Sripimanwat, Keattisak. 2005. *Turbo Code Applications*. 1. Dordrecht: Springer.

[14] Tüchler, M.; Koetter, R., Singer, AC. 2002. Turbo Equalization: Principles And New Results," *Communications, IEEE Transactions.* 50(5): 754-767.

[15] Zhang Shuai, Li Jianping and Chen Jinlun. 2010. Three Simple Iterative Decoding Schemes for BICM-ID,.*Biomedical Engineering and Computer Science (ICBECS), 2010 International Conference.* 1-4.

[16] QinghuaJia; Yongsang Kim; Changkyu Seol; KyungwhoonCheun. 2009. Improving The Performance of SM-MIMO/BICM-ID Systems with LLR Distribution Matching," *Communications, IEEE Transactions on* 57(11): 3239-3243.

[17] Dan Zhao, Axel Dauch, and Tad Matsumoto. 2010. Modulation Doping for Repetition Coded BICM-ID with Irregular Degree Allocation, *Smart Antennas (WSA), 2010 International ITG Workshop*. 312-318.

[18] Qi, X., Zhao, M., Zhou, S. and Wang, J. 2005. Multidimensional modulation used in BICM-ID. *Electronics Letters*. 41(3): 140-142.

[19] Fukawa, K., Ormsub, S., Tölli, A., Anwar, K., and Matsumoto, T. 2012. EXIT-constrained BICM-ID design using extended mapping. *EURASIP Journal on Wireless Communications and Networking.* (1): 1-17.

[20] Anwar, Khoirul, and Tad Matsumoto. 2012. Very Simple BICM-ID Using Repetition Code And Extended Mapping With Doped Accumulator. *Wireless Personal Communications.* 67(3): 573-584.

[21] Pfletschinger, S., and Sanzi, F. 2006. Error Floor Removal for Bit-Interleaved Coded Modulation with Iterative Detection.*Wireless Communications, IEEE Transactions on* 5(11): 3174-3181.

[22] HenkelP. 2006. Extended Mappings For Bit-Interleaved Coded Modulation. In *Personal, Indoor and Mobile Radio Communications, 2006 IEEE 17th International Symposium. 1-4.*

[23] HenkelP. 2007. Doping Of Extended Mappings For Signal Shaping. In *Vehicular Technology Conference, 2007. VTC2007-Spring. IEEE 65:* 1851 –1855.

[24] D. Zhao, A. Dauch, and T. Matsumoto. 2009. BICM-ID Using Extended Mapping and Repetition Code with Irregular Node Degree Allocation. In *Vehicular Technology Conference, 2009. VTC Spring 2009. IEEE 69:* 1–5.

[25] Fukawa K., Dan Zhao, Tolli A, and Matsumoto T. 2010. Irregular Repetition And Single Parity Check Coded BICM-ID Using Extended Mapping -Optimal Node Degree Allocation-.*Communications and Networking in China (CHINACOM), 2010 5th International ICST Conference*.1-6.

[26] J. Roberson and Z. Ding. 2006. A BICM approach to type II Hybrid ARQ", *IEEE International conference ICASSP*.

[27] Deng R.-H.,and Lin, M.L. 1995. A type I hybrid ARQ System With Adaptive Code Rates. *Communications, IEEE Transactions on* 43(2/3/4): 733-737.

[28] BrannstromF. 2004. Convergence Analysis And Design Of Multiple Concatenated Codes. Ph.D. Dissertation, Chalmers University of Technology, Sweeden.

[29] Ten Brink, S. 2001. Convergence Behavior Of Iteratively Decoded Parallel Concatenated Codes. *Communications, IEEE Transactions.* 49(10): 1727-1737.

[30] HagenauerJ. 2004. The Exit Chart - Introduction To Extrinsic Information Transfer In Iterative Processing. *Proc. 12th Europ.Signal Proc. Conf (EUSIPCO)*. 1541–1548.