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A novel BCS code in a downlink LTE system over an LTE-MIMO channel

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Abstract

In general, a concatenated RS/BCH code consists of an outer RS code and an inner BCH code with separation by an interleaver. We create a novel BCS code using a new methodology by combining an outer BCH code with an inner RS code appended by an interleaver to randomize burst errors and help the RS code in correcting the errors. Generally, BCH codes handle binary data, whereas RS codes handle non-binary data. Hence, RS (7, 1) inner code is proposed to achieve compatibility with BCH (15, 5) outer codes and ultimately create a novel BCS code to handle binary data. The proposed BCS code is compared with familiar concatenated RS/BCH codes and single codes (RS and BCH) for BPSK and QPSK modulation schemes. Results show the downlink LTE system performance using the proposed BCS code is significantly better than the uncoded LTE system and single codes (RS and BCH). Moreover, the proposed BCS code also outperforms familiar concatenated RS/BCH codes for both schemes. In contrast, the system performance is improved further when the number of antennas in the MIMO channel is increased from 2 × 2 to 4 × 4. Therefore, the proposed BCS code can be considered a stronger code with high reliability in wireless communication systems.

Keywords BCS · MIMO · LTE · RS · BCH · QPSK · BPSK

1 Introduction

The number of users of mobile broadband has increased rapidly, raising the demand for better data services. Long term evolution (LTE) is the best approach to address the revolution of broadband communication applications, such as high-definition and high-quality applications, voice over IP, video sharing, file loading, online gaming and true on-demand TV. The aims of using LTE are to provide a high capacity, low latency, good coverage and robust quality of service. LTE systems use orthogonal frequency division multiplexing (OFDM) systems with multi-input multi-output (MIMO) systems to increase spectral efficiency. OFDMA is used for the downlink (DL) of LTE while SC-FDMA is used for the uplink. The spacing between subcarriers preserves orthogonality in OFDM systems, thereby removing subcarrier interference. Furthermore, OFDM systems are robust against multipath fading and have a cyclic prefix that can eliminate inter-symbol interference [1].

MIMO techniques with LTE have been proposed by different researchers [2–4] to improve system throughput. The combination of LTE and MIMO systems can increase the peak rate and improve system efficiency. Therefore, it can improve cell coverage and achieve a higher data rate without increment than the average transmitted power or frequency bandwidth [2]. High system throughput and high reliability are achieved when using multi-antennas in the user terminal and base station versus fading of signal strength [4]. Multi-antenna systems are protected better with higher reliability from fading channels than single antenna systems [5]. In contrast, MIMO technology has been suggested in LTE as a key component in providing a high peak rate with good system efficiency [2]. The results of such suggestion have shown that the proposed system can enhance successfully the throughputs of cell-edge users. Bit error rates (BER) at various levels of correlation regarding antenna array configuration was studied in Reference [3] under various modulation schemes. The authors of this reference conducted a comparative analysis for an LTE system supported by

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1.4, 3, 5, 10, 15 and 20 MHz bandwidths and concluded there are a trade-off among all parameters for optimum performance. They reported that the BER for a low-level correlation of MIMO is comparatively low and that the BER performance of the LTE system is the best at the 10 MHz bandwidth.

In wireless communication systems, such as LTE, the error control in the transmission channel is the most important challenge with multipath fading channels [6]. Channel coding has been used in LTE to correct transmission errors and increase the reliability of the received data [7]. Various studies have been conducted to achieve a reliable iterative forward error correction (FEC). For example, turbo codes [8–16], can improve the BER of LTE systems. However, high decoding complexity remains a common drawback in turbo codes [17,18].Other studies [19–21] have proposed using convolutional codes with LTE systems; however, although their techniques can improve system performance, the convolutional decoding complexity is high [22]. Other coding techniques, such as LDPC codes [23], convolutional turbo codes [24], RS codes [25] and BCH codes [26] have also been proposed for LTE systems. BCH and RS codes have achieved good improvements of DL LTE system performance with lower decoding complexity compared with other coding techniques. Hence, we discussed these codes and used them to create a new BCS code that has both of their advantages, thereby achieving extra improvements in the system performance compared with other coding techniques. Here, a novel BCS code was used with an LTE system to increase the reliability of data transmission with moderate decoding complexity. In general, the concatenated technique is a common method used in digital communication systems for error correction to enhance error performance. It consists of inner and outer codes separated by an interleaver, which is used to correct burst errors through distribution [27]. In other words, concatenated coding is a method that combines simple relative codes to obtain a powerful coding system with high performance (low BER) and decreases decoding complexity with a large coding gain [28]. Previously, the performance of concatenated RS-BCH codes on an interference satellite channel was investigated in Reference [29], The outer RS code was used with the inner BCH code. This combination of codes was appropriate for correcting burst errors in the interference satellite channel. The results demonstrated that the improvement from using this concatenated technique was better than that from using only the BCH code. The concatenated RS-BCH codes have also been proposed previously for fibre communications [30] and Rayleigh fading channels [31]. Therefore, depending on previous knowledge, familiar concatenated techniques may include RS and BCH codes, particularly by using RS as the outer code and BCH as the inner code [29–31].

