Optimized Channel Coding of Control Channels for Mobile Packet Communication

Young-Joon Song

Abstract

This paper proposes a coding scheme of control channel for mobile packet communication to maximize the minimum Hamming distance, which is based on shifting of basis vectors of Reed Muller code with optimized dynamic puncturing and/or(partial) sequence repetition. Since the maximum likelihood decoding can be performed using the extremely simple FHT(Fast Hadamard Transformation), it is suitable for real time optimum decoding of control channel information with very little complexity. We show applications of the proposed coding method to TFCI(Transport Format Combination Indicator) code in split and normal modes of 3GPP W-CDMA system. We also discuss how this method can reduce rate indication error over AWGN(Additive White Gaussian Noise) as well as fading channels when the proposed coding scheme is applied to 1xEV-DV system of 3rd generation partnership project 2(3GPP2) to indicate the data rate transmitted on the reverse traffic channel by a Mobile Station(MS).

Key words : Reed Muller Code, FHT, W-CDMA, TFCI, 1xEV-DV, RRI.

Ⅰ. Background

The control channel carries the information related to decoding of data part information such as MAC (Medium Access Control) ID, types of channel coding, code rate, number of logical channels per physical channel, size of payload, length of transmission time interval, etc...[1]~[7]. For the mobile packet communication, the period of control channel information transmission is normally in the range of 2 msec~80 msec according to the packet size and transmission time interval[1]~[7].

The decoding of data part information is processed after reliable decoding of control channel information and thus the decoding error of control channel needs packet retransmission. The simplicity and real time decoding of control channel information help reducing total processing delay. Considering these criteria, a control channel coding scheme based on RM(Reed Muller) code with optimized dynamic puncturing and/or (partial) sequence repetition is discussed. Since the maximum likelihood decoding of RM code can be performed using the extremely simple FHT(Fast Hadamard Transformation)[8],[9], it is suitable for real time decoding of control channel information.

We show that the proposed coding scheme can minimize the loss of Hamming distance in TFCI (Transport Format Combination Indicator) code in split and normal modes of 3GPP(3rd Generation Partnership Project) W-CDMA(Wideband Code Division Multiple Access) system[10]~[12]. We also show how this proposed scheme improve the performance of R-RICH (Reverse Rate Indication Channel) which can be used to indicate the data rate transmitted on the reverse traffic channel by a Mobile Station (MS) of 1xEV-DV system of 3rd generation partnership project 2 (3GPP2)[13].

Ⅱ. Shifting of Basis Vectors and Optimum Puncturing Pattern

The 1st order RM code shows the maximum possible minimum Hamming distance property and provides the extremely fast maximum likelihood decoding using FHT[8],[9],[14]. If a code achieves maximum possible minimum Hamming distance, we call the code satisfies the minimum distance bound. In this section, shifting of basis vectors of RM code to minimize the distance loss due to puncturing is discussed.

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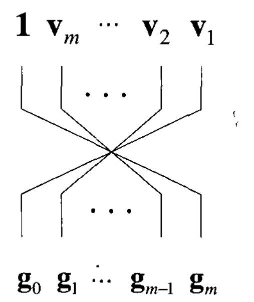


Fig. 1. Shifting of basis vectors of 1st order Reed Muller code.

2-1 Shifting of Basis Vectors of RM Code

The 1st order Reed Muller code, $\mathfrak{R}(1, m)$ have length 2^m, dimension $m+1$, and maximum possible distance 2^{m-1}[8]. Thus the generator matrix of a $\mathfrak{R}(1, m)$ is expressed as (1) and thus the information bits of length $k=m+1$, $\mathbf{d}=(d_0\ d_m\ d_{m-1} \cdots d_1)$, is encoded by (2) and becomes a codeword of length 2^m[8].

$$\mathbf{G} = [1\,\mathbf{v}_m \cdots \mathbf{v}_1]^T \tag{1}$$

$$\mathbf{c} = \mathbf{dG} = (d_0\ d_m \cdots d_1)\begin{bmatrix} 1 \\ \mathbf{v}_m \\ \vdots \\ \mathbf{v}_1 \end{bmatrix} \tag{2}$$

