Design and Performance Analysis of Channel Coding Scheme based on Multiplication by Alphabet-9

Nasaruddin[1], B.Yuhanda[2], Elizar[1] and Syahrial[1]
[1]*Department of Electrical Engineering, Syiah Kuala University, Banda Aceh, Indonesia.*
[2]*Inspectorat Aceh Government Office, Banda Aceh, Indonesia.*
nasaruddin@unsyiah.ac.id

***Abstract*—Currently, communication system plays an important role in people's lives especially in activities such as mobile communications and internet access. However, the transmission of information via communication channel has a major problem; it is very sensitive to disruptions such as noises, distortions, interferences, and multipath fading. Therefore, the transmitted information is prone to errors or face incorrect detection at the receiver, thus decreasing the system's performance. One of the techniques to overcome this problem is by applying the channel coding. In this research, a new channel coding scheme based-on multiplication by alphabet-9 is proposed. The proposed coding and encoder-decoder structure are designed by using mathematical derivations. The proposed channel coding scheme is then simulated in a communication system model to analyze its performance in terms of bit error rate (BER) and throughput. The results show that the BER of the proposed channel coding is lower than those of Hamming code and Reed-Solomon codes for a short code-length. Moreover, the throughput of the proposed coding is also higher than those of the Hamming and Reed-Solomon codes. Finally, it can be concluded that the proposed channel coding scheme has an ability to improve the communication system performance. Thus, its application in a digital communication system seems to be very promising.**

***Index Terms*—Channel Coding; Alphabet-9; Transmission Performance; Bit Error Rate; Throughput.**

I. INTRODUCTION

The demand for digital communication to transmit voice, image, video and other types of multimedia information is increasing from time to time. These types of information transmission require an efficient and reliable communication system. However, the process of digital information transmission over a communication channel is subjected to noises, signal distortions, interferences, and multipath fading of wireless channels. This leads to errors of information and incorrect detection at the receiver, causing a decrease in the system's performance. One of the techniques to reduce the information transmission's error is the use of channel coding in the form of error correction coding (ECC) techniques in order to improve the performance of the system [1]. ECC is used to improve the reliability of the information transmission between the transmitter and the receiver. In this technique, redundancy bits are added to the information signal before the transmission over a noisy channel. The recovery process is required to extract the original signal at the receiver. Thus, the performance of the system can be improved by reducing bit error rate of the received information [2].

The main issue in channel coding is designing an efficient and simple encoder-decoder structure so that the implementation of the system can be made easier and the probability of transmission's error can be minimized. Optimal channel coding design has been proven to increase the performance and the system's security [3]. Nowadays, various channel coding schemes have been implemented both for the communication over cables such as optical orthogonal code introduced in [4] and over wireless such as Hamming code [5-7], Reed-Solomon code [8-10], Polar codes [11], BCH and Convolutional codes [12]. Hamming code is the oldest linear channel coding. This method has been implemented in various communication systems [2], [13]. Thereafter, Reed-Solomon (RS) code is designed based on the algebraic equations. It has been implemented in various communication systems, such as mobile communications [8] and Wimax system [14].

In this research, a new channel coding scheme based on multiplication by alphabet-9 is designed. The performance of the proposed scheme was analyzed when it is applied in a digital communication system. As far as channel coding is concerned, the design of coding and its encoder-decoder structure based on the multiplication by alphabet-9 has never been introduced as an ECC technique for digital information transmission. Thus, this new scheme could be a novel coding for the channel coding scheme. This coding can be classified as a linear code based on its characteristics and features. The coding is quite close to Hamming code, which is the most popular linear code at the moment. However, there are some parameters that distinguish this new proposed code from Hamming code and Reed-Solomon code, as discussed later in this paper. Based on the mathematical design, the encoder-decoder structure for the proposed coding is determined. Then, the designed coding and its encoder-decoder structure are simulated in a communication system model using Matlab in order to obtain the system's performance. The system's performance is analyzed based on the parameters of bit error rate (BER) and throughput. The results show that the proposed coding scheme has an ability to produce a lower BER and a higher throughput compared to those of the Hamming code (7, 4) and Reed-Solomon (15, 13). Therefore, the proposed coding based on multiplication by alphabet-9 has a potential to become a new scheme for channel coding in a digital communication system.