1.1 Related work

In literature, MIMO technology has been suggested in LTE to improve system throughput [2–4].However, their systems lack the reliability of information transmission because they have not used error correction techniques, which are essential for digital communication systems over noisy channel [32–34]. Channel coding is used in LTE to correct transmission errors and increase the reliability of the received data [7]. Thus, various studies have been conducted to achieve a reliable iterative FEC, such as turbo codes [8–16], although they can improve the BER of LTE systems. However, high decoding complexity is still a common drawback in turbo codes [17,18].Other studies [19–21] have proposed using convolutional codes with LTE systems to improve system performance, but the convolutional decoding complexity remains high [22].Other coding techniques, such as LDPC codes [23], convolutional turbo codes [24], RS codes [25] and BCH codes [26], have also been proposed for the LTE system. Nevertheless, a trade-off exists between reducing the implementation complexity and degrading the decoding performance [35].BCH and RS codes [25,26] have achieved good improvements of DL LTE system performance with lower decoding complexity compared with other coding techniques. We discussed these codes and used them to create a new BCS code that has both of their advantages, thereby achieving extra improvements in the system performance compared with other single coding techniques. A novel BCS code was proposed with DL LTE system to increase the reliability of data transmission with moderate decoding complexity.

In general, the concatenated technique is a common method used in digital communication systems for error correction to enhance error performance. It consists of inner and outer codes separated by an interleaver, which is used to correct burst errors through distribution [27]. The concatenated RS-BCH codes have been suggested in References [29–31] for different systems by using outer RS code with the inner BCH code. The results demonstrated that the improvement from using this concatenated technique was better than that from using only the BCH code [29]. Therefore, depending on previous knowledge, familiar concatenated techniques may include RS and BCH codes, but by using RS as the outer code and BCH as the inner code [29–31]. In the current paper, a novel BCS code was suggested for DL LTE system by using new methodology represented of combining an outer BCH code with an inner RS code appended by an interleaver to randomize burst errors and help the RS code in correcting the errors unlike the familiar concatenated RS/BCH codes in References [29–31]. Therefore, a novel BCS code was suggested with DL LTE system to increase the reliability of data transmission with moderate decoding complexity better than both single codes [25,26] and familiar concatenated RS/BSH codes [29–31].

1.2 Paper motivations and contributions

The main paper motivations and contributions are summarized as follows:

- To create a powerful error correcting code that can achieve high reliability in DL LTE systems, a new methodology of combining RS codes with BCH codes and appended with the interleaver has been used to create novel BCS codes.
- To achieve suitable compatibility between BCH and RS codes, RS (7,1) was suggested with BCH (15,5) to create a new BCS code handling binary data.
- To evaluate the performance of the proposed BCS codes in DL LTE systems, BCS codes with single codes (RS and BCH codes) and familiar concatenated RS/BCH codes were compared for BPSK and QPKS modulation schemes.
- To achieve further improvements in DL LTE system performance, LTE-MIMO channel was used with the proposed system. While, the performance of the proposed system between using 2 × 2 and 4 × 4 MIMO channel was compared.

2 A novel BCS code

As mentioned earlier, conventional concatenated techniques can a combination of RS and BCH codes, particularly by using RS as outer code and BCH as inner code [29–31]. In this paper, the proposed BCS code was involved in a new methodology of combining the BCH code in the first stage (as outer code) and the RS code in the second stage (as inner code) and then using an interleaver in the last stage after the RS code. This new combination is illustrated in a block diagram in Fig. 1.

The RS code was chosen as the inner code for three reasons. First, when using a strong inner code, information reliability will be achieved [36].Owing to the better performance of RS codes than BCH codes [37],RS codes would be stronger than BCH codes. Thus, these codes were chosen to be the inner code. Second, utilizing an inner hard-decision RS decoder can considerably reduce the decoding complexity of the outer code [38]. Therefore, a hard-decision RS decoder with lower complexity than soft-decision RS decoders [39] was chosen as inner code to achieve low decoding complexity in the overall system. Lastly, RS codes have a high capability in correcting random and burst errors [40]. Therefore, further improvements in system performance may be achieved when using them as the inner code. In contrast, the BCH code was chosen with the RS code because it can outperform Reed-Muller, polar and LDPC codes [41]. In addition, it has a simple decoding algorithm [29,31]. Where, the BCH code is a powerful code with a better decoding velocity than that of the LDPC and turbo codes [42]. Therefore, using both powerful codes (i.e., RS and BCH codes) with a low decoding complexity [29,31,39],will create a new BCS code with a high capability of error correction with low decoding complexity.