Now consider the basis shifting of 1st order Reed Muller code of Fig. 1. This basis shifting is just simple row matrix operation and thus does not change the coding property. The equivalent generator matrix is expressed as (3)

$$\mathbf{G} = [\mathbf{g}_0\ \mathbf{g}_1 \cdots \mathbf{g}_{m-1}\ \mathbf{g}_m]^T = [\,\mathbf{v}_1\ \mathbf{v}_2 \cdots \mathbf{v}_m\ 1]^T \tag{3}$$

and the codeword becomes

$$\mathbf{c} = \mathbf{dG} = (d_0\ d_m \cdots d_1)\begin{bmatrix} \mathbf{g}_0 \\ \mathbf{g}_1 \\ \vdots \\ \mathbf{g}_m \end{bmatrix} \tag{4}$$

2-2 Optimum Puncturing Pattern

Now assume $\mathfrak{R}(1, m)$ with shifting of basis vectors is used to transmit information bits in the range of $k = m+1-i$, $i=0,\cdots,m$. Then (4) can be equivalently expressed as (5).

$$\mathbf{c} = \mathbf{dG} = (d_0 \ldots d_{m-1})\begin{bmatrix} \mathbf{g}_0 \\ \vdots \\ \mathbf{g}_{m-1} \end{bmatrix} \tag{5}$$

Table 1. Optimum puncturing pattern and minimum distance for the 1st order RM code of length 64 after basis shifting.

k	Puncturing pattern	n	Minimum distance	Distance bound
6	0	64	32	32
5	0,32	62	32	32
4	0,16,32,48	60	32	32
3	0,8,16,24,32,40,48,5656	56	32	32
2	0,4,8,12,16,20,24,28, 32,36,40,44,48,52,56,60	48	32	32
1	0,2,4,6,8,10,12,14, 16,18,20,22,24,26,28,30, 32,34,36,38,40,42,44,46, 48,50,52,54,56,58,60,62	32	32	32

If we puncture coded bits of (5) at the locations of puncturing pattern (6), then the code length after puncturing becomes $2^m - 2^{m-k}$ and maintains the minimum distance bound 2^{m-1}.

$$2^k \cdot i,\ k = 1 \sim m,\ i = 0, \cdots, 2^{m-k}-1 \tag{6}$$

The puncturing pattern denotes the location of coded bits to be punctured. For example, Table 1 shows the optimum puncturing pattern for the 1st order RM code of length 64 which does not reduce the minimum Hamming distance. The first column of Table 1 is the information bits and the third column denotes the code length after puncturing using the optimum pattern of the second column. The resultant minimum distance satisfies the minimum distance bound 32[14].

Ⅲ. Applications

This section shows the applications of the proposed shifting of basis vectors of RM code, optimum puncturing pattern, and/or (partial) sequence repetition to not only TFCI code in split/normal modes of W-CDMA system but also RRI coding of 1xEV-DV of cdma2000 system.

In W-CDMA system, transport channel is accompanied by TFI (Transport Format Indicator) at each time event at which data is expected to arrive for the specific transport channel from the higher layers[3],[5],[6]. The physical layer combines the TFI information from different transport channels to the TFCI. The TFCI is transmitted in the physical control channel to inform the receiver which transport channels are active for the current frame. The maximum possible size of control information bits is informed by a higher layer signaling

[3],[5]. If TFCI is not decoded correctly, the whole data frame is lost since the TFCI indicates the transport format of the data on the same frame[5].

In 1xEV-DV of cdma2000 system, R-RICH is under discussion and RRI (Reverse Rate Indicator) coding can be used by a MS to indicate the data rate transmitted on the reverse traffic channel[2],[13]. The data rate is represented by up to 7 bits at the rate of one indicator per 20 msec. If the RRI information is wrongly decoded, the transmitted packet data from a MS during 20 msec will be wrongly decoded and BS will ask for the retransmission of that packet again since it indicates the data rate on the packet data.

