An Enhanced Feasible Adaptive Scheduling Algorithm for 3GPP LTE-Advanced System

Jian Liu, Xinxin Tan, Ci Huang, and Xin Ji
School of Computer & Communication Engineering, University of Science and Technology Beijing, Beijing 100083, China
Email: jianliusdu@gmail.com; {jennytanxx, cihuang1225, jixino1}@163.com

Abstract —The Third Generation Partnership Project (3GPP) initially defined Release-8 as the first standard of the Long Term Evolution (LTE), a novel high-speed all-IP wireless access technology for mobile communication system using OFDMA and MIMO as native technologies. However, even this high-speed technology was found incapable of meeting true IMT-Advanced 4G requirements. As such, Release-10 Release-11 and Release-12, which is known as LTE-Advanced, was released to achieve this target with further improvements while maintaining backward compatibility with Release-8. The main contribution of this paper is to undergo some thorough research on the key technologies of the adaptive LTE-A system based on 3GPP LTE-A physical layer specifications, and then give the adaptive system performance simulation and analysis. Specifically, in the design scheme of the adaptive LTE-A system, more research about adaptive modulation and coding has been given, which includes a new rate matching algorithm based on circularly selecting and interlaced puncturing as well as a different antenna mechanism based on adaptive scheduling solution in order to enhance the system performance. Simulation results indicate that the system with the improved adaptive schemes has better performance which could also prove the design of the adaptive system is accurate and reasonable.

Index Terms—LTE-A, rate matching, AMC, antenna scheduling

I. Introduction

The LTE (Long Term Evolution) system introduced some new and unique characteristics befitting of a new generation wireless communication system to the extent. It was seen as the “Quasi 4G” technology [1]. LTE networks have been deployed globally as natural evolutions of 3G (3rd-Generation) systems. LTE-A (LTE-Advanced) as a major enhancement of the LTE standard is just around the corner. Its purpose is to meet the higher demand for wireless communications market and additional applications within the next few years. LTE-A adopts Carrier Aggregation (CA), Enhanced UL/DL MIMO (Uplink/Downlink Multiple-Input Multiple-Output), Coordinated Multi-point Transmission & Reception (CoMP), Relay, Enhanced Inter-cell Interference Coordination for Heterogeneous Network (HetNet) and other key technologies, in order to greatly increase the peak data rate, the peak spectral efficiency, cell average spectral efficiency and performance for cell edge users in wireless communication systems, and improve network efficiency of the entire network simultaneously. Adaptive Modulation and Coding (AMC) [2] which is adopted by LTE to further improve system performance is maintained by LTE-A.

In the design procedure of the adaptive LTE-A system, a Rate Matching (RM) [3] algorithm means that bits in transmission channel are repeated or punctured to match the carrying capacity of the physical channel. The carrying capacity is determined by CQI in AMC, therefore, RM algorithm is of great importance in the adaptive system performance. Traditionally, RM mode includes: based on filling bit and based on tail bit. RM based on filling bit has good performance, but the operation is complex and not easy to achieve, RM based on tail bit is simple, but the performance is not that good. In this paper, we propose a new RM algorithm which is on the basis of circularly selecting and interlaced puncturing, and it will be useful for 3GPP (The Third Generation Partnership Project) LTE-A system with better performance and lower complexity. In our algorithm, firstly, we carry out the system-parity information bit stream interleaved merging method for bits collection. Thereafter, regarding combined bit stream, we add or delete corresponding number of bits by cyclic filling or interleaving punch to achieve the coding rate required. Simulation results yield improved BER performance with this novel RM algorithm.

It should be recalled that for the conventional adaptive controller, they mainly concentrate on the control of coding and modulation scheme (MCS). Whereas, in this paper, besides MCS, we introduce the control of the antenna modes to the proposed adaptive system, as smart antennas can enhance performance of wireless communications [4]. The AMC firstly gets the antenna scheduling coefficient through the analysis of the different channel states, and then chooses the suitable antenna mode at the antenna module for transmission. The simulation results indicate that the suggested antenna schedule scheme can enhance the system flexibility without negatively affecting system performance.