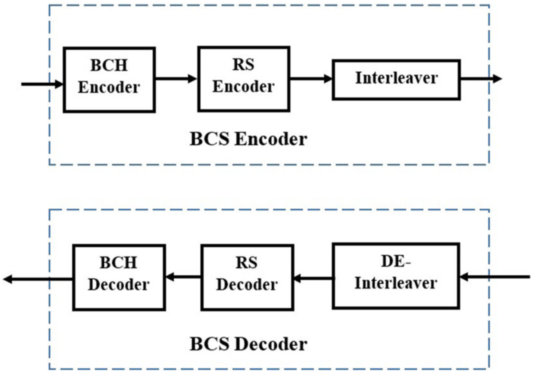

Fig. 1 A novel BCS encoder/decoder

Complex computations have become a challenge in error-correcting techniques. Hence, a trade-off exists between reducing the implementation complexity and degrading the decoding performance [35]. Therefore, a balance between maintaining effective decoding performance and doesn't increasing the decoding complexity should be achieved. The concatenation, which is the core idea of the novel BCS code, is an attractive method to achieve high coding gains with modest decoding complexity [43]. Decoding complexity and the performance of concatenated code are based on the outer code [44]. Thus, BCH codes were used in the proposed BCS code due to their powerful codes and simplicity of decoding process compared with other codes, such as turbo and LDPC codes [31,42].In contrast, utilizing the inner hard - decision RS decoder can considerably reduce the decoding complexity of the outer code [38].Therefore, using a hard-decision RS decoder with low complexity as the inner code will achieve a low decoding complexity in the overall system of the proposed BCS code. Furthermore, using RS and BCH codes with low decoding complexity [31,39,42] in the contents of the new BCS codes are contributed in achieving moderated decoding complexity of the BCS code while maintaining decoding performance due to their high capability of error correction.

On the other hand, the main reason for using these two stages of codes was that the inner code can help the outer code in correcting the remaining errors that were not corrected. Therefore, a strong code as the inner code is necessary to complete the correcting process of the outer code. The use of the inner RS code will increase the capability of correcting burst errors [45] in the first stage. Meanwhile, the use of the interleaver to distribute burst errors will help correct errors [27] in the second stage. The interleaver after the RS encoder is necessary to improve the capability of correcting errors [40]. Therefore, this new methodology of combining codes will create a new strong code that can improve system performance further and correct burst errors with moderate complexity. To achieve a suitable combination of BCH and RS codes, modifications of algorithms and parameters are necessary considering that BCH codes handle binary data, whereas RS codes handle non-binary data. Therefore, RS (7, 1) codes were suggested in this paper to achieve compatibility with BCH (15,5) codes, thereby creating a novel BCS code that deals with binary data.

2.1 BCH code

Bose, Ray-Chaudhuri and Hocquenghem discovered and introduced the BCH codes. The code words are generated by separating a polynomial m(x) by a generator polynomial g(x) then taking the rest as a parity check bit r(x). Hence, C(x) is the encoded data and presented as follows [46]:

$$C(x) = m(x) + r(x)$$

When selecting the generator polynomial g(x), the characteristics of the code are specified. The BCH code can correct independent errors $\leq t$, and it can be presented as follows: $n = 2^m - 1$, $d \geq 2t + 1$ and $n - k \leq mt$, where n is the block length, d is the minimum distance, $(n - k)$ is the parity check bit, $m \geq 3$, and $t < 2^{(m-1)}$ [46].The decoding process is executed in three phases as follows [46]:

1. Determine the syndrome from the received codeword.
2. Select the error location polynomial on the basis of the syndrome and derived equations.
3. Correct the erroneous bits using the error location polynomial.

The ease in encoding and decoding data is one of the most important features of BCH codes. The decoding process is simpler as compared to other coding techniques, such as LDPC and turbo codes [46]. This feature makes the BCH code suitable as part of the novel BCS code. The default BCH (15, 5) code was chosen in this paper.

