2003년도 대한전자공학회 하계종합학술대회 논문집 제26권 제1호

Quasi-Complementary Turbo Codes (QCTC) for cdma2000 1xEV-DV

Min Goo Kim, Sang Hyuk Ha, and Yong Serk Kim

Modem R&D Team, Telecommunication R&D Center, Samsung Electronics,
Maetan-3dong, Paldal-gu, Suwon-si, Gyeonggi-do, Korea 442-600

E-mail address: mingu.kim@samsung.com

Abstract: **The quasi-complementary turbo codes (QCTC) proposed by Kim [1] is used for a fast hybrid ARQ scheme with incremental redundancy and adaptive modulation coding in the cdma2000 1xEV-DV [2]. The QCTC provides various code rates with good performance, a very simple encoder structure, and an inherent channel interleaving. It is shown that the QCTC is a unified scheme of channel coding and channel interleaving. In this paper, we introduce the properties of QCTC and various hybrid ARQ-QCTC schemes for the system.**

I. INTRODUCTION

The latest release of cdma2000 1x standards, referred to the Release C or 1xEV-DV (the 1x evolution with data and voice), significantly increases the efficiency of the air interface by introducing a new packet channel with a peak data rate up to 3.09Mbps [2]. To support efficient mobile communications, adaptive modulation and coding (AMC) and fast hybrid ARQ schemes (automatic repeat request) have been considered. The quasi-complementary turbo codes (QCTC) proposed by Kim [1] has been used for both AMC and fast hybrid ARQ with incremental redundancy (IR).

In the 1xEV-DV, a fast hybrid ARQ scheme using asynchronous and adaptive incremental redundancy (A^2IR) has been investigated to maximize channel utilization. In order to support A^2IR, flexible turbo codes were required with providing variable code rates and various redundancy patterns, maintaining backward compatibility, and achieving the maximal coding gain with soft combining. For lots of combinations of code rates and modulations more than 600 cases in A^2IR, conventional hybrid ARQ schemes using optimal puncturing patterns such as the rate compatible punctured turbo codes (RCPT) or the rate compatible punctured convolutional codes (RCPC) can not be used due to their complexity [3]-[6]. Furthermore, RCPC or RCPT is used for a fixed code rate and fixed puncturing period. On the other hand, the A^2IR has requested flexible combinations of code words with different rates, code bit composition, and puncturing periods. In addition, a channel interleaving must be performed before a redundancy selection to avoid storing all possible interleaving or deinterleaving patterns according to packet sizes.

In general, convolutional codes have equal code bit error sensitivity with a maximum likelihood decoding such as Viterbi algorithm. So, the performance of convolutional codes is good such that "*self-decodable*," only if a code rate is less than 1.0 [8], [9]. However, the situation is different in turbo codes. Unlike convolutional codes, turbo codes have unequal bit error sensitivity. The systematic puncturing provides better performance than that of nonsystematic puncturing as code rate increase [7]-[9]. Turbo codes are usually composed of two constituent encoders linked by a turbo interleaver. Since a maximum likelihood decoding is practically impossible in turbo codes, an iterative decoding algorithm is frequently used that works on the individual trellis of a constituent code at each time [10]. This implies that actual code rate of constituent code can be greater than 1.0 although the overall code rate of turbo code is smaller than 1.0. For example, the decoding fails if the actual code rate of constituent code is greater than 1.0 although the extrinsic information provides the reliable information. We introduce a criterion for "*self-decodable turbo codes.*" The QCTC is designed to avoid the situation by the proposed encoder structure and the puncturing-repetition method.

In section II, we present an overview of the QCTC and its properties. In Section III, we provide several transmission protocols for a type II and III hybrid ARQ-QCTC schemes. Section IV contains numerical results and an analysis of performance of QCTC in the cdma2000 1xEV-DV. Finally, in Section V, the conclusions are given.

II. QUASI-COMPLEMENTARY TURBO CODES

In a conventional physical layer structure of wireless communication systems, the fixed channel interleavers and puncturing-repetition are used after a channel encoding. However, that structure has a problem regarding an AMC with incremental redundancy due to lots of code rates and puncturing-repetition patterns.

