

# Performance Analysis of Turbo Codes for 5G Massive Machine-Type Communication(mMTC)

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**Abstract**—In our present and future wireless communication systems, high-performance codes with low design complexity are required for optimum coding gain. In this paper, an efficient Long Term Evolution (LTE) based Turbo decoding algorithm is proposed. It is derived by remodeling the conventional maximum a posteriori probability (MAP) decoder. The proposed scheme aims to reduce the complexity of actualizing the conventional MAP Turbo decoder in the newly mMTC PHY layer features. The overall system performance is analyzed in terms of bit error rate (BER).

**Keywords**— maximum a posteriori probability (MAP), bit error rate (BER), massive Machine-Type Communication (mMTC)

## I. INTRODUCTION

The advent of 5th Generation (5G) mobile communication triggers the swift deployment of the Internet of things (IoT), whereby a lot of gadgets are connected to the IoT through far-reaching wireless systems mostly through cellular networks. It is proposed that 5G will accommodate over a million devices per square kilometer and thereby creating massive IoT (mIoT) networks [1]. The requirement to deal with such a massive number of MTC devices bring about the concept of massive Machine-Type Communication (mMTC). The mMTC devices are many with low complexity and constrained power associated with automatic data generation, processing, and transmission among several machines with little or no human intervention. Devices in this category include smart watches, connected home appliances, and connected fitness bands among others which requires very fast response time and very low latency. Two more technology use case introduced by the 5G era are: Enhanced mobile broadband (EMBB) and Ultra-reliable low-latency communication (URLLC). EMBB improves several functionalities by providing quicker data rates across a large coverage area, such as in VR gaming, telemedicine, and 8K video streaming. In crucial functions, URLLC improves

service speed and quality, such as in industrial automation, medical remote surgery, public safety, and so on [2].

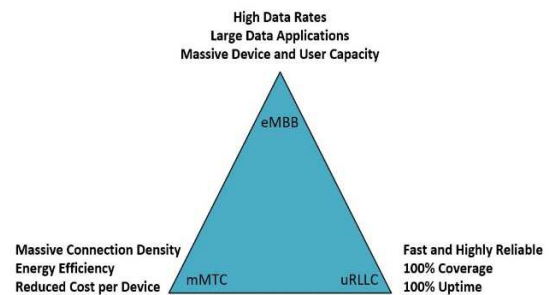


Fig. 1. 5G Triangle Design Scenario.

Despite the current 5G rapid development, 4G will continue to be useful by providing sizeable coverage on low budget. Therefore, mMTC applications with low power wide area coverage (LPWA) requirements will run on 4G technology in couple of years to come. Use cases supporting mMTC utilizing 5G networks will likely receive full attention when 5G coverage extends beyond cities [3].

To meet the requirements for mMTC applications, an appropriate PHY layer technology must be selected. According to the 3GPP standard, mMTC is built on current LTE PHY layer technology. Its channels and baseband signals are also LTE inherited, with more repetition variables to fulfill the requirements. mMTC adopted LTE Turbo coding, the FEC and SC-FDMA as the multiplexing scheme in 4G/5G technology [3-4] due to the advantage of Peak-to-Average Power Ratio (PAPR) that emerges from efficient power amplification over standard OFDMA technology. Forward Error Correction (FEC) is a technique for improving the reliability of user data transmission over noisy wireless

communications medium. This is accomplished by adding redundant data before transmission over noisy channel. The transmitted data can utilize the redundant bit in multiplexing the original information message at the destination to rectify any error introduced by the channel [5].