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The rest of the paper is structured as follows: The second part describes the architecture of adaptive LTE-A system. In the Part III, the interlaced-puncturing RM algorithm for adaptive system is discussed. Part IV discusses the feasible antenna schedule algorithm in the presented system. Part V shows the simulation results of the novel RM algorithm and the antenna scheme. At last, conclusion remarks are presented in Part VI.

II. SYSTEM MODEL

The model of the adaptive LTE-A system is shown in Fig. 1. The system model includes two parts: a transmitter and a receiver. The transmitter is composed of adaptive module, coding and modulation modules and the multi-antenna module. The information from the Media Access Control (MAC) layer is firstly divided into several transmission blocks (TB) in order to adapt to the different coding modulation modes. Each transmission block needs to take the rate matching process after turbo encoding, and then the codes change to symbols through the data mapping and modulation modules, which is under the control of the AMC by a Channel Quality Indicator (CQI). In [5], it can be observed how CQI delays affect the cell throughput. The symbols after modulation will be sent to different antenna ports, and the specific antenna transmission mode is decided by antenna scheduling algorithm through AMC. Finally, the signals will be converted to analog signals and sent out from different antenna ports.

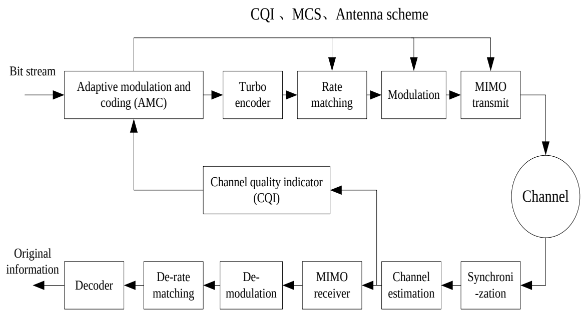

Fig. 1. Model of the adaptive LTE-A system

The signals will be transmitted to the receiver via the radio channel. Upon reception, the receiver first applies synchronous processing to eliminate system time and frequency offset, and then makes use of reference signals to complete channel estimation and tracking. On one hand, we need to obtain channel state CQI information by estimating the channel state, and then the CQI is transmitted through a feedback channel to AMC to realize the system adaptive processing. On the other hand, we need to provide data compensation to the signals at the receiver and restore the original information by the demodulation and decoding operations.

Turbo codes, also referred to as a Parallel Concatenated Convolutional Code (PCCC), are a set of high-performance Forward-Error-Correction (FEC) codes implemented by a combination of two or more convolution codes with a random interleaver. In the realization of random thoughts, interleaving is introduced to construct a long code by short codes. The output of a turbo encoder is a system bit stream d_k^0, and two parity bit stream d_k^1 and d_k^2, where $k = 0,1,\ldots,K-1$, K is the transport block size. The architecture of the RM processing block for LTE-A turbo codes is depicted in Fig. 2 [6].

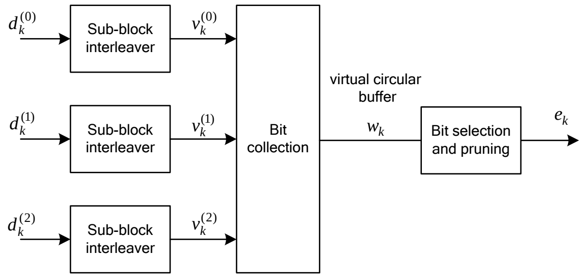

Fig. 2. RM processing block

The bit stream $d_k^{(i)}, i = 0,1,2$ is interleaved by the sub-block interleaver, and then we can obtain an output sequence, $v_0^{(i)}, v_1^{(i)}, v_2^{(i)}, ..., v_{K_\Pi -1}^{(i)}, i = 0,1,2$, where K_Π is set as interleaving length.

Then merge the $v_k^{(0)}$, $v_k^{(1)}$, $v_k^{(2)}$ according to certain rules into a new bit sequence w_k, and store w_k in a virtual circular buffer, where $k = 0,1,...,K_w -1, K_w = 3K_\Pi$. Finally, complete the padding and puncturing of sequence w_k, obtain the output sequence e_k, where $k = 0,1,\cdots,E-1$, E is the length of output sequence. $E = K_\Pi / R$, R is system target rate, determined by adaptive modulation coding controller AMC.