II. LITERATURE REVIEW

A. Hamming Code

Linear block codes are the most widely used codes in various applications of digital communication systems [7]. Hamming code and Reed-Solomon codes are two examples of linear block codes. The proposed code is also a kind of linear block codes. It is close to the Hamming and Reed-Solomon codes properties.

This review focuses on both codings. The Hamming code is a form of forward error correcting (FEC) code, where it has an ability to detect and correct the data error received by the receiver. Hamming code has the length of code as follows [15]:

$$n = 2^m - 1 \tag{1}$$

and the data message (information bits) is:

$$k = 2^m - m - 1 \tag{2}$$

where: m = bit symbols
$m \geq 2$ and it is an integer

Hamming code is designed for the minimum Hamming distance of $d = 3$. Hamming distance is the smallest non-zero from codewords. For example, the distance between the codewords of (1 0 0 0 1 1 0) and (0 1 0 0 0 1 1) is four. A codeword is a set of binary (0, 1) of length n bits that consist of data message k and redundancy r bits. Hamming code is denoted by Hamming (n, k) and constructed by G and H matrices. Then, the code rate can be calculated as:

$$R = \frac{k}{n} \tag{3}$$

For example, a Hamming (7,4) code is represented by the following generator matrices [15]:

$$G = \begin{bmatrix} 1\,0\,0\,0\,1\,1\,0 \\ 0\,1\,0\,0\,0\,1\,1 \\ 0\,0\,1\,0\,1\,1\,1 \\ 0\,0\,0\,1\,1\,0\,1 \end{bmatrix} \tag{4}$$

and

$$H = \begin{bmatrix} 1\,0\,1\,1\,1\,0\,0 \\ 1\,1\,1\,0\,0\,1\,0 \\ 0\,1\,1\,1\,0\,0\,1 \end{bmatrix} \tag{5}$$

It can be verified by $H.G^T = 0$, where G^T is the transpose of the matrix G.

B. Reed-Solomon Code

Reed-Solomon (RS) code is a code that was introduced by Irving Reed and Gus Solomon in 1960 [9]. This code is systematically described to obtain a code that has the ability to correct both random and burst error bits at the received data packets [10]. An RS code is denoted by $(n, k) = (2^m - 1, 2^m - 1 - 2t)$, where $n - k = 2t$ is the number of parity bits and t is the number of bits that can be corrected. The RS code is constructed using a polynomial generator as follows [10]:

$$g(x) = (x + \alpha^b)(x + \alpha^{b+1}) \ldots (x + \alpha^{b+2t-1}) \tag{6}$$

$$g(x) = g_0 + g_1 x + g_1 x^2 + \cdots + g_{2t-1} x^{2t-1} + x^{2t} \tag{7}$$

The degree of a polynomial generator is the same as the number of parity bits, that is, $2t$ so that the root of the polynomial generator is a primitive element of the Galois field and b can be chosen to be equal to zero (b=0). The primitive element (α) has the same degree as follows:

$$\alpha, \alpha^2, \alpha^3, \ldots, \alpha^{2t} \tag{8}$$

The RS encoder is used to encode the information bits by adding the parity bits to the original data (message). The polynomial codeword at an RS encoder can be obtained as:

$$U(x) = p(x) + x^{n-k} m(x) \tag{9}$$

where: $U(x)$ = the codeword
$p(x)$ = the parity bit that can be obtained by:

$$p(x) = x^{n-k} m(x) \bmod g(x) \tag{10}$$

and $m(x)$ is the data message. At a decoder, the received codeword is represented by:

$$r(x) = U(x) + e(x) \tag{11}$$

where: $r(x)$ = the received codeword
$U(x)$ = the transmitted codeword
$e(x)$ = the error bit

If $r(x) = U(x)$, there is no error bit at the received bits.

III. PROPOSED CODE DESIGN

The design of Alphabet-9 code is divided into two stages: the code generation stage and the design of encoder-decoder structure stage.

A. Encoding

The procedures of Alphabet-9 code generation on the encoder are as follows:

1. Determining the value of variable $i = \{1,2, \ldots, 5\}$.
2. Determining the multiplication of the variable i by Alphabet-9 through the following mathematical equation:

$$i \times 9 = R \tag{12}$$

3. Assuming that R has two decimal digits, r_1 and r_2, as redundancies.
4. Especially for $i = 1$, R has only one digit and is then assumed as "09", where the first digit, r_1, is 0 and the second digit, r_2, is 9.
5. Converting the decimal value of r_1 and r_2 into binary values of $\{0, 1\}$ with a four-bit code.