2.2 RS codes

Reed-Solomon codes are non-binary cyclic codes with symbols consisting of m-bit sequences, represented as follows: RS(n, k), where $0 < k < n < 2^m + 2$, m is any positive integer > 2 , n implies to the number of code symbols inside the encoded block, and K the number of encoded data symbols. Traditional RS(n, k) is presented as follows [47]:

$$(n, k) = (2^m - 1, 2^m - 1 - 2t)$$

where t is the erroneous symbols that can be corrected, and $(2t = n - k)$ is the number of parity symbols. RS codes are active in correcting bursts errors [47]. In general, the RS decoding phases are as follows [46]:

1. Determine the syndrome from the received codeword.
2. Select the error value polynomial and error location by the syndrome and derived equations.
3. Correct the corrupted symbols using the obtained information.

The ability to correct burst errors and erasures is one of the features of RS codes and the efficiency of RS codes is increased with code length [46]. Therefore, RS codes were chosen with the BCH code to create the novel BCS code. Assuming that a primitive element of $GF(q)$ is α and $\alpha^{q-1} = 1$, the RS code can be generated by the following polynomial expression [48]:

$$\begin{aligned} g(X) &= (X - \alpha)(X - \alpha^2)\cdots(X - \alpha^{n-k}) \\ &= (X - \alpha)(X - \alpha^2)\cdots(X - \alpha^{2t}) \\ &= g_0 + g_1 X + g_2 X^2 + \cdots g_{2t-1} X^{2t-1} + g_{2t} X^{2t} \end{aligned} \tag{1}$$

Given (1), an RS code $CRS(n, n - 2t)$ is a linear and cyclic block that contains the code polynomial $c(x)$ with an $(n - 1)$ degree or less. All coefficients of this polynomial are elements in $GF(2^m)$. When the code polynomial is multiplied by the generator polynomial, its roots can be obtained, assuming that m(X) is the message polynomial [48]:

$$m(X) = m_0 + m_1 X + m_2 X^2 + \cdots m_{k-1} X^{k-1} \tag{2}$$

All coefficients of the message polynomial are also elements in $GF(2^m)$. So, the systematic form, like the method of the binary BCH code, is used when obtaining the remainder p(x) through dividing $X^{n-k} m(X)$ by g(X) as follows [48]:

$$X^{n-k} m(X) = q(X) g(X) + p(X) \tag{3}$$

In this paper, the rate of RS (7, 1) code was proposed for the novel BCS code because of the following reasons:

1. The BCH codes are binary codes while the RS codes are non-binary codes; thus, both codes are necessary to be unified. When k = 1 of the RS codes and the input data that comes from the BCH encoder are binary, the output

Table 1 The Galois field $GF(2^3)$ that generated by $pi(X) = 1+X+X^3$ [48]

Expr. Repr.	Poly. Repr.	Vector Repr.
0	0	0 0 0
1	1	1 0 0
α	α	0 1 0
α^2	α^2	0 0 1
α^3	$1+\alpha$	1 1 0
α^4	$\alpha+\alpha^2$	0 1 1
α^5	$1+\alpha+\alpha^2$	1 1 1
α^6	$1+\alpha^2$	1 0 1

data of the RS encoder will be only binary (0 and 1). Therefore, the RS codes will be used as binary codes.

2. By contrast, if familiar parameters k = 3 or 5 for n = 7 are used, then two stages of converters from binary to decimal and vice versa are needed before the RS encoder and decoder because the output data of the BCH encoder and the input data of the BCH decoder are binary. These four stages will increase the complexity and the extra process may affect system performance. Meanwhile, when k = 1, these converters are not required.
3. The capability of correction using k = 1 is more than k = 3 or 5; thus, t = 3 for k = 1, whereas t = 2 and 1 for k = 3 and 5.

The derivation of the generator polynomial from (1) required for our proposed RS (7, 1) code is as follows:

$$\begin{aligned} &n-k = 7-1 = 6, \text{ thus,} \\ &g(x) = (X-\alpha)(X-\alpha^2)(X-\alpha^3)(X \\ &\qquad -\alpha^4)(X-\alpha^5)(X-\alpha^6) \end{aligned}$$

From Table 1, it can be concluded that:

$$\begin{aligned} \alpha^7 &= \alpha^6\alpha = (1+\alpha^2)\alpha = \alpha+\alpha^3 = \alpha+1+\alpha = 1 \\ \alpha^8 &= \alpha^7\alpha = \alpha \\ \alpha^9 &= \alpha^8\alpha = \alpha^2 \\ \alpha^{10} &= \alpha^9\alpha = \alpha^3 = 1+\alpha \\ \alpha^{11} &= \alpha^{10}\alpha = (1+\alpha)\alpha = \alpha+\alpha^2 \\ \alpha^{12} &= \alpha^{11}\alpha = 1+\alpha+\alpha^2 \\ \alpha^{13} &= \alpha^{12}\alpha = \alpha+\alpha^2+\alpha^3 = \alpha+\alpha^2+1+\alpha \\ &= 1+\alpha^2 \\ \alpha^{14} &= \alpha^{13}\alpha = \alpha+\alpha^3 = \alpha+1+\alpha = \alpha^0 \end{aligned}$$