Next, we will discuss the generation of $v_k^{(i)}, i = 0,1,2$.

The input bits of the sub-block interleaver are marked by $d_0^{(i)}, d_1^{(i)}, d_2^{(i)}, ..., d_{K_\Pi}^{(i)}$ and the output can be derived as follows.

The columns of the matrix are defined as $C_{subblock}$ ($C_{subblock} = 32$). The rows of the matrix are defined as $R_{subblock}$. To obtain minimum integer $R_{subblock}$,

$$K_\Pi = \left(R_{subblock} \times C_{subblock}\right) \tag{1}$$

The input sequence $y_k = d_2^{(i)}, k = 0,1,..., K_\Pi -1$ is input into the $\left(R_{subblock} \times C_{subblock}\right)$ matrix row by row.

For $d_k^{(0)}$ and $d_k^{(1)}$, execute the inter-column permutation for the matrix according to the pattern P. The permutation function P is defined in Table I [6].

TABLE I. INTER-COLUMN PERMUTATION PATTERN FOR SUB-BLOCK INTERLEAVER

Number of columns $C_{subblock}^{TC}$	Inter-column permutation pattern $< P(0), P(1), \ldots, P(C_{subblock}^{TC}-1) >$
32	< 0, 16, 8, 24, 4, 20, 12, 28, 2, 18, 10, 26, 6, 22, 14, 30, 1, 17, 9, 25, 5, 21, 13, 29, 3, 19, 11, 27, 7, 23, 15, 31 >

The output bit sequence from the sub-block interleaver is read out column by column from the inter-column permuted $(R_{subblock} \times C_{subblock})$ matrix. The bits from sub-block interleaving are marked by $v_0^{(i)}, v_1^{(i)}, v_2^{(i)}, ..., v_{K_\Pi -1}^{(i)}$, where $v_0^{(i)}$ corresponds to $y_{P(0)}$, $v_1^{(i)}$ corresponds to $y_{P(0)+C_{subblock}}$, and so on.

For $d_k^{(2)}$, the output of the sub-block interleaver is marked by $v_0^{(2)}, v_1^{(2)}, v_2^{(2)}, ..., v_{K_\Pi -1}^{(2)}$, where $v_k^{(2)} = y_{\pi(k)}$ and where,

$$\pi(k) = (P(\lfloor k / R_{subblock} \rfloor) + C_{subblock} \times (k \bmod R_{subblock}) + 1) \bmod K_\Pi \quad (2)$$

The authors in [7] proposed an architecture for the LTE-A turbo code to reduce the complexity of rate-matching and de-matching. In this paper, we propose a new RM algorithm which will improve performance and reduce complexity. Fig. 3 shows the RM processing diagram. In our algorithm, first we use system-parity bit-by-bit permutation for bit collection. Then, we use circular padding or interleaved punching method to add or delete some bits so as to get the corresponding code rate, thereby implement rate matching.

A. Bit Collection

As shown in Fig. 3, in this processing, the three output data streams after turbo coding are system bit stream d_k^0, parity bit stream 1 d_k^1, and parity bit stream 2 d_k^2. These three bit streams are interleaved by the sub-blocks and can get three output sequences $v_k^{(0)}, v_k^{(1)}, v_k^{(2)}$.Unlike the method referred in the LTE-A standard [6], [8], after the process of bit collection, these three sequence bits are interleaved and merged together, and the collected sequence w_k is generated as follows.

$$\begin{aligned} w_{3k} &= v_k^{(0)} \quad, k = 0, ..., K_\Pi - 1 \\ w_{3k+1} &= v_k^{(1)}, k = 0, ..., K_\Pi - 1 \\ w_{3k+2} &= v_k^{(2)}, k = 0, ..., K_\Pi - 1 \end{aligned} \quad (3)$$