For example, for $i = 1$ and by using Equation (12), $R = 9$ is obtained and then R be 09 as in step 4). Subsequently, the decimal value of $r_1 = 0$ is converted into 4 digit binary of 0000, and then $r_2 = 9$ into 1001. Using this procedure, the encoder redundancy can be observed for all variable i as in Table 1.

In the channel coding, redundancy bit will be added to the encoder's information bits to form a transmitted codeword. Suppose the information bits are k bits, the length of the codeword of the proposed code can be calculated by using the following equation, i.e.:

$$n = r_1 + k + r_2 \tag{13}$$

Thus, the above variables will form the (n, k) code based on the multiplication by Alphabet-9. The encoder structure for Alphabet-9 coding is as shown in Figure 1. The encoder requires two redundancy bit generators and k input bits generators to form a codeword. Based on the encoder structure, k bits of information will be added by redundancy bits (r_1 and r_2), which will be a codeword. Suppose the information is 1100 and $R\{r_{1,}r_2\} = 09$, then the codeword is 000011001001. The encoder codeword is transmitted through a communication channel to the receiver via a decoder. The information bit errors can occur during the transmission due to the influence of noises and this leads to a decrease in the system's performance.

Table 1
Encoder Redundancy

i	r_1	r_2
1	0000	1001
2	0001	1000
3	0010	0111
4	0011	0110
5	0101	0100

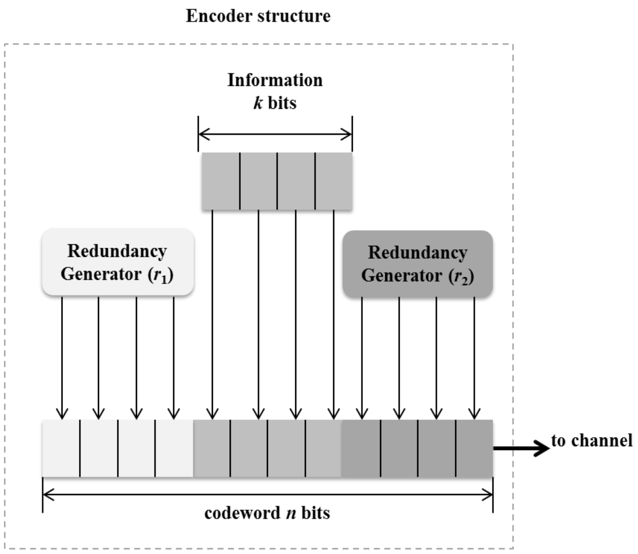

Figure 1: Encoder structure for the proposed code

Table 2
Decoder Syndrome

j	s_1	s_2
10	1001	0000
9	1000	0001
8	0111	0010
7	0110	0011
6	0100	0101

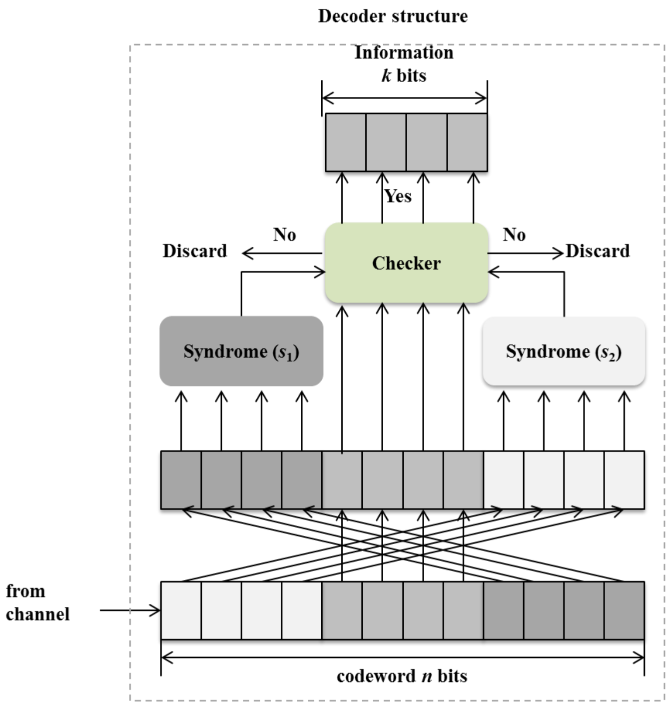

Figure 2: Decoder structure for the proposed code

B. Decoding

In designing a decoder for the Alphabet-9 code, one of the most important steps is obtaining the coding syndrome. The coding syndrome procedure is as follows:

1. Determining the value of variable $j = \{10, 9, \ldots, 6\}$.
2. Determining the multiplication of the variable j by Alphabet-9 through the following mathematical equation:

$$j \times 9 = S \tag{14}$$

3. S has two decimal digits, s_1 and s_2, as syndromes.
4. Converting the decimal value of s_1 and s_2 into binary values of $\{0, 1\}$ with a four-bit code.