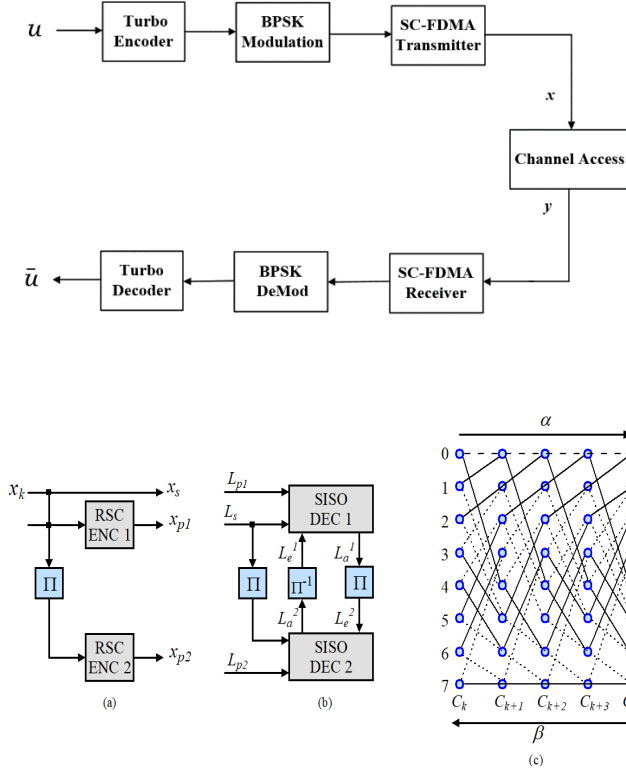


Fig. 3. (a) The turbo encoder, (b) The turbo decoder, and (c) Turbo codes state transition diagram.

Turbo codes are modern day error correction coding that achieves high error rate execution while remaining close to Shannon limits of error correction performance [6]. Turbo codes exceptional features have led to their acceptance in a variety of communications standards, including a component of mMTC in 5G technology. However, turbo codes great performance is apparently attributed to excessive decoding complexity, which results to significant power consumption at the receiving end for correct decoding [7]. Similarly, the computing complexity of turbo decoder considerably surpasses other parts in a mMTC LTE receiver, particularly for greater data rates and low latency communications. Several iterative Turbo decoding models have been proposed in [8-11]. In order to improve this complication, an efficient Turbo decoding is highly needed. Finally, this work offers a sufficiently robust model that can increase the reliability of UE data transfer while reducing computing complexity in a mMTC system.

## II. SYSTEM ARCHITECTURE

### A. System Model

Consider the PHY layer of the mMTC system having  $k = 1, \dots, K$ , UE of  $u_k = (u_0, u_1, \dots, u_{m-1})$ ,  $u_i \in \{0,1\}$  transport blocks (TBs) concurrently transmitted to the base station (BS) for network access as shown in Figure 2. The scheme utilizing single-tone SC-FDMA with  $N_k$  subcarriers spaced with  $\Delta f_n = 15\text{kHz}$  and  $\Delta f_n = 3.75\text{kHz}$  SCS.

A  $u$  TB to be transmitted are encoded via the LTE Turbo encoder. Recursive System Convolution (RSC) codes are mainly used as component codes. The input to the encoder, at any time  $k$ , is a bit  $u_k$ , transformed to relative code bit  $c_k$  based on generator polynomials defined by

$$G(D) = \left[1, \frac{g_1(D)}{g_0(D)}\right] \quad (1)$$

where  $g_1 = 1 + D^2 + D^3$  and  $g_0 = 1 + D + D^3$  and each internally disconnected by interleaver  $\pi$  at  $1/3$  coding rate ( $R$ ) resulting in an encoded sequence that is rate matched and mapped onto a constellation of binary phase-shift keying (BPSK). The coding symbol generates 4 redundancy versions (RV), selected from the sequence  $\{0,2,3,1\}$ , of TB as code block [11]. Each RV is transmitted in an available sub-frame on each channel, structured in the RU for transmission scheduling.

The end code bits are mapped on  $a_k$  symbols. The generated samples are then transformed to time domain via  $N_k$  Inverse Discrete Fourier Transform (IDFT) along  $n$ th subcarrier as follows:

$$x_k = \frac{1}{\sqrt{N_k}} \sum_{n=0}^{N_k-1} a_k e^{j2\pi n \Delta f_n}, 0 \leq n \leq N_k - 1 \quad (2)$$

where  $\Delta f_n$  is the subcarrier spacing (15 kHz or 3.75 kHz). A cyclic prefix (CP) is attached to  $x_n$ , to stop the inter block interference (IBI), then the sample-bits are conveyed all at once. The received signals in baseband equivalent in the discrete time domain can be expressed as follows:

$$y_k = \sum_{k=1}^{K-1} H_k x_k + z \quad (3)$$

where  $H_k$  represents the CIR matrix with  $[h_{k,0}, h_{k,1}, \dots, h_{k,L-1}, 0, \dots, 0]^T$  as its corresponding column entry and  $z$  being the additive white Gaussian noise (AWGN) vector with a zero mean and variance  $\sigma_z^2$ . The maximum a posterior probability (MAP) detection is carried-out after  $y_k$  symbol is received, to calculate the likelihoods for all demodulated symbol to convey a soft symbol to be decoded.