Therefore, g(x) can be obtained from the following:

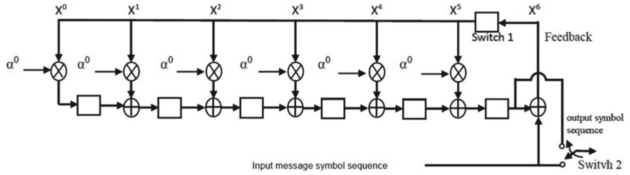

Fig. 2 LFSR encoder for the proposed RS(7, 1) code

1. $(X-\alpha)(X-\alpha^2) = X^2-\alpha^2X-\alpha X+\alpha^3 = X^2-(\alpha^2+\alpha)X+\alpha^3 = X^2-\alpha^4X+\alpha^3$
2. $(X-\alpha^3)(X-\alpha^4) = X^2-\alpha^4X-\alpha^3X+\alpha^7 = X^2-(\alpha^4+\alpha^3)X+\alpha^7 = X^2-\alpha^6X+\alpha^7$
3. $(X-\alpha^5)(X-\alpha^6) = X^2-\alpha^5X-\alpha^6X+\alpha^{11} = X^2-(\alpha^5+\alpha^6)X+\alpha^{11} = X^2-\alpha X+\alpha^{11}$

Then,
$(X^2-\alpha^4X+\alpha^3)(X^2-\alpha^6X+\alpha^7) = X^4-\alpha^6X^3+\alpha^7X^2-\alpha^4X^3+\alpha^{10}X^2-\alpha^{11}X+\alpha^3X^2-\alpha^9X+\alpha^{10} = X^4-(\alpha^6+\alpha^4)X^3+(\alpha^7+\alpha^{10}+\alpha^3)X^2-(\alpha^{11}+\alpha^9)X+\alpha^{10} = X^4-\alpha^3X^3+X^2-\alpha X+\alpha^3$
So,

$$\begin{aligned} &(X^2-\alpha X+\alpha^{11})(X^4-\alpha^3X^3+X^2-\alpha X+\alpha^3) \\ &\quad = X^6-\alpha^3X^5+X^4-\alpha X^3+\alpha^3X^2-\alpha X^5 \\ &\qquad +\alpha^4X^4-\alpha X^3+\alpha^2X^2-\alpha^4X \\ &\qquad +\alpha^{11}X^4-\alpha^{14}X^3+\alpha^{11}X^2 \\ &\qquad -\alpha^{12}X+\alpha^{14} \\ &\quad = X^6-(\alpha^3+\alpha)X^5+(1+\alpha^4+\alpha^{11})X^4 \\ &\qquad -(\alpha+\alpha+\alpha^{14})X^3+(\alpha^3+\alpha^2+\alpha^{11})X^2 \\ &\qquad -(\alpha^4+\alpha^{12})X+\alpha^{14} \\ &\quad = X^6-X^5+X^4-X^3+X^2-X+\alpha^{14} \\ &\quad = \alpha^0X^6-\alpha^0X^5+\alpha^0X^4 \\ &\qquad -\alpha^0X^3+\alpha^0X^2 \\ &\qquad -\alpha^0X+\alpha^{14} \end{aligned}$$

Therefore, the generator polynomial of RS(7, 1) is:

$$\begin{aligned} g(X) = {} & \alpha^0X^6+\alpha^0X^5+\alpha^0X^4+\alpha^0X^3+\alpha^0X^2+\alpha^0X \\ & +\alpha^0 \end{aligned} \tag{4}$$

The design of the RS encoder [49] is shown in Fig. 2. The received polynomial $r(X)$ affected by noise is [48]:

$$r(X) = c(X) + e(X) \tag{5}$$

where $e(x)$ is the error polynomial:

$$e(x) = e_0 + e_1X + \cdots + e_{n-1}X^{n-1}$$

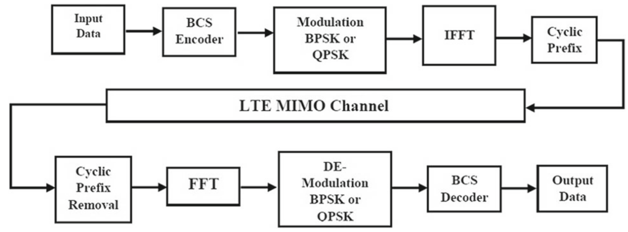

Fig. 3 Novel BCS code in the downlink LTE system

Assuming τ errors in the transmission, e(X) has τ non-zero elements at $X^{j_1}, X^{j_2}, X^{j_3} \ldots X^{j_\tau}$, and $j_\tau \leq n - 1$. The number of error location is calculated as follows [48]:

$$\beta_j = \alpha^{j_i} \text{ where } i = 1, 2, 3, \ldots \tau$$

Syndrome calculation is executed by changing the variable X with roots $\alpha^i = 1, 2, 3, \ldots 2t$ as follows [48]:

$$r(\alpha^i) = e(\alpha^i) = c(\alpha^i) + e(\alpha^i)$$

The system is expressed as follows [48]:

$$\begin{aligned} s_1 &= r(\alpha) = e(\alpha) = e(j_1)\beta_1 + e(j_2)\beta_2 + e(j_3)\beta_3 + \cdots \\ &\quad + e(j_\tau)beta_\tau \\ s_2 &= e(j_1)\beta_1^2 + e(j_2)\beta_2^2 + e(j_3)\beta_3^2 + \cdots + e(j_\tau)\beta_\tau^2 \\ &\quad . \\ &\quad . \\ &\quad . \\ s_{2t} &= e(j_1)\beta_1^{2t} + e(j_2)\beta_2^{2t} + e(j_3)\beta_3^{2t} + \cdots + e(j_\tau)\beta_\tau^{2t} \end{aligned}$$

2.3 Interleaver/de-interleaver

The interleaver/de-interleaver was used to re-arrange input bits in a non-adjacent manner and ultimately increase the robustness of transmission versus burst of errors [50].

3 System diagram

Figure 3 shows the DL LTE system using the novel BCS code with the LTE parameters [51] in Table 2. System performance was tested over a 2 × 2 and 4 × 4 LTE-MIMO channel with a multipath fading channel. Two modulation schemes were used in the proposed system (BPSK and QPSK) to determine which could better improve the system performance.

4 Simulation results

The DL LTE system performance was evaluated and simulated using MATLAB software over a 2 × 2 LTE-MIMO channel to elucidate the effect of using different coding techniques on system performance. Then, the results were compared using the novel BCS code. Two important criteria in these results are BER against SNR and what suitable coding technique achieved a satisfactory BER at a low SNR.

Table 2 Simulation environment of the LTE system [51]

Transmission bandwidth	20 MHZ
Channel	LTE-MIMO channel Multipath fading channel
Number of IFFT/FFT points	2048
No. of occupied sub-carriers	1200
Cyclic prefix length	144
Modulation	BPSK and QPSK
Sampling rate	30.72 MHz
Error correcting techniques	BCS codes

In this paper, the simulation framework was concentrated on the BER performance of the proposed BCS code as compared with the existing methods, such as uncoded and RS and BCH codes, to highlight the superiority of using the proposed BCS code in improving DL LTE system performance among existing methods. The RS and BCH codes has better BER performance and decoding complexity than those of convolutional and turbo codes [25,26].The uncoded system lacks error-correcting techniques that improve system performance. Hence, outperforming the proposed BCS code on the RS and BCH codes in terms of the BER means that also outperforming the uncoded and convolutional and turbo codes. The proposed BCS codes were compared with conventional concatenated (RS/BCH) codes to show the superiority of proposed BCS codes in terms of BER performance. The concatenated techniques are attractive methods that achieve high coding gains with modest decoding complexity [43] and are considered a competitor to the proposed BCS codes in terms of BER performance. Hence, it can be used in the comparison of BCS codes versus conventional concatenated RS/BCH codes. The last comparison concentrated on the MIMO channel and showed the usefulness of increasing the number of antennas on the BER performance. On the other hand, using the two stages of powerful error correcting (RS and BCH) codes and then appending by interleaver in the proposed BCS code was expected to increase the capability of correcting random and burst errors and enhancing BER performance than existing single codes. The new methodology of combining RS and BCH codes to create the proposed BCS codes was also expected to outperform the conventional concatenated RS/BCH codes in terms of BER performance.

The uncoded and BCH and RS coding techniques were compared with the proposed BCS code in the DL LTE system over the LTE-MIMO channel with the BPSK and QPSK modulation schemes as shown in Figs. 4 and 5.