For example, for $j = 10$ and using Equation (14), $S = 90$ is obtained. Subsequently, the decimal value of $s_1 = 9$ is converted into 4 digit binary of 1001, and thus $s_2 = 0$ into the binary of 0000. Using the procedure, the decoder syndromes can be observed for all variable j as in Table 2.

The decoding process will determine whether the transmitted information can be recovered and extracted according to the information sent by the transmitter via the encoder. The decoder structure for Alphabet-9 coding is given in Figure 2. The working principle of this decoder is as follows:

1. The decoder will receive the encoder's transmitted codeword.
2. The codeword will be mapped into its information and s_1 and s_2 syndromes as shown in Figure 2.
3. The checker will examine the syndromes and the information before both bits are extracted from the decoder.
4. The checker has knowledge in the form of a code book of r_1, r_2, s_1 and s_2, and it gives decision by the following two possibilities:

- If $s_1 = r_2$ and $s_2 = r_1$, then the information will be received.
- If the above condition is not fulfilled, then the information will be discarded.

5. If the error bit occurs at the information bit, the checker is then processed by the following expressions:

$$y[n] = x[n] + e[n] \tag{15}$$

where $y[n]$ is the received codeword by the decoder, $x[n]$ is the transmitted codeword by the encoder and $e[n]$ is the error bits.

- To recover the information bit, the error bit pattern should be obtained by:

$$e[n] = y[n] - x[n] \tag{16}$$
$$x[n] = y[n] - e[n] \tag{17}$$

- If $y[n] = x[n]$, there is no error in the information. Otherwise, no data are received by the receiver.

Assuming that the decoder receives the codeword without any error, the codeword is the same as the transmitted codeword by the encoder e.g., 000011001001. Then, the codeword is mapped into the syndrome, that is, 100111000000. Since the checker has the knowledge of redundancy, it will confirm the syndrome with redundancy. If $s_1 = r_2$ and $s_2 = r_1$, then the correct information is received e.g., 1100. Otherwise, if one or more error bits of the codeword is/are received by the decoder, for example, 010011011001, the mapped codeword is 100111010100. The checker will detect that $s_1 = r_2$ and $s_2 \neq r_1$ and then decided that the data is discarded. The checker also detects the error at the data message by using the expressions in Equation (15) to (17).

IV. SIMULATION MODEL AND PERFORMANCE ANALYSIS

A. Simulation Model

A simple simulation model of the proposed codes is developed to evaluate the performance in terms of BER and throughput, as shown in Figure 3. In general, this model consists of a transmitter, a channel, and a receiver. A computer simulation is developed by using Matlab programming. The simulation starts from generating input data by random data generator. The input data is a sequence of digitized information in the form of binary 0 or 1. Then, they are encoded by the proposed encoder. The encoder will map the sequence to a distinct codeword. The mapping is the process of *k* digits incoming into the encoder and *n* digits outgoing from the encoder. The output of the encoder is modulated by BPSK modulator. Furthermore, the encoded and modulated information are transformed into the specified signals for transmission through additive white Gaussian noise (AWGN) channel. At the channel, some noises will be added to the transmitted signals that cause some errors. At the receiver, the received information carries out the reverse process of the transmitter. The demodulator will demodulate the incoming noisy signal before it is passed onto the decoder. The decoder, by the decoding rule, will estimate the transmitted codeword in order to minimize error probability. Finally, BER is calculated by comparing the transmitted data to the received data. Based on the calculated BER, the throughput can be obtained.

In this paper, the computer simulation has been conducted in Matlab in order to evaluate the performances of the proposed codes, Reed-Solomon code and the Hamming code over AWGN channel. The simulation parameters are shown in Table 3.