3-1 TFCI Coding in Split Mode

For the downlink high speed packet transmission, if one of the DCH (Dedicated Channel) is associated with a DSCH (Downlink Shared Channel), the TFCI code word will be in split mode. In this mode, the information bits are coded using the 1st order (16,5) RM code after shifting basis vectors.

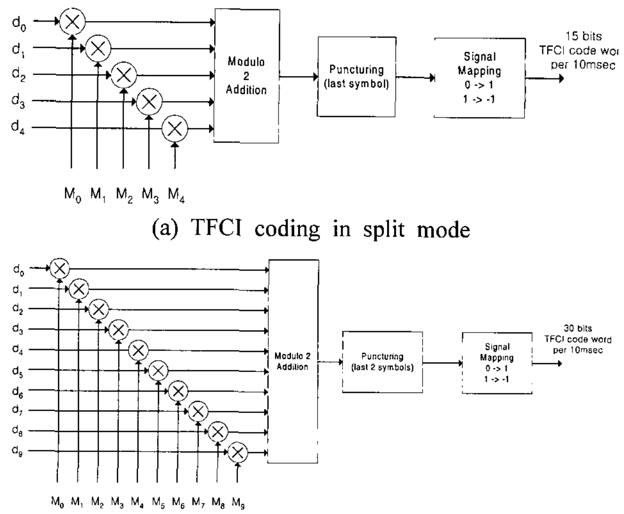
The maximum possible size of control information bits is informed by a higher layer signaling[3],[5]. And thus we can assume the size of information bits is varying in the range of $5-i$, $i=0,\cdots,4$. Therefore (4) can be equivalently expressed as

$$\mathbf{c}=\mathbf{dG}=(d_0\ \ldots\ d_{4-i})\begin{bmatrix} g_0 \\ \vdots \\ g_{4-i}\end{bmatrix},\ i=0,\cdots,4 \tag{7}$$

where basis vectors are:

$\mathbf{g}_0$ = [0101010101010101]
$\mathbf{g}_1$ = [0011001100110011]
$\mathbf{g}_2$ = [0000111100001111]
$\mathbf{g}_3$ = [0000000011111111]
$\mathbf{g}_4$ = [1111111111111111]

And then we should puncture one bit for 15 slots per frame structure of W-CDMA system. Thus one coded bit is transmitted in one slot time and becomes 15 coded bits per frame. When TFCI carries 4 bits using $\Re(1,4)$ with basis vector shifting, we can maintain the distance bound 8 for (15, 4) binary linear code[14] using optimum puncturing pattern of 0th position from (6). Since puncturing pattern 0th position is included in all the other optimum puncturing patterns for 1, 2, 3, 4 bits of TFCI, puncturing 0th position bit results in no loss of minimum Hamming distance for these cases. Furthermore, if we puncture 0th position bit in the case of 5 bits TFCI, the resultant code word of length 15



(a) TFCI coding in split mode

(b) TFCI coding in normal mode

Fig. 2. TFCI coding in W-CDMA system.

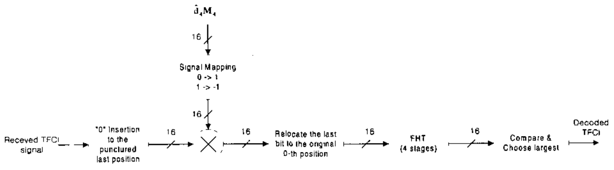
satisfies the minimum distance bound 7 for (15, 5) code[14]. If the shifting of basis vector of $\Re(1, 4)$ code and optimum puncturing were not used, there would be loss of minimum Hamming distance since without shifting of basis vectors of RM code, any puncturing pattern reduces the minimum distance.