The process repeats a few iterations to obtain the desired decoded output bits.

### B. MAP Turbo Decoding

The Turbo decoder uses the maximum a posteriori (MAP) algorithm to accomplish decoding procedures as seen in Figure 3, where the signal sequence received, is demultiplexed into 3 sequences [12]: two parity sequences  $y^{p1}$  and  $y^{p2}$ , and the systematic sequence  $y^s$  respectively. The  $y^s$  and  $y^{p1}$  (or  $y^{p2}$ ) are used by 1 SISO decoder as inputs and calculates the *log-likelihood ratio* (LLR) of every information bit based on the trellis structure in Figure 3 (c), where the  $k$ th information bit  $u_k$  is defined as

$$L(\hat{u}_k) = \log \frac{P(u_k=+1|y)}{P(u_k=-1|y)} \quad (4)$$

$$= \log \left( \frac{\sum_{u_k=+1} \tilde{\alpha}_{k-1}(s') \tilde{\beta}_k(s) \tilde{\gamma}_k(s', s)}{\sum_{u_k=-1} \tilde{\alpha}_{k-1}(s') \tilde{\beta}_k(s) \tilde{\gamma}_k(s', s)} \right)$$

where  $\tilde{\alpha}_k(s)$ ,  $\tilde{\beta}_k(s)$ , and  $\tilde{\gamma}_k(s', s)$  denotes 3 (forward, backward, and branch) matrices. The  $s$  and  $s'$  indexes are as well related with trellis steps  $k$  and  $k-1$ . The MAP algorithm crosses in the forward as well as the backward direction to obtain state matrices  $\tilde{\alpha}_k(s)$  and  $\tilde{\beta}_k(s)$ , respectively. At  $k$ th stage, transmission values from  $s'$  state to  $s$  state is denoted by  $\tilde{\gamma}_k(s', s)$ . The  $\tilde{\alpha}_k(s)$ ,  $\tilde{\beta}_k(s)$ , and  $\tilde{\gamma}_k(s', s)$  matrices are calculated as

$$\tilde{\alpha}_k(s) = \sum_{s'} \tilde{\gamma}_k(s', s) \tilde{\alpha}_{k-1}(s') \quad (5)$$

$$\tilde{\beta}_{k-1}(s') = \sum_s \tilde{\gamma}_k(s', s) \tilde{\beta}_k(s) \quad (6)$$

$$\tilde{\gamma}_k(s', s) = \exp \left[ \frac{1}{2} L_e(u_k) u_k + \frac{1}{2} L_c X_k^s u_k + \frac{1}{2} L_c X_k^p c_k \right] \quad (7)$$

where  $L_e(u_k)$  denotes extrinsic LLR value of  $u_k$ ,  $L_c$  channel reliability measure,  $X_k^s$  and  $X_k^p$  transmitted bits of  $x_k^s$  and  $x_k^p$ , respectively. The MAP algorithm has a high computational cost because of the exponential and multiplication calculations. In most cases, a corresponding logarithmic form is used, in which multiplication is replaced by addition. As a result, the analogous equations in (5) – (7) can be reworked using the matrices calculated as follows:

$$\alpha_k(s) = \log \left[ \sum_{s'} \exp(\gamma'_k(s', s) + \alpha_{k-1}(s')) \right] \quad (8)$$

$$\beta_{k-1}(s') = \log \left[ \sum_s \exp(\gamma'_k(s', s) + \beta_k(s)) \right] \quad (9)$$

$$\gamma'_k(s', s) = \frac{1}{2} L_e(u_k) u_k + \frac{1}{2} L_c X_k^s u_k + \frac{1}{2} L_c X_k^p c_k \quad (10)$$

where the quantities  $\tilde{\alpha}_k(s)$ ,  $\tilde{\beta}_k(s)$ , and  $\tilde{\gamma}_k(s', s)$  are defined in the following [13]

$$\alpha_k(s) = \log(\tilde{\alpha}_k(s)) \quad (11)$$

$$\beta_k(s) = \log(\tilde{\beta}_k(s)) \quad (12)$$

$$\gamma'_k(s', s) = \log(\tilde{\gamma}_k(s', s)) \quad (13)$$

As seen in The SISO MAP decoding algorithm from the above-mentioned logarithmic computation is applied to actualize the hardware implementation of the algorithm. The  $\gamma'$  values are easily achieved through a few numbers of additions, stable in hardware. The algorithm main computing component is the computation of  $\alpha$ ,  $\beta$ , and  $LLR$  values, that has a significant effect on silicon area and power consumption.