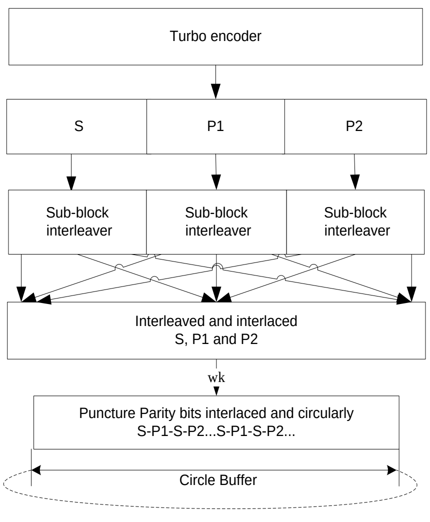

Fig. 3. RM processing block based on padding and puncturing

B. Padding and Puncturing

Assumed that the output after RM process is e_k, $k = 0, 1, \cdots, E-1$, E is the length of output sequence, $E = K_\Pi / R$, R is the system target rate, controlled by adaptive modulation coding AMC. Defined value of the padding or puncturing number in the RM process is M.

$$M = K_w - E = 3K_\Pi - E \quad (4)$$

Thus, M is negative, the rate matching is padding process. The padding process can be expressed as follows. First, export all K_w bits of merged sequence w_k, and then from the starting position of the circular buffer, read $|M|$ bits cycle continuously and output, a matching output sequence e_k whose length is E will then be obtained. The schematic process is as shown in Fig. 4.

Conversely, the rule is interlaced puncturing the bits between parity1 and 2. If it reaches the end of the buffer, the parity bits will continue to be punctured by wrapping to the beginning, until the punctured bits equal to M. According to the range of values of M, interleave puncturing can be divided into the following three cases.

Case 1: $M < K_\Pi$. Puncturing the M bits between parity1 and parity2 interlacedly and getting output sequence e_k. The corresponding sketch is showed in Fig. 5.

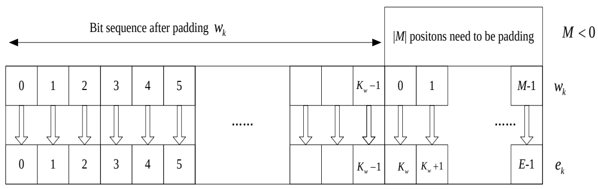

Fig. 4. The sketch of padding

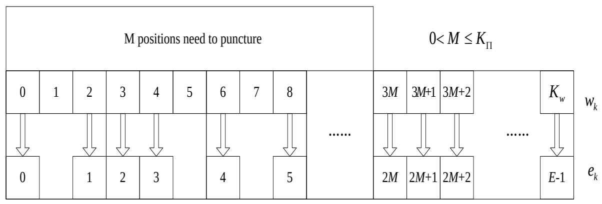

Fig. 5. The sketch of puncturing-case 1

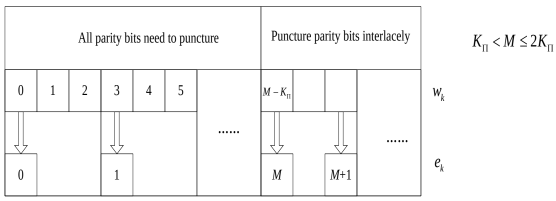

Fig. 6. The sketch of puncturing-case 2

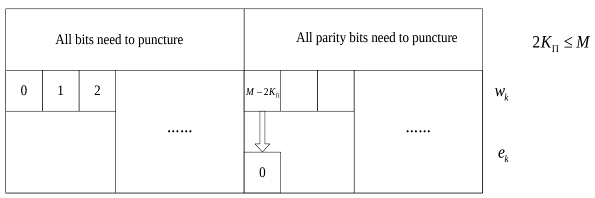

Fig. 7. The sketch of puncturing-case 3

Case 2: $K_{\Pi} < M < 2K_{\Pi}$. Firstly, we need to puncture the parity M bits between parity1 and parity2 interlacedly, and then repeat the operation from the remaining sequence until M bits have been punctured. The corresponding sketch is shown in Fig. 6.

Case 3: $2K_{\Pi} < M$. Firstly, we need to puncture all parity bits, and then puncture $M-2K_{\Pi}$ system bits successively; finally we can get the output sequence e_k . The corresponding sketch is shown in Fig. 7.