2.1 Construction of a Family of QCTC

The encoder structure of quasi-complementary turbo codes is given in Fig. 1. The encoder of QCTC consists of two parts such as a conventional turbo encoder with code rate R and a proposed permutation block where systematic symbols X and parity symbols of Y_0, Y_1, Y'_0, Y'_1 are separated into sub-blocks, respectively [11]. Each sub-block has a sub-block interleaving to randomize input symbols as well as to maintain uniformity of puncturing in systematic symbols and parity symbols independently. After that, the permuted parity symbols are interlaced each other to provide uniform puncturing and the balance of number of punctured symbols. The QCTC symbol selection block performs the formation of sub-code word every transmission. The number of QCTC code symbols is same as in a turbo code with code rate of R. In the QCTC, the separation of systematic symbols is used in order to enhance performance of a high rate turbo code. The QCTC is regarded as a two dimensional turbo code for an adaptive incremental redundancy scheme such that code rates and puncturing patterns are selected simultaneously. The QCTC uses a flexible puncturing period that is determined automatically by a code rate and an initial position for the QCTC symbol selection. It is different to the RCPC and the RCPT using a constant puncturing period.

2.2. High Rate Turbo Codes and Iterative Decoding

In Fig. 2, a turbo code of code rate of 1/5 and the corresponding SISO decoder are given. Let us assume that the information block length is *L* bits. To make a code with code rate of $R_s=4/5$, we have to select *5L/4* among *5L* code bits. Let us assume that a random permutation is used in the symbol selection block in order to uniformly distribute systematic symbols and parity symbols. Then, the actual code rate R_1 of the first constituent decoder in Fig. 2 is *4/3* because only *3L/4* input code symbols such as *L/4* systematic symbols, *L/4* Y_0 parity symbols, and *L/4* Y_1 parity symbols contributes the first decoder. The situation is same in the second constituent decoder. Therefore it can not be expected for an *R-4/5* turbo code to have good performance. In high rate turbo codes, the following criterion is strictly required for good performance.

Criterion for *self-decodable* turbo codes

*The turbo code is **self-decodable** if and only if a turbo code has code rates of each constituent code less than 1.0. It is equal to that*

$$^{\forall k}\left(N^S + N_k^P\right) > P. \tag{1}$$

where k is an index for a constituent encoder and K is the number of constituent encoders. N^S *and* N_k^P *mean the number of systematic symbols and the number of parity symbols of k'th constituent code in a puncturing matrix A with a puncturing period P, respectively.*

From (1), two necessary conditions are induced for the symbol selection of turbo codes in a type II or III hybrid ARQ scheme. First, it is better to select the systematic symbols for a given code rate R_s. Because of the systematic symbols are counted in every constituent code. Second, the criterion will be satisfied as much as the puncturing period P increases through increase of freedom of code symbol selection. According to the criterion and analysis, it is shown that a turbo code is likely to have decoding failure if a code rate R_s is greater than 3/5 under an uniform distribution of systematic and parity symbols. The QCTC is designed to avoid the situation and to mitigate the impact by adopting the proposed encoder structure and the puncturing method.

2.3. Soft Combining

A hybrid ARQ scheme with soft combining has the inherent imbalance of symbol energy level due to symbol combining according to a retransmission protocol. So, the imbalance of symbol energy levels should be minimized as possible as a hybrid ARQ scheme can do. A hybrid ARQ-QCTC scheme resolves this issue by transmitting code symbols sequentially on the circle that is a code word with code rate of *R*. At the receiver, the initial packet and retransmitted packets are combined on the circle. The symbol energy levels are accumulated if the number of code symbols becomes larger than *L/R* where *L* is the information block length. The normalized symbol repetition factor (or energy level) $\overline{N}_{SR}$ is given by (2) where N_{TS} is the total number of received code symbols. So, all symbols are repeated as much as $\overline{N}_{SR}$ and the rest symbols are distributed evenly over them. So, QCTC provides the balanced code symbol energy levels in a turbo decoder regardless of the number of retransmission and soft combining.

$$\overline{N}_{SR} = \left\lfloor \frac{N_{TS}}{L/R} \right\rfloor \tag{2}$$

III. HYBRID ARQ SCHEMES USING QCTC

3.1 Sub Packet Formation with QCTC

It is assumed that transmission and re-transmission units for incremental redundancy are the sub-packets where the QCTC are used for sub-packet formation. The encoder packet can have various sub-packets. Let the sub-code rates be R_i, $i=0,1,2,.., N_{sc}-1$, where N_{sc} is the number of possible sub-code rate R_i. Let the sub-code set size be S_i that is the number of code words in C_i. Then a QCTC sub-code C_{ij}, $j=0,1,2,..,S_i-1$ in S_i and R_i are defined as a sub-code. The transmitter sends sub-code C_{ij} corresponding to the sub-code rate and incremental redundancy.