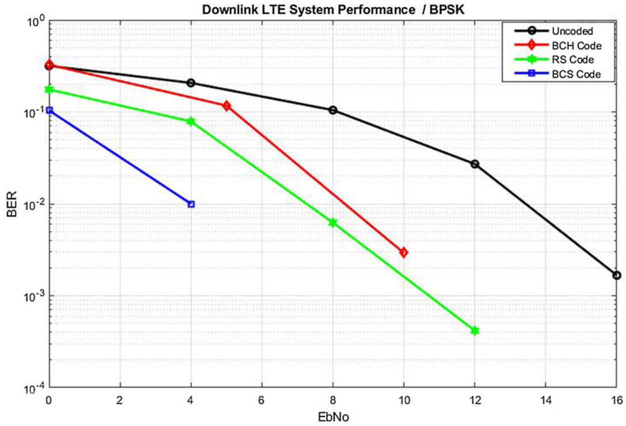

Fig. 4 Downlink LTE system performance with BPSK

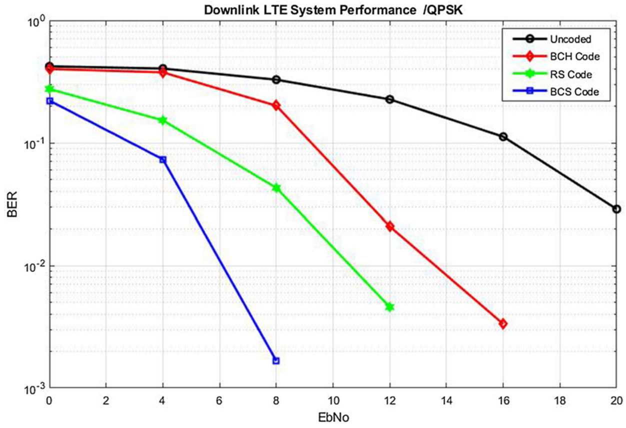

Fig. 5 Downlink LTE system performance with QPSK

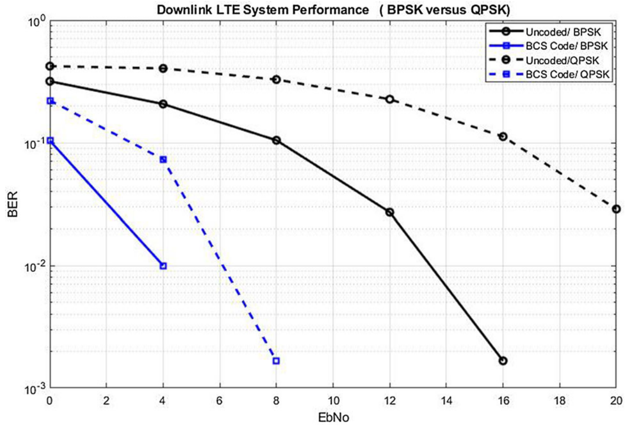

Fig. 6 Downlink LTE system performance using BPSK versus QPSK

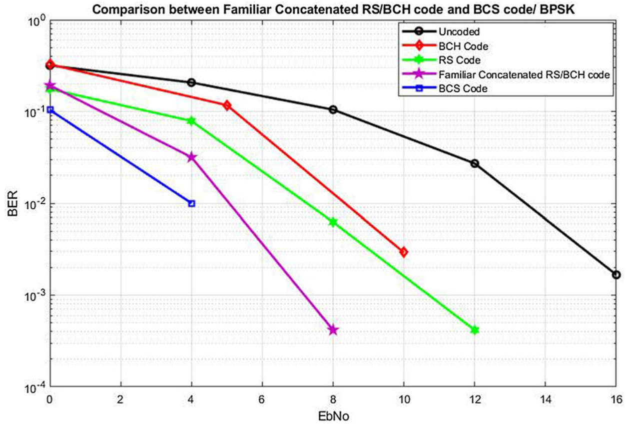

Fig. 7 BCS and familiar concatenated RS/BCH codes in the downlink LTE system/BPSK

The figures show that the performance of the DL LTE system was better using the proposed BCS code as compared with uncoded and RS and BCH codes for BPSK and QPSK modulation schemes. The worst performance was observed when a coding technique was not used. Thus, the use of coding techniques contributes to the robustness of the system against errors. Nonetheless, each RS and BCH code can improve the LTE system performance by decreasing BER against EbNo, which increases its reliability. However, the use of both codes together with the interleaver in the proposed BCS code is a better option than using each code alone to improve system performance further in both modulation schemes. Using BCS code in the LTE system achieved more than 3 and 4 dB coding gain at 10^{-2} against the RS and BCH codes for the BPSK modulation scheme, respectively. Meanwhile, the BCS code also achieved about 5 and 7 dB coding gain at 10^{-2} against RS and BCH codes for the QPSK modulation scheme, respectively. The improvement from using the BCS code may be attributed to the high capability of the coding techniques in error correction in two stages (BCH and RS codes). This suitable combination of codes may also be efficient in correcting random and burst errors, especially with the use of an interleaver to disperse burst errors and help error correction.