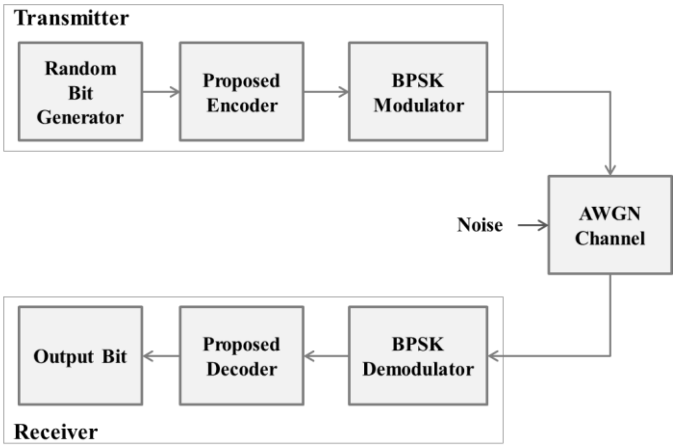

Figure 3: System model for the proposed code simulation

Table 3
Computer simulation parameters

No	Parameter	Value(s)
1	Input	10^6 bits
2	Proposed Codes	(11, 3), (12, 4) and (13, 5)
3	Hamming code	(7, 4)
4	Reed-Solomon code	(15, 13)
5	Channel	AWGN
6	Modulation	BPSK
7	Data Rate	10 Mbps
8	SNR	0 – 12 dB

B. Performance Analysis

Based on the simulation model, there are several ways or methods to analyze the performance of communication systems, as described below:

- The signal to noise ratio (SNR). It is a ratio of signal power to noise power at the receiver. SNR is represented in the unit of decibel (dB) and is calculated as [16]:

$$SNR(dB) = 10\log_{10}(SNR) \tag{18}$$

- The bit error rate (BER). It is often used as a parameter to analyze the performance of digital communication system. BER is the number of error bits received by the receiver compared to the total number of transmitted bits. In other words, BER is the probability of error bit received by the destination expressed by [17]:

$$BER = \frac{\text{Number of error bits}}{\text{Total of transmitted bits}} \tag{19}$$

- The throughput. It is the amount of information bits transmitted to the destination in a unit of time. It is also defined as the number of data packets successfully transmitted to the destination in a second. This parameter is commonly used in measuring the performance of the communication system and can be modified from [18] as follows:

$$T_R = (1 - BER) \times R \tag{20}$$

where: $R =$ the data rate.

V. Results and Discussions

A. Bit Error Rate

Bit error rate (BER) is one of the general parameters used to analyze the performance of communication system. In order to reduce the BER, a communication system needs to use an appropriate channel coding scheme. The BER performance of the proposed code has been analyzed by using a computer simulation. The comparison between the proposed code and the existing channel codes are shown in Figure 4. It can be observed that the proposed (12, 4) code shows a better performance compared to those of Hamming code (7, 4) and Reed-Solomon code (15, 13). The codings can be fairly compared because they have the same ability for a single error correction ($t = 1$) and the same number of bit symbols, which are $m = 4$ and $m = k = 4$ for the proposed code, whilst the length of code is different from each other. In particular, when BER=10^{-3}, the proposed code needs SNR value of 6.2 dB, whilst the Hamming code and Reed-Solomon code need SNR value of 9.8 dB and 12 dB respectively. Therefore, it gives the coding gain of 3.6 dB and 5.8 dB compared to the performance of Hamming and Reed-Solomon codes, respectively. Furthermore, if the performance of proposed code is compared to the performance of uncoded AWGN, it gives a coding gain of 7.4 dB at BER=10^{-2}. So this is quite significant values for a new coding scheme. However, the code rate of the proposed code is $r_{\text{proposed}} = 1/3$, which is smaller than those of the Hamming, $r_{\text{Hamming}} = 4/7$ and $r_{\text{Reed-Solomon}} = 13/15$. Reed-Solomon codes typically have a very high rate depending on the error correction capability needed. In general, Figure 4 shows that the BER decreases as the SNR value is increased. This indicates that the bit error occurs because of the noise in the communication channel. However, this can be minimized by the addition of the signal power.