An example of encoder packet encoding and sub-packet formation with the QCTC is depicted in Fig. 3. Three sub-code sets are used for sub-packet formation in which R_0, R_1, and R_2 are 1/7, 2/7, and 4/7, respectively. For a conventional type II or type III hybrid ARQ scheme with a fixed code rate of R_0, the sub-codes C_{0j}, $j=0, 1, 2, ..., S_0-1$ are used. Any sub-codes C_{ij} is selected according to sub-code rate and incremental redundancy at each time. As it is shown, any combination of sub-codes is possible in the QCTC symbol selection and sub-packet formation [11].

3.2 QCTC Symbol Selection Modes

The code symbol selection for sub-packets is performed according to sub-packet sizes, data rates, encoder packet sizes, and available Walsh codes in the cdma2000 1xEV-DV. Let *k* and N_{EP} be the sub-packet index and the number of bits in the encoder packet, respectively. Let $N_{Walsh,k}$ be the number of 32-chip Walsh channels for the *k*-th sub-packet and let $N_{slots,k}$ be the number of 1.25-ms slots for the *k*-th sub-packet. Finally, let m_k be the modulation order for the *k*-th sub-packet (m_k = 2 for QPSK, 3 for 8-PSK, and 4 for 16-QAM). It is assumed that the symbols in the concatenated sequence of QCTC symbols are numbered from zero. Let $L_{SC,k}$ be the length of the *k*-th sub-packet and $F_{s,k}$ and $L_{s,k}$ be the positions of the first symbol and the last symbol of the *k*-

th sub-packet, respectively. It is assumed that $SPID_k$ is the sub-packet ID for the k-th sub-packet and has value of 0, 1, 2, or 3. For all modes, the initial packet has to use $F_{s,0}$ of zero [2], [11].

SSPM (Sequential Starting Point Mode)

The positions of the first and last symbols of sub-packets are determined by the N_{EP} and $L_{SC,k}$. All sub-codes are linked each other sequentially at the receiver. The SSPM has the advantage of maximizing a coding gain but it has the disadvantage in terms of robustness in missing sub-packets. If a previous sub-packet is missed then error propagation can occur for that encoder packet.

$$L_{SC,k} = 1536 \times \frac{N_{Walsh,k}}{32} \times m_k \times N_{slots,k} \tag{3}$$

$$F_{s,k} = (L_{s,k-1} + 1) \bmod (5 \times N_{EP}) \tag{4}$$

$$L_{s,k} = \left(F_{s,k} + L_{SC,k} - 1\right) \bmod \left(5 \times N_{EP}\right) \tag{5}$$

FSPM (Fixed Starting Point Mode)

For a simple protocol for a type III hybrid ARQ scheme, the starting position of sub-packet can be fixed to $g(SPID_k)$ corresponding to $SPID_k$. The $g(SPID_k)$ is a predetermined constant in $[0, 5N_{EP}-1]$. The advantage is that a receiver can know the exact first symbol position regardless of missing previous packets and there is no error propagation as in the SSPM. However, the FSPM has performance degradation due to imperfect concatenation of sub-codes. In FSPM, the $SPID_k$ is determined by a transmitter to minimizing the latency (puncturing) or the overlapping (repetition) between consecutive sub-packets as in (7). On the other hand, a receiver knows the exact $F_{s,k}$ by the received $SPID_k$ directly without examination. $L_{SC,k}$. and $L_{s,k}$ are same as in (3) and (5), respectively.

$$F_{s,k} = g\left(SPID_k\right) \tag{6}$$

$$SPID_k = \begin{cases} 0 & \mathit{for}\ \ k=0 \\ \min\limits_{n\in\{1,2,3\}}^{-1} \left| \left[g\left(SPID_n\right) \bmod \left(5 \times N_{EP}\right) \right] - L_{s,k-1} \right| & \mathit{otherwise} \end{cases} \tag{7}$$

PCCM (Partial Chase Combining Mode)

For a Chase combining (a type I hybrid ARQ), the first position $F_{s,k}$ of sub-packet corresponding to all $SPID_k$ is fixed to zero [12]. If the length of sub-packet is not constant (or sub-code rate is not a constant) then this protocol supports the partial Chase combining (PCC).