The performance of the DL LTE system in the BPSK and QPSK modulation schemes was compared and the results of the comparison are shown in Fig. 6. The results demonstrated that the performance of the DL LTE system was better when the BPSK modulation scheme was used as compared with the QPSK modulation scheme in the uncoded case and with the proposed BCS code. The proposed BCS code in the DL LTE system achieved 2 dB coding gain at 10^{-2} for BPSK against QPSK modulation schemes.

The comparison between the performance of the DL LTE system using the familiar concatenated RS/BCH codes and the novel BCS code is shown in Figs. 7 and 8. Although using the familiar concatenated RS/BCH codes in the DL LTE system against single RS and BCH codes showed good improvements, the novel BCS code still outperformed the familiar concatenated techniques, achieving around 2 and 3 dB coding gain at 2×10^{-2} in the BPSK and QPSK modulation schemes, respectively. The proposed BCS code

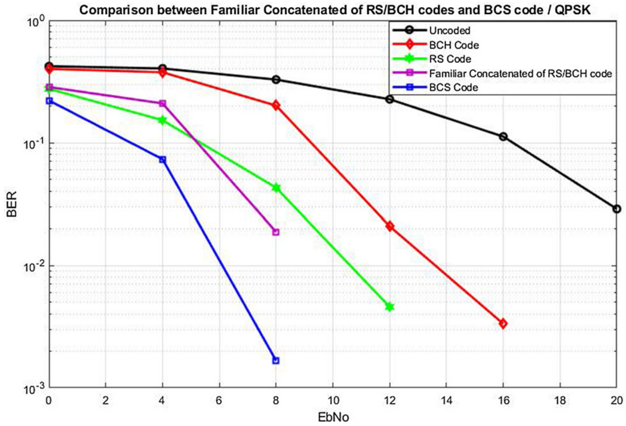

Fig. 8 BCS and familiar concatenated RS/BCH codes in the downlink LTE system/ QPSK

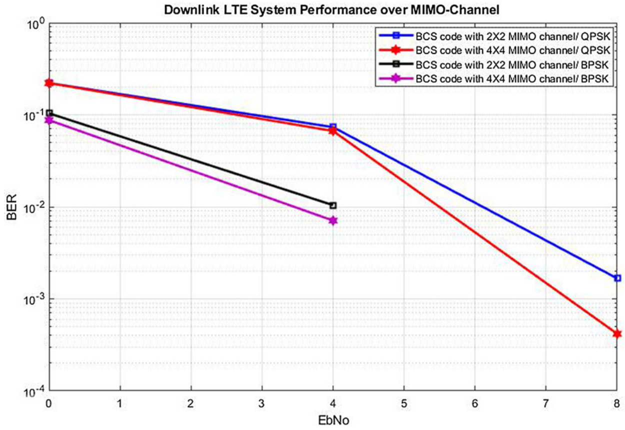

Fig. 9 Downlink LTE system performance over the MIMO channel

outperformed all familiar concatenated RS/BCH codes and single codes (BCH and RS codes) in correcting errors. Thus, it can be considered a strong code with high reliability in wireless communication systems.

The system capacity increased when the number of antennas in the MIMO channel was increased, which in turn improved system performance as shown in Fig. 9. The results revealed that the BER decreased by increasing the number of antennas in the MIMO channel from 2 × 2 to 4 × 4, thereby improving system performance, which achieved 0.5 dB coding gain at 10^{-2} in the two modulation schemes.

5 Conclusion

In this paper, we present a novel BCS code with a DL LTE system over an LTE-MIMO channel. The DL LTE system was simulated using MATLAB software for the BPSK and QPSK modulation schemes over multipath fading channel. The results showed that the use of the novel BCS code in the DL LTE system improved system performance further by decreasing the BER as compared with the conventional concatenated RS/BCH codes and single RS and BCH codes. Using BCS code in the LTE system achieved around 3 and 4 dB coding gain at 10^{-2} for the BPSK modulation scheme and about 5 and 7 dB for the QPSK modulation scheme against RS and BCH codes, respectively. It also achieved around 2 and 3 dB coding gain at 2×10^{-2} against conventional concatenated RS/BCH codes for the BPSK and QPSK modulation schemes, respectively. The DL LTE system performance was the best when BPSK is used, achieving 2dB coding gain at 10^{-2} against QPSK. The effect of increasing the number of antennas in the MIMO channel was also investigated. The DL LTE system performance improved when the 4 × 4 was used, achieving 0.5dB coding gain at 10^{-2} against 2 × 2 MIMO channel in both modulation schemes.

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