TFCI coding in split mode is described in Fig. 2(a), and the following shows basis vectors of (16, 5) TFCI code in split mode:

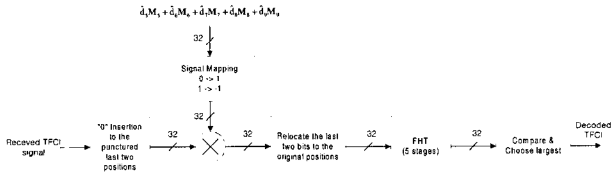
$\mathbf{M}_0$ = [1010101010101010]
$\mathbf{M}_1$ = [0110011001100110]
$\mathbf{M}_2$ = [0001111000011110]
$\mathbf{M}_3$ = [0000000111111110]
$\mathbf{M}_4$ = [1111111111111111]

We can easily see that the TFCI coding is the same as $\Re(1,4)$ after shifting of basis vectors except moving the 0th position bit of basis vectors to the last position since the last position shall be punctured in the physical layer specification of W-CDMA system[10]. The encoded 15 bits are transmitted during one frame of 10 msec after signal mapping 0 to 1 and 1 to -1.

The decoding of TFCI code in split mode can be accomplished using Fig. 3(a). First we need "0" inser tion to the punctured position of received TFCI signal and multiplication by $\hat{d}_4\mathbf{M}_4$ to estimate $\hat{d}_4$. We need to relocate the last bit to the original 0th position to perform the extremely fast FHT operation of Fig. 4. After the FHT, we can easily estimate $\hat{d}_0, \hat{d}_1, \hat{d}_2, \hat{d}_3$ using the operation of Compare & Choose largest. Thevector $\hat{d}_4\mathbf{M}_4$ of Fig. 3(a) can be two possible vectors



(a) Decoding of TFCI in split mode



(b) Decoding of TFCI in normal mode

Fig. 3. Decoding of TFCI in W-CDMA system.

$\mathbf{M}_4$ or $\mathbf{0}$. Thus the estimated $\hat{d}_4$ is simply the value of $\hat{d}_4$ when the largest output of FHT is chosen.

3-2 TFCI Coding in Normal Mode

In normal mode, TFCI carries 1 to 10 information bits and the information is encoded by using (32, 10) sub-code of $\Re(2, 5)$, the 2nd order RM code[10]. The 2nd order RM code is constructed by adding 4 basis vectors to $\Re(1,5)$ code whose 6 basis vectors are [8]

$\mathbf{1}$ = [11111111111111111111111111111111]
$\mathbf{v}_5$:= [00000000000000001111111111111111]
$\mathbf{v}_4$:= [00000000111111110000000011111111]
$\mathbf{v}_3$:= [00001111000011110000111100001111]
$\mathbf{v}_2$:= [00110011001100110011001100110011]
$\mathbf{v}_1$:= [01010101010101010101010101010101].

As explained in TFCI coding in split mode, to obtain the gain in terms of minimum distance after puncturing, we consider the following vectors after basis shifting:

$\mathbf{g}_0$:= [01010101010101010101010101010101]
$\mathbf{g}_1$:= [00110011001100110011001100110011]
$\mathbf{g}_2$:= [00001111000011110000111100001111]
$\mathbf{g}_3$:= [00000000111111110000000011111111]
$\mathbf{g}_4$:= [00000000000000001111111111111111]
$\mathbf{g}_5$:= [11111111111111111111111111111111]