IV. NUMERICAL RESULTS

Simulations were performed to analysis the properties of QCTC. The Max-log-MAP algorithm was used for a turbo decoding. In these simulations, a rate-1/5 turbo code with constraint length 4 and 16-QAM were used in the cdma2000 1xEV-DV[2].The channel was assumed to be an AWGN channel. A 16 bits CRC code in [2] was used to detect errors. For a soft metric, we have used the dual minimum metric (DMM). The throughput η is defined as N_{EP}/N_T where N_T is the total number of transmitted bits per the correctly decoded encoder packet.

In Fig. 4, the bit error rates for various puncturing patterns are given for the encoder packet size of 1024 and QPSK. The bit error rate with puncturing period 2 has shown bit error rate flow that can be estimated by the fact that the actual code rate R_1 of the first constituent encoder is 1.0. Puncturing patterns and periods are given in Table 1.

Table 1. Puncturing patterns of R-2/3 turbo codes

	Puncturing Period	
Output	2	4
X	1 0	1 1 1 1
Y_0	0 1	1 0 0 0
Y_1	0 0	0 0 0 0
X'	0 0	0 0 0 0
Y'_0	1 0	0 0 1 0
Y'_1	0 0	0 0 0 0

In Fig. 5, the throughput of SSPM and PCCM are shown where the initial sub-code rate is 4/5 and maximum two retransmissions are allowed. The encoder packet of 3072 and 16-QAM were assumed. The ratio in dB between the energy accumulated over one PN chip period (E_C) to the total transmit power spectral density, Ec/Ior, is fixed to -1.0dB [2], [11]. The SSPM yields remarkable throughput gain about 3.5dB compared to Chase combining with a retransmission and the performance gap becomes larger as the retransmission increases. In Fig. 6, we have shown the combined symbol energy level of a turbo decoder using QCTC. The QCTC provides almost uniform symbol energy level of code bits that promises good decoding performance.

V. CONCLUSIONS

We have presented in this paper a new class of turbo codes called the quasi-complementary turbo codes (QCTC). The advantage is that the QCTC provides various code rates with good performance, a very simple encoder structure, and an inherent channel interleaving. These features are desirable especially in AMC with incremental redundancy. It was shown that the systematic puncturing is required to maintain good performance with high rate turbo codes and an iterative decoding can limit the maximal code rate of turbo code in hybrid ARQ schemes.

REFERENCES

[1] M. G. Kim, "Enhanced throughput with HARQ," *3GPP2 TSG-C, C50-20001023-018*, Kyoto, Oct. 2000.

[2] *Physical Layer Standard for Cdma2000 Spread Spectrum Systems Release C*, May 2002.

[3] J. Hagenauer, "Rate compatible punctured convolutional codes (RCPC codes) and their applications," *IEEE Trans. Commun.* vol. COM-36, pp. 389-400, Apr. 1988.

[4] A. S. Barnulescu and S. S. Pietrobon, "Rate compatible turbo codes," *Electronics Lett.*, vol. 31, pp. 535-536, Mar. 1995.

[5] P. Jung and J. Plechinger, "Performance of rate compatible punctured turbo-codes for mobile radio applications," *Electronics Lett.*, vol. 33, pp. 2102-2103, Dec. 1997.

[6] S. Kallel, "Complementary punctured convolutional (CPC) codes and their applications," *IEEE Trans. Commun.* vol. COM-43, pp. 2005-2009, June 1995.

[7] M. Kim, "On the systematic punctured convolutional codes," *IEEE Trans. Commun.* vol. COM-45, pp. 133-139, Feb. 1997.

[8] M. G. Kim and B. J. Kim, "Unified rate matching scheme for turbo/convolutional codes and up/down links," *3GPP Tdoc R1-99-919*, Espoo, Filand, July 1999.

[9] *3GPP Release99 W-CDM: Multiplexing and channel coding (FDD)*, 3G TS 25.212, May 2000.