Through the above analysis, the output sequence e_k , $k = 0,1,..., E-1$ is given

$$e_k = w_{Q(k,M,K_{\Pi})}, k = 0,..., E-1 \quad (5)$$

$Q(k,M,K_{\Pi})$ plays an role of a permutation function, defined by (6).

$$Q(k,M,K_{\Pi}) = \begin{cases} k \bmod K_{\Pi} & ,M < 0 \\ Q_1(k,M,K_{\Pi}) & ,0 \le M \le K_{\Pi} \\ Q_2(k,M,K_{\Pi}) & ,K_{\Pi} \le M \le 2K_{\Pi} \\ 3(M-2K_{\Pi}+k) & ,M > 2K_{\Pi} \end{cases} \quad (6)$$

where $Q_1(k,M,K_{\Pi})$ and $Q_2(k,M,K_{\Pi})$ can be calculated by (7) and (8).

$$Q_1(k,M,K_{\Pi}) = \begin{cases} 3k & ,k < M \,\&\&\, k \text{ is even} \\ 3k+1+(k \bmod 2) & ,k < M \,\&\&\, k \text{ is odd} \\ 3M-1+k, & ,k \ge M \end{cases} \quad (7)$$

$$Q_2(k,M,K_{\Pi}) = \begin{cases} 3k & ,k < M-K_{\Pi} \\ 3K_{\Pi}+1+(k \bmod 2), & k \ge M-K_{\Pi} \end{cases} \quad (8)$$

From (5), we can see the rate matching process simply means padding and puncturing of the combined sequence w_k in some positions, and system-parity bit position can derive from (6)-(8). For different rate requirements of system, the value of M is also different, the correspondence between the combined sequence w_k and match output sequences e_k is also different.

The novel algorithm is based on cycle padding and interleaved puncturing to ensure that each code word repeats as a few redundant bits and preserves as much of the systematic bits to reduce the transmission of redundant information, and obtain the higher coding gain [9]. At the same time, we use the interlaced bit collection method in the turbo code procedure. When compared with algorithm used by LTE-A [10], it shows better performance and has the advantage of flexibility. Moreover, by ignoring search and puncture dummy bits, the algorithm computational complexity can decrease, so it can be implemented in software and hardware easily. In Part V, we will use BER as an assessment to verify that the algorithm can improve system performance.

III. Antenna Schedule

In the system model shown in Fig. 1, the AMC module can not only dynamically adjust modulation and code schemes through channel states information (CSI), but also make use of feedback channel information from the receiver and adopt different judgment criteria to choose the appropriate multiple antenna modes [11]. The judgment criteria based on SNR, channel capacity, minimum BER have been given in references [12]-[14]. In the antenna scheduling algorithm, we take channel capacity criterion to obtain the multi-antenna scheduling coefficient and then further control multi-antenna models to choose different antenna mode, which includes single input and single output (SISO), transmit diversity (TD) and spatial multiplexing (SM). The antenna scheduling model is illustrated in Fig. 8.

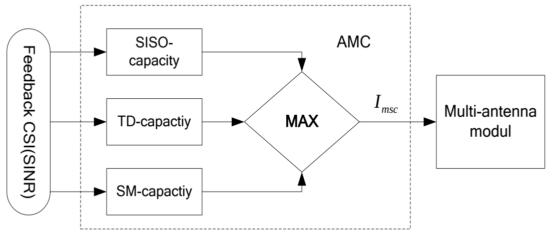

Fig. 8. The antenna schedule model

Multiple-antenna adaptive scheduling model is shown in Fig. 8. The basic idea of the adaptive scheduling can be simply expressed as: firstly calculate channel capacity through feedback SINR information under three different antenna modes, and then obtain the multiple-antenna scheduling coefficient based on channel capacity judgment criterion, and lastly, take the I_{msc} value back to the antenna modules so as to choose the right antenna modes to transmit. Next, we will introduce the antenna scheduling algorithm in details.

