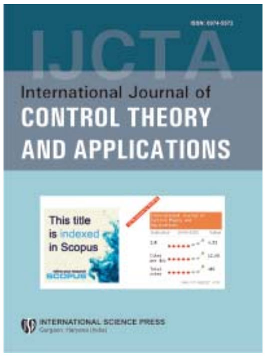

International Journal of Control Theory and Applications

ISSN : 0974–5572

Volume 10 • Number 27 • 2017

Highly Improved Hybrid Turbo Codes for High Speed Networks

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Abstract: 4G wireless standards specifies the peak speed for internet communication at 100 Mbps for high mobility users and 1 Gbps for low mobility users. For the above standards to establish error free communication a low complex error correcting code is needed. The Highly Improved Hybrid Turbo Code (HIHTC) is the novel error correcting code developed for 4G and above standards. In this paper we analyze the HIHTC code for High Speed Networks.

Keywords: *Turbo codes, High Speed Networks, Error Correcting Codes.*

1. INTRODUCTION

Modern 4G and 5G high speed networks assures higher data rates than 3G of the order 100 Mbps for mobile users and 1 Gbps for fixed and nomadic users. The air interface and MAC optimized for IP traffic with IPV6 and QoS where adaptive modulation and power control coding is adopted. The Quadrature Amplitude Modulation (QAM) is adopted for higher data rates. The above standards need an error free data communication. The HIHTC is the low complex hybrid turbo code with the combination of Turbo Convolution Code (TCC) and Zigzag Hadamard (ZH) Code with higher Bit Error Rate (BER) of the order E_b/N_o of 1.7 dB at 10^{-5} BER which approaches Shannon's Limit. HIHTC is the advanced version of Improved Low Complexity Hybrid Turbo Code (ILCHTC) and Low Complexity Hybrid Turbo Code (LCHTC). The HIHTC decoder needs less number of iterations than ILCHTC and LCHTC. Hence HIHTC is suitable for 4G and 5G high speed networks .

1.1. Description of Encoder

In HIHTC the information bits are arranged in a rectangular array of size PxQ

$(p + (j - 1) \text{ X } q)^{th}$ information bit is denoted by $d(j, k)$

$$d = \{d(j, k)\},\ 1 \le j \le \text{P and } 1 \le k \le \text{Q}$$

The HIHTC uses Zigzag Hadamard Code and Recursive Systematic Convolution (RSC) code as shown in Fig (1)

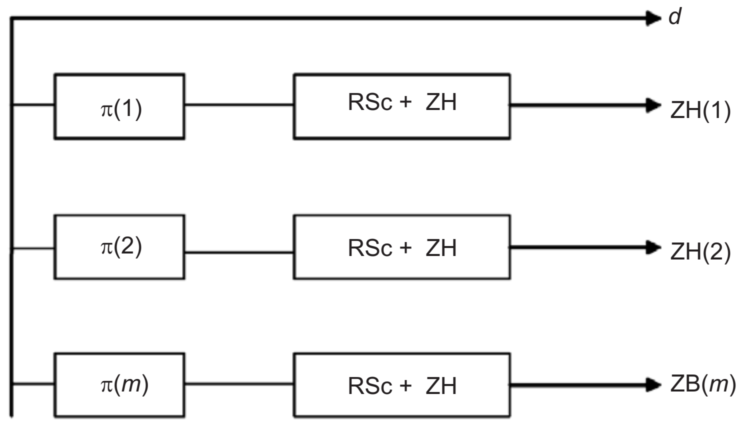

Figure 1: HIHTC Encoder

The Zigzag Hadamard parity vector of m^{th} constituent encoder is

$$ZH(m) = \{ZH^{(m)}(k)\} \quad i \le k \le Q$$

The Zigzag encoder parity bits are completed for each column of the array of information bits.

$$ZH^{0}(m) = 0$$

The encoded bits are given by

$$ZH^{(m)}(k) = \sum_{j=1}^{J}[d(j,k) + ZH^{m}\ (k-1)] \bmod 2$$

1.2. Interleaver

Two stage interleaver is used in HIHTC. Initially random interleaver is used to interleave the total information bits. Then bits are arranged in array of PxQ. 'S' condition is realized in each of the P rows of array.