### III. SIMULATION RESULTS

As seen in Figures 4 and 5, the BER performance for the decoding iterations is compared to the signal-to-noise ratio (SNR). After performing I=7 iterations, the BER performance of this model is attained. The decoder with CRC error detection and the result of coding rates R=1/2 and R=1/3 BER performances are shown in Figures 6 and 7.

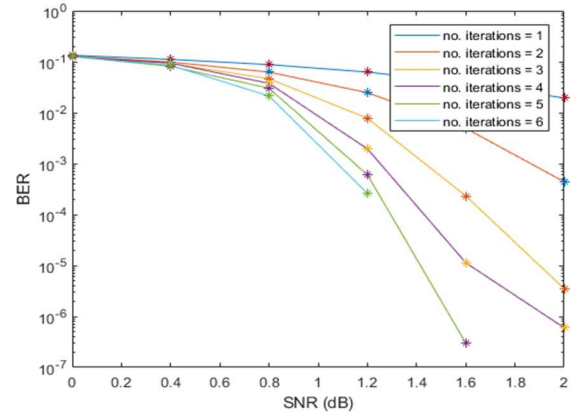


Fig. 4. Turbo decoding BER performance using  $\Delta f_n = 15kHz$ .

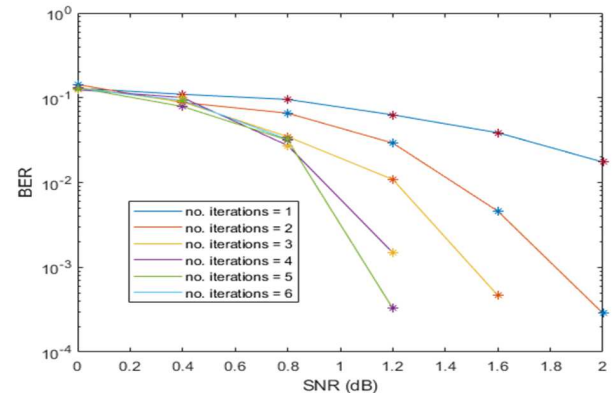


Fig. 5. Turbo decoding BER performance using  $\Delta f_n = 3.75kHz$ .

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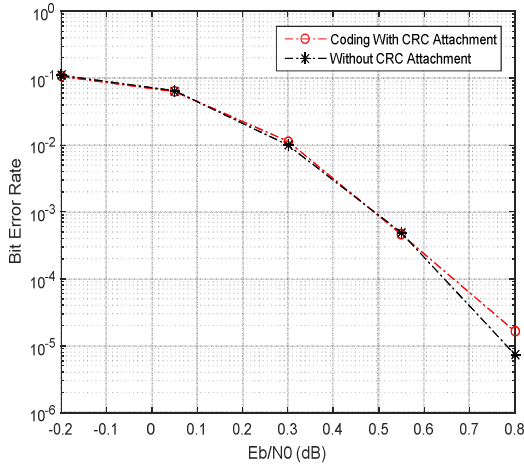


Fig. 6. BER performance using CRC mechanism.

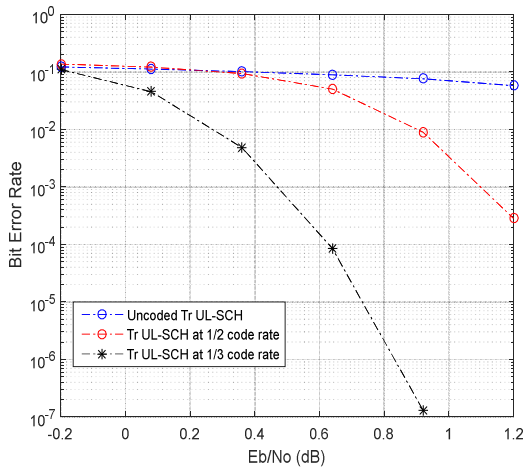


Fig. 7. Turbo decoding BER performance using different code rates.

## IV. CONCLUSION

An efficient model for current and future mMTC applications is derived in this paper. Based on the MAP Turbo decoding algorithm, we presented a low-complexity receiver scheme. In addition, the analytical and mathematical formulation of our suggested model is presented. The BER performance from our simulation result shows that our model outperforms traditional LTE, indicating that it can improve transmission reliability.

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