Suppose the channel quality information from the i -th feedback channel is $SINR_R^i$, which can be derived from [6], $i = 0,1,...,T$, T represents the number of feedback channels. The antenna number at the transmitter and receiver is M and N , respectively. Thus the equivalent channel quality information corresponding to the three antenna modes can be expressed as,

$$SINR_{SISO} = \frac{1}{T}\sum_{i=1}^{T} SINR_R^i \quad (9)$$

$$SINR_{TD} = \frac{M}{T}\sum_{i=1}^{T} SINR_R^i \quad (10)$$

$$SINR_{SM} = 2^{\frac{1}{T}\sum_{i=1}^{T}\log_2(1+SINR_R^i)^N} - 1 \quad (11)$$

According to the Shannon theorem, the equivalent channel capacities of the three antenna modes are:

$$C_{SISO} = \log_2(1+SINR_{SISO}) \quad (12)$$

$$C_{TD} = \log_2(1+SINR_{TD}) \quad (13)$$

$$C_{SM} = M \times \log_2(1+SINR_{SM}) \quad (14)$$

From the above formulas, when $M = N = 1$, three kinds of antenna mode have the same equivalent channel quality information and channel capacity:

$SINR_{SISO} = SINR_{TD} = SINR_{SM}$, $C_{SISO} = C_{TD} = C_{SM}$, when $M, N > 1$, the TD and SM modes have larger equivalent channel capacities than SISO mode, hence, in the scheme algorithm, we introduce the sentence coefficient α ($0 < \alpha \le 1$),

$$\alpha = \frac{C_{SISO}}{\max(C_{TD}, C_{SM})} \tag{15}$$

In addition, in order to further distinguish antenna modes, we introduce the single and multi-antenna decision threshold α_{th} based on the sentence coefficient. When $\alpha \ge \alpha_{th}$, we could choose the single antenna mode to transmit; otherwise, we should choose multi-antenna modes (TD or SM). The threshold value can be estimated by the specific simulation [12]. By comparison between judgment coefficient and threshold value, we can be made aware, which kind of antenna mode will get the highest channel capacity, and then choose the right mode in the antenna module to realize adaptive operation.

This point is known as the antenna decision criteria. The basic idea is to first compare the equivalent channel capacities under different antenna modes and obtain the judgment coefficient, and then take the consideration of the system performance and realization complexity for single or multi-antenna. Finally, the value of the coefficient of the antenna scheduling is determined. Mathematically, this process can be expressed as:

$$I_{msc} = \begin{cases} 0, & \alpha_{th} \le \alpha \le 1 \\ 1, & C_{TD} \ge C_{SM} \ \&\&\ 0 < \alpha < \alpha_{th} \\ 2, & C_{TD} < C_{SM} \ \&\&\ 0 < \alpha < \alpha_{th} \end{cases} \tag{16}$$

I_{msc} ($I_{msc} = 0,1,2$) indicates that the antenna module will choose SISO, TD and SM mode to transmit, respectively.

This kind of antenna scheme algorithm originates from the measurement to the channel quality information at the receiver, and then selects the most suitable antenna transmission mode through judgment criteria. The system can choose different transmission mechanism according to the different characteristics of the channel, which can improve the efficiency of the transmission system and performance gains.

IV. Performance Results

In this part, simulation results are presented to verify the algorithm put forward above. The simulation consists of rate matching algorithm and antenna adaptive scheme presented in this paper. Matlab which is mainly used in the numerical calculation and visualization image processing engineering is adopted as our simulation platform.

A. *Rate Matching Simulation*

CQI [6] is the channel quality information and different CQI values indicate different modulation and Code Rate (CR) combinations. In the simulation, we use 64QAM modulation scheme and CR value is 0.455, 0.754 and 0.926, corresponding to three CQI indices (10, 13, 15) to compare the Proposed RM Algorithm (PRMA) with Traditional RM Algorithm (TRMA). The simulation is based on VehA (Vehicular A) channel and carried out 1000 times. Fig. 9 gives the BER performance curves. For different CQI values, they have the same modulation scheme but different code rate. From Fig. 9, we can observe that compared with the TRMA, the PRMA has better performance when CQI value remains the same. With the two different methods, BER performance varies inconsistently when CQI condition is different. In addition to the above, when the CQI increases, (implying code rate raises), the performance gap expands between PRMA and TRMA. Therefore, the proposed RM algorithm on the basis of interlaced puncturing is more appropriate for LTE-A rate matching because of its high performance and its feasibility across inclusive code rate and SNR.