For a given S of

$$|x - y| < s \text{ then}$$
$$[I(a) - I(b)] > s$$
$$0 < a,$$
$$b < k$$

Where a and b are column numbers of two bit positions before inter leaving.

1.3. Zigzag Hadamard Codes

Zigzag Hadamard Code can be described as shown in fig(2)

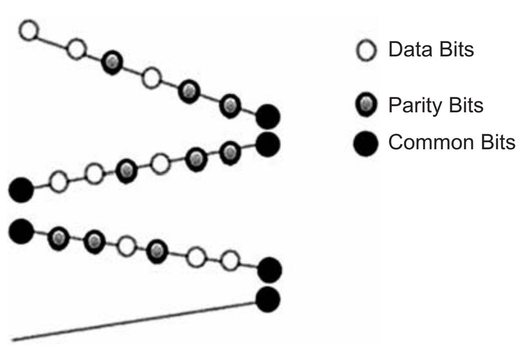

Figure 2: Unpunctured Zigzag Hadamard code

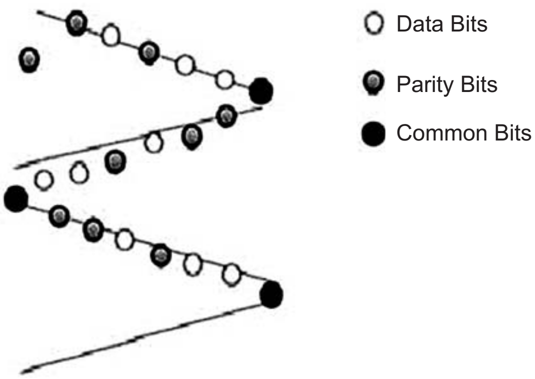

Figure 3: Punctured Zigzag Hadamard code

The information bit sequence D is first segmented into blocks.

$$d_k = [d_k(1), d_k(2), \ldots\ldots\ldots\ldots d_k(r)]$$
$$k = 1,2, \ldots\ldots\ldots\ldots k$$

represented by white nodes. The last parity bit of previous segment is the first input the current segment of ZH encoder.

The coded segment is given by $C_k = H[C_{k-1}(2^r - 1), d_k(1), \ldots\ldots\ldots\ldots d_k(r)]$

Where the code word vector is $C_k = [C_k(0), C_k(1), \ldots\ldots\ldots C_k(2^r - 1)]$

$$C_k(0) = C_{k-1}(2^r - 1) \text{ and}$$
$$C_k(2^{j-1}) = d_k(j)$$
$$j = 1,2, \ldots\ldots\ldots\ldots r$$

For a non systematic ZH code $\tilde{d}_k = C_{k-1}(2^r - 1) \oplus d_k(j),$

where $j = 1,2, \ldots\ldots\ldots\ldots r$

$\oplus$ is binary addition

The Hadamard encoding is given by $\{\tilde{d}_k(j)\}$

$$C_k = H[C_{k-1}(2^r - 1), \tilde{d}_k(1), \tilde{d}_k(2) \ldots\ldots\ldots\ldots \tilde{d}_k(r)]$$

Where $C_k(2^{j-1}) = \tilde{d}_k(j),$

$$j = 1,2, \ldots\ldots\ldots\ldots r$$
$$d_k = [\tilde{d}(1), \tilde{d}(2), \ldots\ldots\ldots\ldots \tilde{d}(r)]$$

The common bits are punctured to improve code rate.