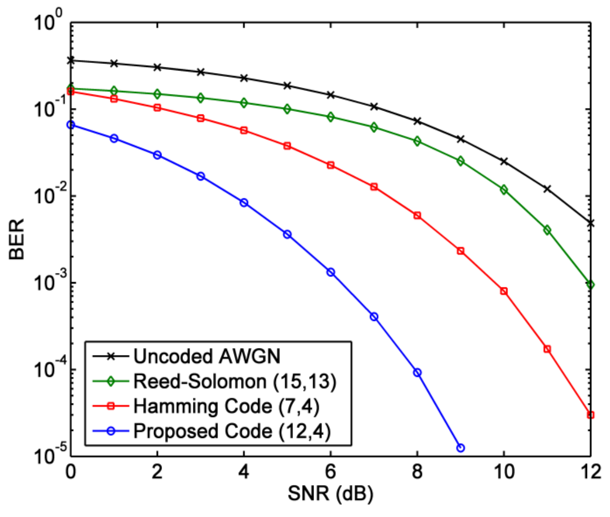

Figure 4: BER performance versus SNR for the proposed code, Hamming code and Reed-Solomon code

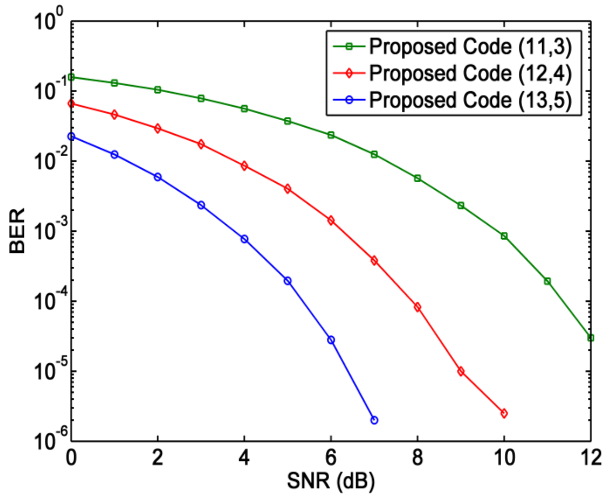

Figure 5: BER performance versus SNR for several proposed codes

The BER performance with data bits ($k = 3, 4$ and 5) and different length of proposed codes have also been simulated and the results are shown in Figure 5. The results show that the BER performance of the proposed codes is significantly improved when the number of data bits and the length of codewords are increased. For example, to reach BER=10^{-4}, the proposed (11, 3), (12, 4) and (13, 5) codes need SNR values of 11.5 dB, 7.8 dB, and 5.4 dB respectively. From the results, coding gain between (11, 3) code and (12, 4) code is 3.7 dB. Moreover, the coding gain of 2.4 dB is obtained between (13, 5) code and (12, 4) code. Furthermore, in addition to improving BER performance, the proposed code has another interesting added feature; it also increases the transmission rate. It is shown in the results that the data rate (r) for each (11, 3), (12, 4) and (13, 5) codes are 0.27, 0.33 and 0.38, respectively.

B. Throughput

The throughput performance is critical in communication systems because it indicates the ability of the system to transmit the amount of information to the receiver in each second. To this end, computer simulations have been conducted in order to analyze the throughput of the proposed code (12, 4). The result is compared to those of the Hamming code (7, 4) and Reed-Solomon Code (15, 13) for the data rate of 10 Mbps. The result is shown in Figure 6. Generally, for SNR<10 dB, the throughput performance of the proposed code is better than those of the Hamming code and Reed-Solomon code. As an example, for an SNR value of 5 dB, the throughput of the proposed code is 9.92 Mbps while those of the Hamming code and Reed-Solomon code are 9.62 Mbps and 9 Mbps, respectively. Thus, the proposed code can improve the system's throughput by 0.3 Mbps and 0.92 Mbps compared to the throughput of Hamming and Reed-Solomon codes, respectively. However, for SNR = 12 dB, the throughput performance of the coding schemes is similar.

The simulation has also been conducted to find out the effect of increased number of data bits and the length of a codeword of the proposed codes on the throughput performance. The result is presented in Figure 7. In general, the throughput performance is critically influenced by the number of data bits and the length of the codeword. Bigger data bits resulted in better throughput. A similar thing happened to the length of the codeword: Longer codeword resulted in better throughput. For SNR value of 5 dB, the proposed (12, 4) code increases the throughput by 0.34 Mbps compared to that of the proposed (11, 3) code. When using the proposed (13, 5) code, the throughput improvement obtained is 0.381 Mbps when compared to that of the proposed (11, 3) code.