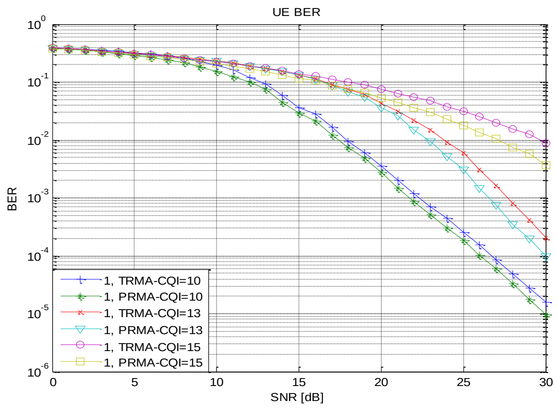

Fig. 9. BER performance with different CR

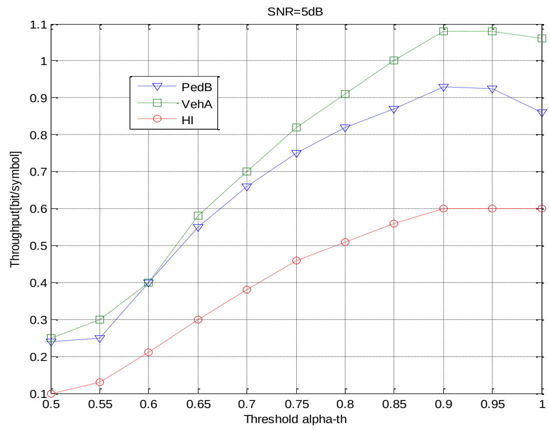

Fig. 10. Throughput with different threshold alpha-th values

B. *Antenna Schedule Algorithm Simulation*

With regards to frequency resource, a lot of solutions have been proposed [15]. In this simulation process, we choose three antenna modes: Single Input Single Output (SISO), Transmit Diversity (TD) and Spatial Multiplexing (SM). In order to obtain a better result, the antenna schedule simulations are conducted with different channel modes: PedB channel, VehA channel and HI channel [16]. Firstly, the simulation chart for system throughput on the condition of the single and multi-antenna decision threshold, with different values in three channels has been shown in Fig. 10, respectively.

From the figure, the throughput performance increases with the value and then tends towards stability, and maximizes when sentence coefficient is between 0.9 and 0.95. Hence, we could choose 0.9 as the decision threshold. That is, when sentence coefficient is greater than 0.9, SISO mode will be adopted, and conversely, TD or SM mode will be considered. If $C_{TD} \geq C_{SM}$, TD mode will be chosen, otherwise SM is used.