The code rate of HIHTC is given by $Rc = \sum_{i=1}^{N}\sum_{i=1}^{N} C(i, j)^2$

P $\rightarrow$ Array size

L $\rightarrow$ No of rows of array of information bits

M $\rightarrow$ No of constituent encoders

1.4. Decoder Description

For low complexity decoding A Posteriori Probability (APP) algorithm is used. Let $x = [x(0), x(1), \ldots\ldots\ldots x(2r - 1)]$ be the received sequence of channel corrupted ZH code word $c = [c(0), c(1), \ldots\ldots\ldots, c(2^r - 1)]$

The Log Likelihood Ratios (LLRs) of coded bits are calculated by

$$L(i) = \log \frac{P((i) = +1/x)}{P(i) = -1/x)} = \log \frac{P(x/c(i) = +1)\, P(C(i) = +1)}{P(x/c(i) = -1) P(C(i) = -1)}$$

$$= \log \frac{\sum C \in \{\pm h^j\} : C(i) = +1\, P(x/e) P(c)}{\sum C \in \{\pm h^j\} : C(i) = -1\, P(x/e) P(c)}$$

where $i = 0, 1, \ldots\ldots\ldots 2^r - 1$

The following steps are used in APP decoding

1. The priori LLRs are calculated for $\{C_k(i)\}$ is given by

$$\bar{L}_k(i) = \frac{2x_k(i)}{\sigma^2} i, k$$

2. **Forward Recursion :** For $k = 1, 2, \ldots\ldots\ldots k$ apply APP decoding to the last bit of K^{th} segment. Then update a priori LLR of the first bit M the $(K + 1)^{th}$ segment by adding a posteriori LLR of the last bit in the K^{th} segment.
3. **Backward Recursion:** Keep the updating for the first bit in every segment as in Forward Recursion Apply APP decoding to the K^{th} segment to obtain the output of LLRs. Update the a priori LLR of the last bit in the $(K - 1)^{th}$ segment by adding the extrinsic LLR of the first bit in the K^{th} segment.

1.5. Performance Analysis of HIHTC

The performance comparison of HIHTC, ILCHTC, LCHTC and TCC is shown in the fig (3)

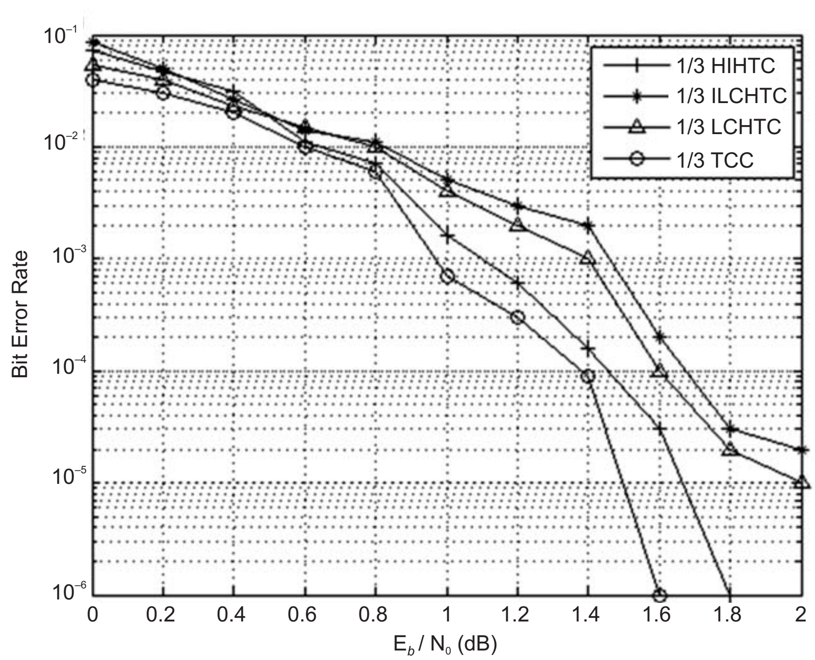

Figure 4: Performances of HIHTC, ILCHTC, LCHTC and TCC, R*c* = 1/3

Here the HIHTC shows E_b/N_o of 1.8 dB at 10^{-6} BER which is closer to the performance of TCC

1.6. Complexity Analysis

Let θ_A be the number of additions / Information Bit/ Iteration (A/ IB /I) and θ_M be the number of multiplications / Information Bit/ Iteration required to decode one bit.