To transmit 2 coded bits every slot time, we should puncture 2 coded bits for 15 slots per frame structure. When $\Re(1, 5)$ code after basis shifting carries 4 bits of TFCI, from (6) we see the optimum puncturing patterns are $2^4 \cdot i$, $i = 0,1$, that is, 0^{th} and 16^{th} positions. We can easily see that there is no loss in minimum distance and maintains the minimum distance bound 16 for (30, 4) binary linear code[14]. Since the optimum puncturing pattern of (6) includes 0^{th} and 16^{th} positions in all cases of 1, 2, 3, 4 bits of TFCI, puncturing 0^{th} and 16^{th} positioned bits results in no loss of minimum Hamming distance. Optimum puncturing pattern for 5 bits TFCI is 0^{th} position bit. If we puncture 0^{th} and 16^{th} positioned bits for 5 bits TFCI, we see the resultant code (30, 5) still satisfies the minimum distance bound 15[14]. Furthermore, if we puncture 0^{th} and 16^{th} positioned bits in the case of 6 bits TFCI, the resultant code word of length 30 satisfies the minimum distance bound 14 for (30, 6) code[14]. Thus it is optimum to puncture 0^{th} and 16^{th} positioned bits to transmit 2 coded bits per slot time and 30 coded bits per frame time. Similarly in normal mode the two punctured bits are moved to the last 2 positions. We can easily verify this from the following first 6 basis vectors of TFCI code of Fig. 2(b)[10]. The coded 30 bits are transmitted within 10 msec frame time after signal mapping 0 to 1 and 1 to -1. Without using the shifting of basis vector of $\Re(1, 5)$ code and optimum puncturing pattern, there would be minimum Hamming distance loss since in this case any puncturing pattern without basis shifting reduces the minimum distance.

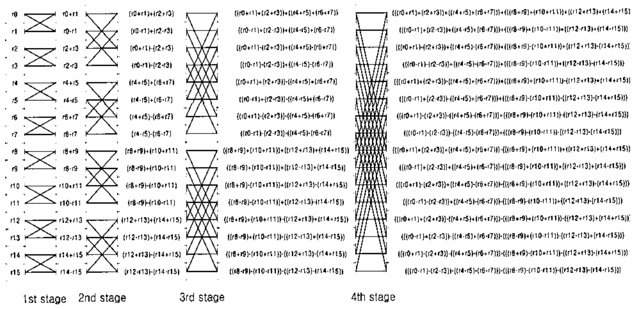


Fig. 4. Operation of 4 stages FHT.

$\mathbf{M}_0$ = [10101010101010110101010101010100]
$\mathbf{M}_1$ = [01100110011001101100110011001100]
$\mathbf{M}_2$ = [00011110000111100011110000111100]
$\mathbf{M}_3$ = [00000001111111100000001111111100]
$\mathbf{M}_4$ = [00000000000000011111111111111101]
$\mathbf{M}_5$ = [11111111111111111111111111111111]
$\mathbf{M}_6$ = [01010000110001111100000111011101]
$\mathbf{M}_7$ = [00000011100110111011011100011100]
$\mathbf{M}_8$ = [00010101111100100110110010101100]
$\mathbf{M}_9$ = [00111000011011101011110101000100]

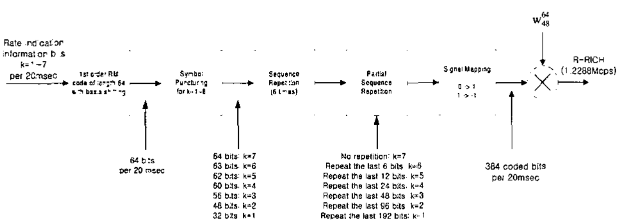
The decoding of TFCI code in normal mode can be accomplished using Fig. 3(b). First we need "0" insertion to the punctured positions of received TFCI signal and multiplication by

$$\hat{d}_5\mathbf{M}_5 + \hat{d}_6\mathbf{M}_6 + \hat{d}_7\mathbf{M}_7 + \hat{d}_8\mathbf{M}_8 + \hat{d}_9\mathbf{M}_9 \tag{8}$$