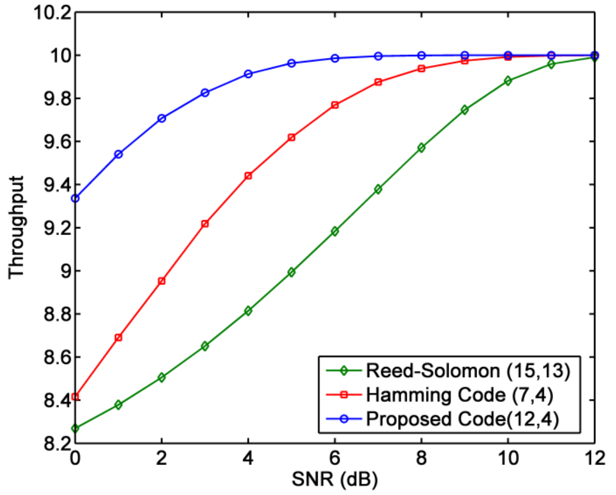

Figure 6: Throughput performance versus SNR for the proposed code, Reed Solomon and the Hamming code

From Figure 4 and 6, it can be seen that the BER and the throughput performance of the proposed code are better than those of the Hamming and Reed Solomon codes. However, the code rate of the proposed code is lower than those of the Hamming and Reed-Solomon codes. This can be overcome by increasing the number of data bits of the code so that the data rate will be increased. Furthermore, the proposed code performance is heavily influenced by the number of data bits and the length of the codeword. For the noise sensitive digital communication applications, such as data and video transmission, the proposed code can be applied by using bigger data bits and longer codeword lengths.

The proposed code has many similarities with the Hamming and Reed-Solomon codes in terms of features and code construction. Some of the comparable features among the channel coding schemes are shown in Table 4. There are two interesting features from the proposed code that are much better than those of the Hamming and Reed-Solomon codes. The proposed codes have lower BER and higher throughput. This is because the proposed code uses two blocks of redundancy bit that makes the code longer. Theoretically, the use of two blocks of redundancy bits can increase the security level of the system because the data bits will be flanked by both blocks. However, the security issue is not the focus of this research.

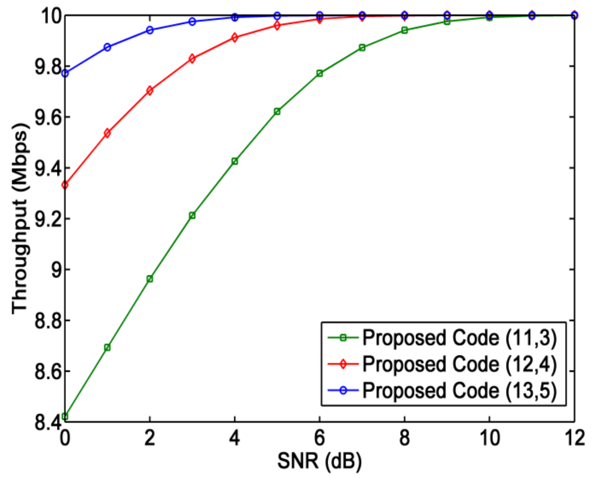

Figure 7: Throughput performance versus SNR for the proposed codes with various codeword lengths

Table 4
Features of Reed-Solomon, Hamming, and the Proposed Codes

No	Parameter	Reed-Solomon Code	Hamming Code	Proposed Code
1	Code complexity	High	Moderate	Simple
2	Code notation	(n, k)	(n, k)	(n, k)
3	Data symbols	k	k	k
4	Code length	$2^m - 1$	$n = k + r$	$n = r_1 + k + r_2$
5	Redundancy	$n - k = 2t$	r	r_1 and r_2
6	BER	High	Moderate	Low
7	Throughput	Low	Moderate	High
8	Bit rate	High	Moderate	Low

VI. Conclusion

In this paper, we have designed a novel channel coding based on multiplication by the Alphabet-9. The designed coding procedure related to the encoder redundancy and the decoder syndrome has been presented as well as the corresponding encoder, and decoder for the proposed coding method have been constructed. Furthermore, a computer simulation model of the proposed coding has been introduced in order to analyze the performance of the coding in terms of BER and throughput. The computer simulation was conducted by using Matlab programming in order to simulate the impact of the coding technique on the system's performance. The results show that the BER of the proposed coding performs better than those of the Hamming code and Reed-Solomon code with the coding gains of 3.6 dB and 5.8 dB, respectively. The BER of the proposed coding decreases with the increase of the code length and the information bit. The performance of the proposed coding could also produce higher throughput than those of the Hamming and Reed-Solomon codes as reflected in the simulation. When the SNR is 5 dB, the proposed code increased the throughput about 0.3 Mbps and 0.92 Mbps compared to the Hamming and Reed-Solomon codes, respectively. Moreover, the throughput of the proposed code increases with the increase of the coding length and the information bits. Therefore, it is believed that the proposed novel channel coding scheme could perform better in a digital communication system with lower BER and higher throughput.