For a HIHTC decoder

$$\theta_M = \frac{[L * (8 * S - 2)]}{H}$$

$$\theta_A = \{[(16 * S - 1)/H] + [(3 + 2)/H]\} - 1$$

Table 1
Computational Complexity Analysis of Decoders

Decoder	*R*	*Parameter*	θ_M	θ_A
TCC	1/2	M = 2	120	256
	1/3	M = 2	120	256
LCTCC	1/2	M = 2. H = 3. L = 2	40	96
	1/3	M = 2. H = 3. L = 2	60	145
ILCHTCC	1/2	M = 2. H = 3. L = 2	30	79
	1/3	M = 2. H = 3. L = 2	60	150
HIHTC	1/2	M = 2. H = 3. L = 2	25	60
	1/3	M = 2. H = 3. L = 2	50	140

Table 2
Average Number of Iterations of Decoders

E_b/N_o	E_b/N_o 0.4	E_b/N_o 0.8	E_b/N_o 1.2	E_b/N_o 1.6	E_b/N_o
TCC	18	17	15	7	4
LCTCC	21	19	13	8	8
ILCHTCC	20	19	15	6	5
HIHTC	19	18	14	6	4

HIHTC shows lowest complexity as compared with TCC , ILCHTC and LCHTC which is suitable for modern wireless systems.

1.7. AWGN Channel Performance

A Gaussian noisy channel with mean M and variance σ^2 is denoted as $N(M, \sigma^2)$

$$f_x(x) = \frac{1}{\sqrt{2\pi}\,\sigma}$$

The receiver output at the sampling instant T, the conditional distributions of random variable are

$$f_u(u/‘1’) = \frac{1}{\sqrt{2\pi}\,\sigma_0}\exp\left[\frac{-(u-\mu_1)^2}{2\sigma_0^2}\right]$$

σ_0^2 is variance of the noise

$$\sigma_0^2 = (N_0/2)E$$

$$\mu_1 = E_1$$

and $$\mu_2 = -E \text{ are the means of conditional parabolize}$$

The performance of HIHTC, ILCHTC, LCHTC and TCC for code rate Rc = $\frac{1}{3}$ in AWGN channel is shown in Figure 5

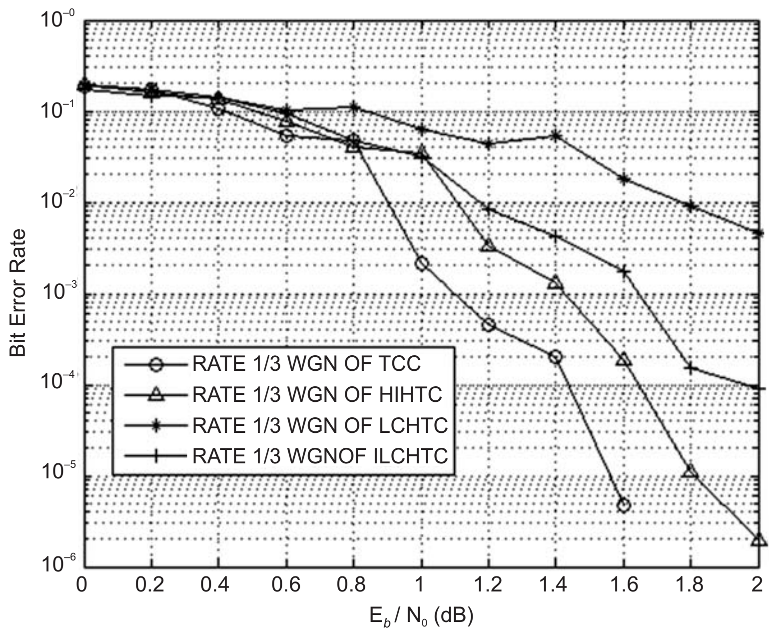

Figure 5: Performances of HIHTC, ILCHTC, LCHTC and TCC, R*c* = 1/3. in AWGN Channel

The code of rate $\frac{1}{3}$ encoders are analyzed. The HIHTC shows E_b/N_0 of 1.8 dB for the BER of 10^{-5}. The E_b/N_0 of ILCHTC and LCHTC are more than that of HIHTC.