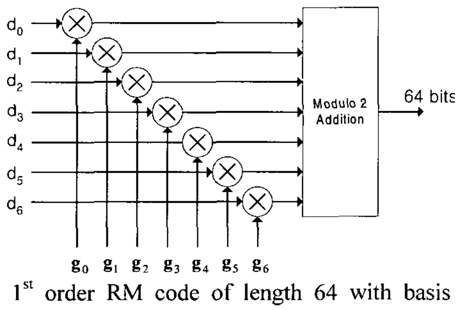
to estimate $\hat{d}_5, \hat{d}_6, \hat{d}_7, \hat{d}_8, \hat{d}_9$. We need to relocate the last two bits to the original 0^{th} and 16^{th} positions to perform the extremely fast FHT operation of 5 stages. After the FHT, we can easily estimate $\hat{d}_0, \hat{d}_1, \hat{d}_2, \hat{d}_3, \hat{d}_4$ using the operation of Compare & Choose largest. The remaining estimated values are just the values of $\hat{d}_5, \hat{d}_6, \hat{d}_7, \hat{d}_8, \hat{d}_9$ of (8) when the largest output of FHT is chosen. Thus in this case the complexity of the decoding is approximately $2^5 = 32$ times more than simple FHT of 5 stages.

3-3 RRI Coding

Fig. 5 shows the proposed R-RICH structure and RRI coding method to indicate the data rate transmitted on the reverse traffic channel by a mobile station. RRI carries up to 7 bits during 20 msec frame time. The $k = 1 \sim 7$ rate indication bits are encoded using 1^{st} order RM code of length 64 with shifting of basis vector and then punctured according to the optimum pattern of Table 1. The resultant sequence is repeated 6 times and then partial sequence repetition is applied to be 384 coded bits. Using the shifting of basis vector of $\mathfrak{R}(1, 6)$ code and optimum puncturing pattern of Table 1, we could avoid minimum Hamming distance loss. Furthermore, using the partial sequence repetition, we could increase the minimum Hamming distance. There is no symbol puncturing and no symbol repetition in



(a) Structure of R-RICH



(b) The 1^{st} order RM code of length 64 with basis shifting

Fig. 5. Structure of R-RICH and RRI coding.

Table 2. Number of last symbols for partial sequence repetition.

RRI Coding (384,k), k=1~6	Number of last symbols for partial sequence repetition
(384,7)	none
(384,6)	6
(384,5)	12
(384,4)	24
(384,3)	48
(384,2)	96
(384,1)	192

Table 3. Minimum Hamming distance of RRI code.

(384,k), k=1~7	Minimum distance (Proposed coding)	Minimum distance bound for (64,k) code	Minimum distance bound for (64,k) * 6 times repetition
(384,7)	**192**	32	192
(384,6)	**192**	32	192
(384,5)	**196**	32	192
(384,4)	**204**	33	198
(384,3)	**219**	36	216
(384,2)	**256**	42	252
(384,1)	**384**	64	384

the case of k = 7. There are last 6, 12, 24, 48, 96, and 192 symbols of partial sequence repetition for k = 6, 5, 4, 3, 2, 1, respectively. This repetition pattern is summarized in Table 2. The minimum Hamming distance of the proposed RRI coding is shown in the second column of Table 3. The third column shows the minimum distance bound of binary linear codes of (64, k), k=1~7, and the last column denotes the minimum distance after 6 times repetition of the code. From Table 3, we see that the proposed coding scheme shows better minimum distance property than that of the repetition of binary linear codes (64, k), k=1~7, with minimum distance bound. Furthermore the proposed coding scheme can be easily constructed using straightforward manner using at most 3 steps, 1) shifting of basis vectors of RM code, 2) puncturing, 3) and/or (partial) sequence repetition.

Fig. 6 shows the simple decoder using FHT. First we combine bit energy from and/or (partial) sequence repetition. And then we need "0" insertion to the punctured positions and multiplication by $\hat{d}_6\mathbf{g}_6$ to estimate $\hat{d}_6$. After FHT of 6 stages, we can easily estimate $\hat{d}_0, \hat{d}_1, \hat{d}_2, \hat{d}_3, \hat{d}_4, \hat{d}_5$ using the operation of

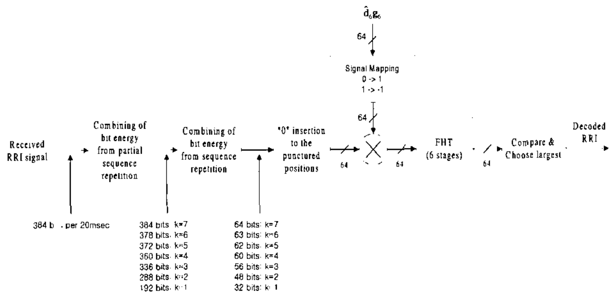


Fig. 3. Decoding of RRI.