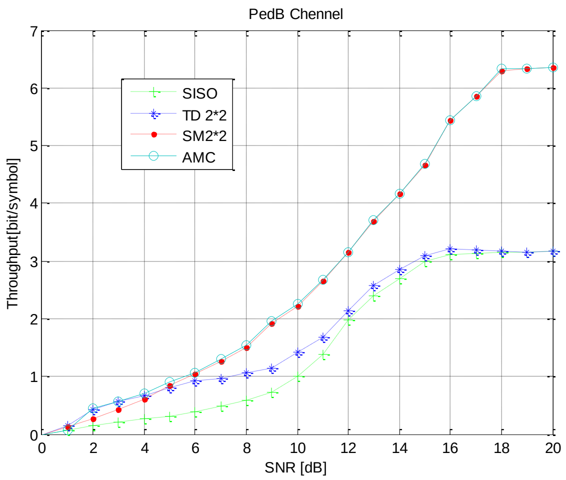

Fig. 11. Throughput with different antenna modes in PedB channel

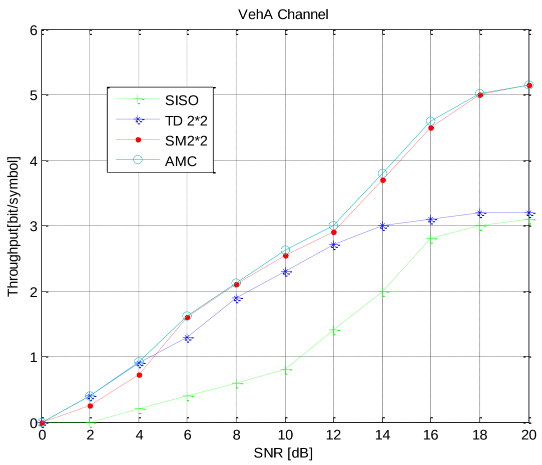

Fig. 12. Throughput with different antenna modes in VehA channel

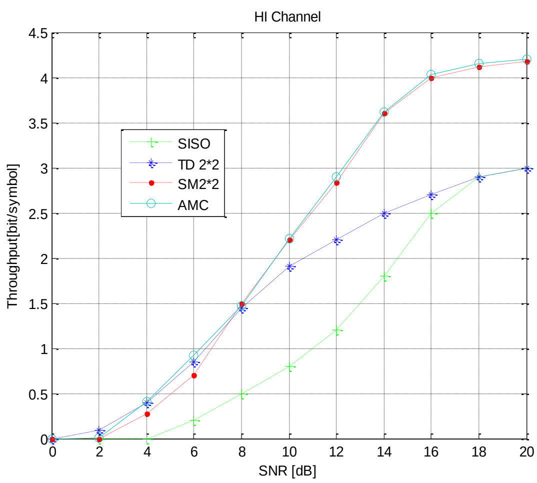

Fig. 13. Throughput with different antenna modes in HI channel

Finally, this section of the paper presents the system throughput performance simulations with different antenna modes in three different channels. As can be seen from the Fig. 11, Fig. 12 and Fig. 13, the antenna scheduling algorithm (AMC antenna mode) presented in this paper has better performance when the channel is in low signal-to-noise (SNR) environment. With an increasing number of SNR value, the AMC performance is normally quite close to the SM mode and well above the TD and SISO modes.

Based on simulation results for the system, the following conclusions have been drawn: irrespective of the type of simulation environment and channel conditions, compared to the other three fixed antenna modes, the adaptive antenna scheduling mode has better throughput performance and shows a stable performance advantage. It can be proved that our adaptive design for LTE-A system is therefore accurate.

V. Conclusions

The main contribution of this paper is a novel rate matching algorithm and a different antenna mechanism, as well as the adaptive system performance simulation and analysis. According to the adaptive LTE-A system design scheme, we build the simulation platform, and the system performance and adaptive ability are simulated and analyzed. Simulation results prove the performance of the rate matching algorithm under different modulation and coding schemes, and more adaptive scheduling between different antenna modes. It is also observed that the system with the improved adaptive schemes has better performance, which also affirms that the design of the adaptive system is accurate and reasonable. However, even though the proposed algorithms improve the performance and flexibility, they also introduce some computational complexity, which will need to be investigated and minimized both in the software and hardware as a future research.

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Jian Liu received his B.S. degree in Automatic Control Theory and Applications from Shandong University, China, in 2000, and the Ph.D. degree in School of Information Science and Engineering from Shandong University in 2008. He is currently an associate professor of University of Science and Technology Beijing (USTB), Beijing, China. His research interests include cognitive radio networks, mobile mesh networks, and LTE-A. He is an IEEE member since 2009.

Xinxin Tan was born in Hubei Province, China. She got the Bachelor's degree of University of Science & Technology Beijing (USTB) in 2014, and now she is studying for a master's degree at USTB. Her research field includes wireless communication and cognitive radio.

Ci Huang was born in Hubei Province, China. He received the Bachelor's degree from the University of Science & Technology Beijing (USTB) in 2014. Nowadays, He is studying for a master's degree at USTB. His major is Information and Communication Engineering. He is studying FPGA and doing some hardware research.

Xin Ji was born in Shandong Province, China. He received the B.E. degree in 2012, and now he is studying for a master's degree at University of Science & Technology Beijing. His research interests include the key technology of next generation of mobile communication and mobile ad-hoc network.