[10] C. Berrou, A. Glavieux, and P. Thitimajshima, "Near Shannon limit error-correcting coding and decoding: Turbo codes," in *Proc. ICC'93*, Geneva, Switzerland, May 1993, pp. 1064-1070.

[11] L3QS, "Joint physical layer proposal for 1xEV-DV," *3GPP2 TSG-C,C50-20010212-029*, Phoenix, USA, Feb. 2001.

[12] D. Chase, "Code combining-A maximum likelihood decoding approach for combining an arbitrary number of noisy packets," *IEEE Trans. Commun.* vol. COM-33, pp. 385-393, May 1985.

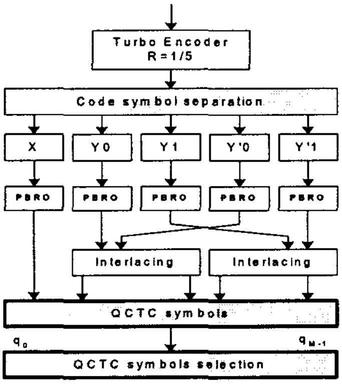

Fig. 1. QCTC encoder structure and symbol selection.

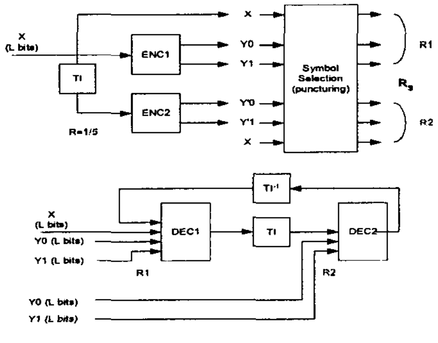

Fig. 2. High rate turbo codes and actual sub-code rates

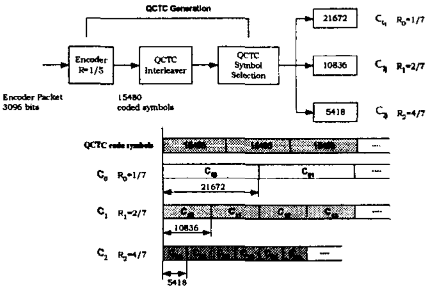

Fig. 3. Encoder packet encoding and sub-packet formation.

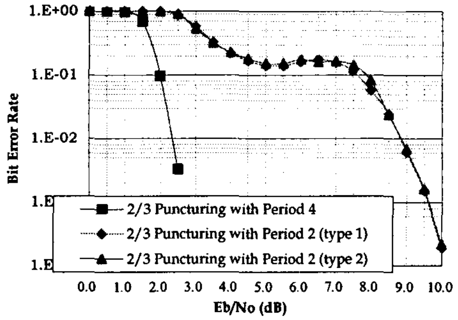

Fig. 4. Bit error rate of high rate turbo codes regarding to puncturing.

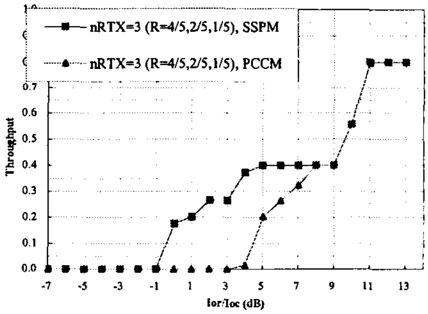

Fig. 5. Throughput of EP=3072 and 16QAM with R of 4/5.

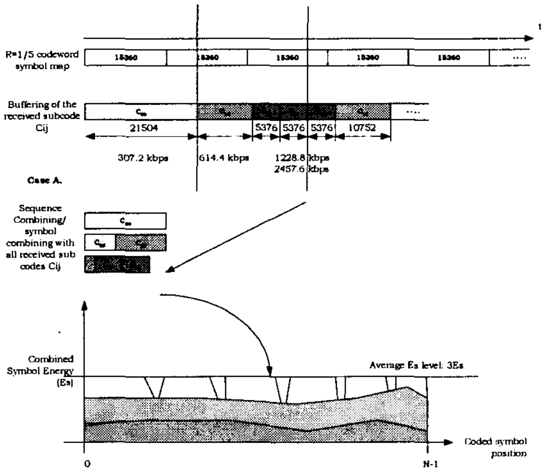

Fig. 6. Combined symbol energy levels of QCTC.