1.8. Performance with QAM

In Quadrature Amplitude Modulation (QAM) we transmit two signals in same frequency but in phase and quadrature is given by

$$\varphi\text{QAM}(t) = m_1(t)\cos(w_e t) - m_2(t)\sin(w_e t)$$

While demodulation

$$x_1(t) = 2\varphi\text{QAM}(t)\cos w_e t$$

$$= 2(m_1\cos(w_e t) - m_2\sin w_e t)\cos w_e t$$

$$x_1(t) = m1(t) + m_1(t)\ \cos(2w_e t) + m_2(t)\sin(2w_e t)$$

The QAM signal can be easily recovered by averaging the squared analog to digital converter output samples.

$$P(n) = (1-c)r^2(n) + CP(n-1)$$

P(n) is the power estimate

The performance of HIHTC, ILCHTC and LCHTC for QAM modulation scheme is shown in the Fig 6

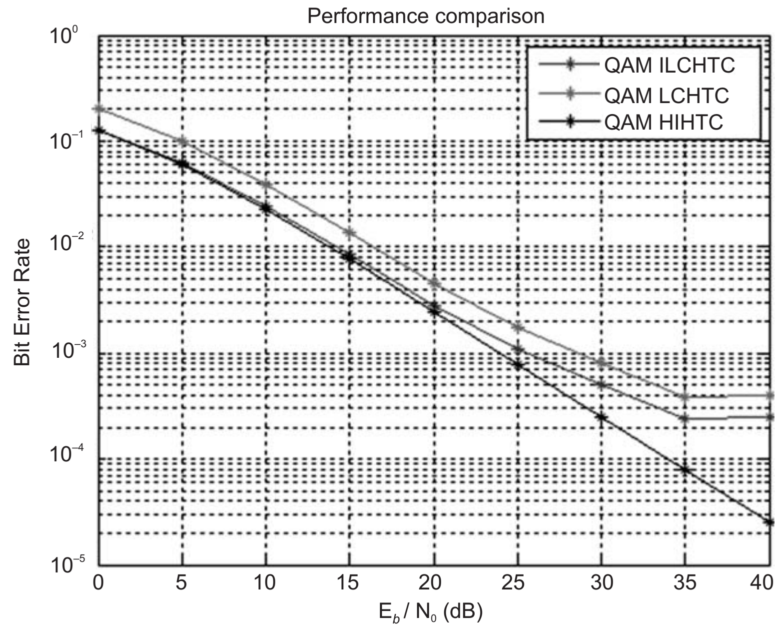

Figure 6: Performance of HIHTC, ILCHTC and LCHTC for QAM modulation

For a BER of 10^{-3} in QAM the HIHTC shows E_b/N_o of 23.5 dB. ILHTC shows 25 dB and LCHTC shows 28 dB. Here HIHTC shows less bit energy to Noise output ratio which is most suitable for high speed data applications.

2. CONCLUSION

The performance of HIHTC is analyzed with various standards of 4 G wireless systems. In QAM modulation scheme the simulation results shows E_b/N_o of 23.5 dB at BER of 10^{-3}. In QAM the performance of HIHTC is better than ILCHTC and LCHTC. In rate 1/3 AWGN channel HIHTC shows E_b/N_o of 1.8 dB at 10^{-5} BER. HIHTC detects and corrects the burst errors in multipath faded channels also. The complexity of HIHTC decoder is 45% less than the High complex TCC decoder.

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