Table 4. Minimum Hamming distance comparison between proposed code and RM code.

(384,k), k=1~7	Proposed coding scheme	RM code with 6 times sequence repetition	Difference
(384,7)	**192**	192	**0**
(384,6)	**192**	192	**0**
(384,5)	**196**	192	**4**
(384,4)	**204**	192	**12**
(384,3)	**219**	192	**27**
(384,2)	**256**	192	**64**
(384,1)	**384**	384	**0**

Compare & Choose largest. The estimated $\hat{d}_6$ is simply the value of $\hat{d}_6$ when the largest output of FHT is chosen.

For the fair performance evaluation, the proposed coding scheme using 3 steps, that is, 1) shifting of basis vectors of $\Re(1, 6)$ code, 2) ideal puncturing pattern, 3) 6 times sequence repetition and partial sequence repetition, are compared to code with 6 times sequence repetition. Table 4 shows the difference on minimum Hamming distance between two schemes. In the case of k=1, the code words generated using two coding schemes becomes all "0" or "1" of length 384 when k=0 or k=1, respectively. In the case of k=2~6, we can see the gains in terms of minimum Hamming distance because of no loss of minimum Hamming distance due to the shifting of basis vectors followed by ideal puncturing, 6 times sequence repetition, and partial sequence repetition. We see that there are minimum distance gains of 64, 27, 12, 4 when k=2~5. In the case of k=6, although there is no gain in terms of minimum distance, there is gain in terms of weight distribution of code words due to the partial sequence repetition of 6 symbols. In the case of k=7, since there is no puncturing, only 6 times sequence repetition is used. Thus for k=7, two sets of code words generated using two methods are identical and thus the distance becomes 192. Therefore, it is reasonable to show the performance results of two coding schemes in the range of k=2~6.

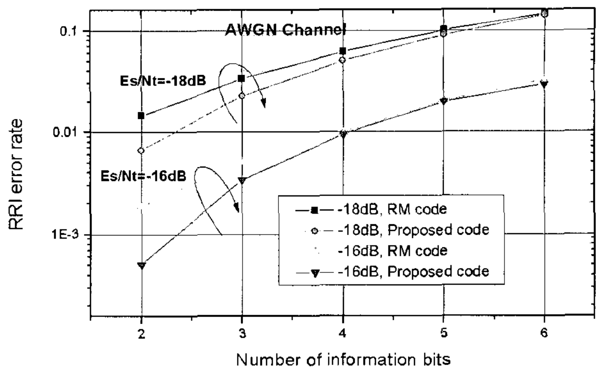


Fig. 7. RRI error rate over AWGN channel.

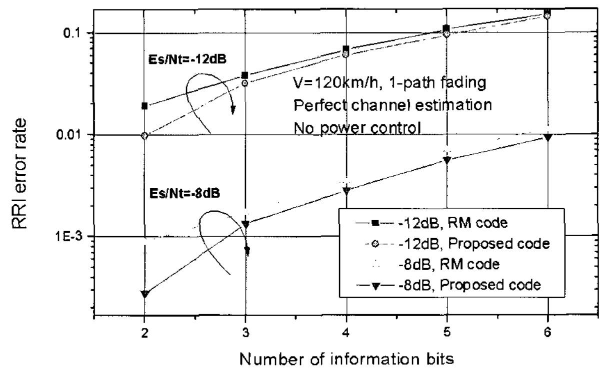


Fig. 8. RRI error rate over fading channel at 120 km/h.