References

[1] C. E. Shannon, "A Mathematical Theory of Communication," *The Bell System Technical Journal*, vol. 27, pp. 379-423, 1948.

[2] J. C. Moreira and P. G. Farrel, *Essentials of Error-Control Coding*, England: John Wiley & Sons. 2006.

[3] M. Franklin, R. Gelles, R. Ostrovsky, and L. J. Schulman, "Optimal Coding for Streaming Authentication and Interactive Communication," *IEEE Transactions on Information Theory*, vol. 61, no. 1, pp. 133-145, 2015.

[4] Nasaruddin and T. Tsujioka, "A novel design of reconfigurable wavelength-time optical codes to enhance security in optical CDMA networks," *IEICE Trans. Communication*, vol.E99-B, no. 6, pp. 2516-2524, 2008.

[5] T. Zhang and Q. Ding, "Design of (15, 11) Hamming Code Encoding and Decoding System Based on FPGA," in *Proceedings of International Conference on Instrumentation, Measurement, Computer, Communication and Control*, pp. 704-707, 2011.

[6] R. Ma and S. Cheng, "The Universality of Generalized Hamming Code for Multiple Sources," *IEEE Transactions on Communications*, vol. 59, no. 10, pp. 2641-2647, 2011.

[7] Nasaruddin and R. Kurnia, "Hamming Coding for Multi-relay Cooperative Quantize and Forward Networks," in *Proceedings of IEEE Region 10 Symposium* (TENSYMP), pp. 315-319, 2016.

[8] S. Siikavirta, J. Manner, and L. Wang, "Reed-Solomon feasibility in mobile transport," in *Proceedings of Cyber-Enabled Distributed Computing and Knowledge Discovery*, pp. 363-368, 2009.

[9] I.S. Reed and G. Solomon, "Polynomial Codes over Certain Finite Fields," *SIAM Journal of Applied Mathematics*, vol. 8, no. 2, pp. 300-304, 1960.

[10] C.K.P. Clarke, *Reed-Solomon Error Correction*. BBC R&D White Paper, WHP 031, July 2002.

[11] A. Bravo-Santos, "Polar Codes for the Rayleigh Fading Channel," *IEEE Communications Letters*, vol. 17, no. 12, pp. 2352-2355, 2013.

[12] Melinda, Nasaruddin, Syahrial, and A. Yuwaldi, "Performance of Trajectory Plot for Serial Concatenation of BCH and convolutional Codes," In *Proceedings of IEEE Comnetsat*, pp. 26-30, 2013.

[13] S. S. Sarnin, N. F. Naim, and W.N.S.W Muhamad, "Performance evaluation of phase shift keying modulation technique using BCH code, Cyclic code and Hamming code through AWGN channel model in communication system," in *Proceedings of Information Sciences and Interaction Sciences* (ICIS), pp. 60-65, 2010.

[14] R. Logeshwaran and I. J. L Paul, "Performance study on the suitability of Reed Solomon Codes in WiMAX," in *Proceedings of Wireless Communication and Sensor Computing*, ICWCSC 2010, pp. 1-4, 2010.

[15] D. J. Costello and S. Lin, *Error Control Coding*, Second Edition, Prentice Hall, NJ, 2004.

[16] H. Simon and M. Michael, *Modern Wireless Communication*, Pearson Prentice Hall. Upper Sadley River, New Jersey. 2005.

[17] J. Goldie and M. Wilson, "LVDS Performance: Bit Error Rate (BER) Testing Test Report #2," National Semiconductor Corporation Report, 2000.

[18] T. C. W. Schenk, G. Dolmans, and I. Modonesi, "Throughput of a MIMO OFDM based WLAN System," in *Proceedings of IEEE SCVT*, 2004.