Fig. 7 shows the simulation results of $\Re(1, 6)$ code with 6 times sequence repetition and proposed code over AWGN channel at $E_s / N_t = -18$ dB and -16 dB for k=2~6 bits, where E_s / N_t denotes the ratio in dB of the received energy per symbol to the effective noise power spectral density. Fig. 8 denotes the simulation results over fading channels using the following environments at $E_s / N_t = -12$ dB and -8 dB for k= 2~6 bits.

- Carrier frequency: 2 GHz
- Vehicle speed: 120 km/h
- Jakes' Doppler spectrum
- Perfect channel estimation
- No power control

Fig. 7 and 8 show that we can optimize the performance of RRI code over AWGN as well as fading channels by using the proposed coding method without

Table 5. Performance improvement factor over AWGN and fading channels.

K	AWGN channel		Fading channel at 120 km/h	
	Es/Nt= – 18 dB	Es/Nt= – 16 dB	Es/Nt= – 12 dB	Es/Nt= – 8 dB
2	2.19	3.7	1.95	3.24
3	1.48	1.5	1.19	1.3
4	1.22	1.27	1.11	1.23
5	1.11	1.24	1.14	1.25
6	1.03	1.1	1.07	1.21

increasing complexity. The simulation results are summarized in Table 5, which illustrates the benefit of proposed code using the improvement factor. For example, the improvement factor 2 means that RRI error rate is reduced by half. As the number of information bits decreases, the improvement factor increases dramatically. Especially, in the case of k=2, we can reduce the error rate approximately 2～3.5 times less than the RM code over AWGN and fading channels.

Ⅳ. Conclusion

This paper has proposed optimum puncturing pattern and shifting of basis vectors of 1st order RM code to achieve the minimum distance bound. Based on this idea, we could construct a very simple coding scheme suitable for channel coding of control channels for mobile packet communication. This coding scheme is composed of at most 3 steps: 1) shifting of basis vectors of RM code, 2) puncturing, 3) and/or (partial) sequence repetition. For applications in mobile packet communication, the principles of encoding/decoding of TFCI code in split mode and normal modes of W-CDMA system using the first 2 steps are explained in detail. We have also shown that when the proposed coding scheme is applied to 1xEV-DV system to indicate the data rate on the reverse traffic channel by a Mobile Station, it gives approximately up to 2～3.5 times better performance than RM code without increasing hardware complexity over AWGN and fading channels.

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References

[1] www.3gpp.org.
[2] www.3gpp2.org.
[3] 3GPP TS 25 Series.
[4] 3GPP2 C.S000 Series.
[5] Harri Holma, Antti Toskala, *WCDMA for UMTS*, 2nd edition, John Wiley & Sons Ltd, 2002.
[6] Keiji Tachikawa, *W-CDMA Mobile Communications System*, John Wiley & Sons Ltd, 2002.
[7] Vijay K. Garg, IS-95 *CDMA and cdma2000*, Prentice Hall PTR, 2000.
[8] S. B. Wicker, *Error control systems for digital communication and storage*, Prentice Hall, 1995.
[9] N. Ahmed, K. Rao, *Orthogonal Transforms for Digital Signal Processing*, Spring-Verlog, 1975.
[10] "3GPP TSG RAN; Multiplexing and channel coding (FDD)", 3G TS 25.212, V3.8.0 (2001-12).
[11] "3GPP TSG RAN; Physical channels and mapping of transport channels onto physical channels (FDD)", 3G TS 25.211, V3.9.0 (2001-12).
[12] Young Joon Song, "Method for coding and transmitting transport format combination indicator", EP 1104130 A2, *European patent office*, Application no. 00125148.7, Date of publication; May 30, 2001.
[13] LG Electronics, LSI Logic, Lucent Technologies, Qualcomm Incorporated, Samsung Electronics, *Updated Joint Physical Proposal for 1xEV-DV*, 3GPP2-C50-20010611-009, Jun. 11, 2001.
[14] A. E. Brouwer, Tom Verhoeff, "An Updated Table of Minimum-Distance Bounds for Binary Linear Codes", *IEEE Trans. Inform. Theory*, vol. 39, pp. 662-677, Mar. 1993.

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