Channel Decoder Design of Physical Broadcast Channel for Coverage Enhancement in LTE

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***Abstract*— Recently, Long Term Evolution (LTE) are proposed for machine type communication (MTC) of the low-cost devices in 3GPP discussion. However, some MTC devices may be located in poor environment with high penetration loss such that some enhancements are required to ensure the radio coverage.**

Physical broadcast channel (PBCH) carries the most important system information for the devices to access the network. In this paper, we propose a new PBCH decoder with lower the decoding complexity to improve the coverage for PBCH. Following the 3GPP simulation settings, we observe performance gain so that we believe the proposed low-complexity channel decoder design is promising for the coverage enhancement in LTE.

I. Introduction

Recently, modern telecommunication moves the world into a networked society, where all kinds of devices share information with one another. Different from usual human-to-human communication, those interact between devices are called Machine Type Communication (MTC) in 3GPP. The cost of those MTC devices is usually low and operators nowadays rely on the existing GSM/GPRS network for MTC. Furthermore, low-cost MTC device support limited mobility and are low power consumption modules [1].

As LTE technology is developing gradually, operators would like to reduce the cost of overall network maintenance by minimizing the number of RATs (Radio Access Technology) [1]. Low-cost MTC with LTE should be designed to ensure service coverage not worse than GSM/GPRS, at least comparable and preferably improved beyond what is possible for providing MTC services over GPRS/GSM today.

Currently, 3GPP discussion focuses on coverage improvement for around 15 dB for all uplink and downlink channels [1] due to some MTC users are installed in bad locations, such as basements of residential buildings or locations shielded by foil-backed insulation, metalized windows and traditional thick-walled building construction etc. These users would experience significantly greater penetration losses on the radio interface than normal LTE devices.

In this paper, we focus on the receiver design of physical broadcast channel (PBCH). In order to meet the coverage enhancement requirement of low cost MTC, we investigate several kinds of receiver design and examine the performance improvement for PBCH. The rest of this paper is structured as follows: in section II. we will briefly introduce the legacy PBCH transmission in the LTE. In section III, we introduce several channel decoders for tail biting convolution code and show the simulation results in section IV. Finally, we give our conclusion in section V.

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II. PBCH Design in LTE

Physical broadcast channel (PBCH) carries part of the important system information, required by the terminal in order to access the network [2]. These basic system information included in the 24-bit Master Information Block (MIB) are shown in Table I.

TABLE I: Master Information Block (MIB) Content [2]

MIB Content	# of Bits	Frequency of Change
Downlink Bandwidth	3	Infrequently
PHICH Configuration	3	Infrequently
System Frame Number (SFN)	8	Change every 40 ms
Spare Bits	10	set to 0 by RRC spec [3]

Next, we explain the channel coding, modulation and transmission of PBCH [4], [5] as shown in Fig. 1. The 24-bit MIB is first attached with 16-bit CRC. Next, code rate 1/3 tail-biting convolutional encoder is used to encode the 40-bit CRC-coded message to output 120-bit tail-biting codeword. Then, the 120-bit tail-biting codeword are rate-matched, which repeat the 120-bit codeword by 16 times to 1920 bits for the robust transmission. Next, scrambling with psuedo-random sequence are used to eliminate the inter-cell interference (ICI). Furthermore, lowest modulation rate, QPSK as the modulation scheme and space frequency block code (SFBC) [6] are used for better protection. After that, the resource element mapping maps the PBCH data to the physical resource. The final procedure is the OFDM symbol generation which contains inverse fast Fourier transform (IFFT) and cyclic prefix (CP) insertion.

III. Channel Decoder Design for Physical Broadcast Channel

The flow chart of legacy PBCH receiver is shown in Fig. 2. In this paper, we focus on the channel decoder design. For other blocks, interested people may find solutions in references [2][6].

A. Circular Viterbi Decoder [7][8]

We introduce the tail-biting circular decoder which is often used for the legacy PBCH receiver. By utilizing the cyclic property of tail-biting convolutional code, circular decoder solving the unknown initial state problem by adding the front/rear training window to the original data. Assume vector $\mathbf{r} = (r_0, r_1, \cdots, r_{N-1})$ in input to the tail-biting decoder, where $N = 120$ in the PBCH case. The circular decoder first copy the first nB bits, $(r_0, r_1, \cdots, r_{nB-1})$, to the rear of $\mathbf{r}$ and the last nF bits, $(r_{N-nF-2}, r_{N-nF-3}, \cdots, r_{nF-1})$ to the

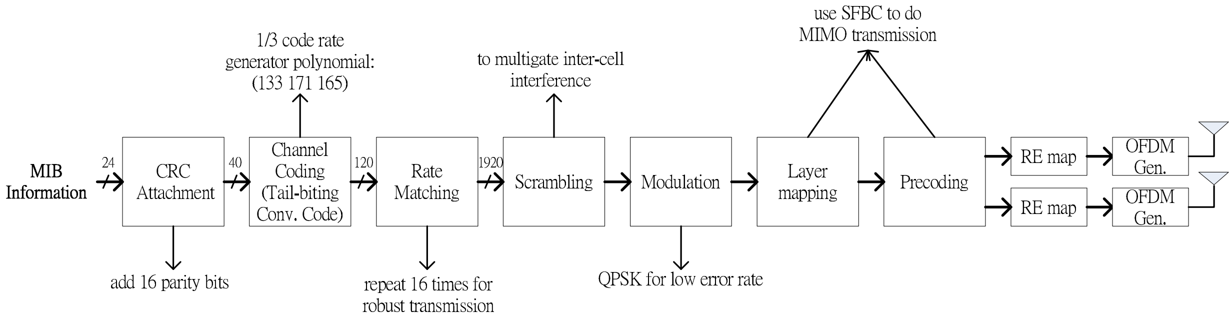

Fig. 1: Flow Chart of Channel Coding and Modulation for LTE PBCH.

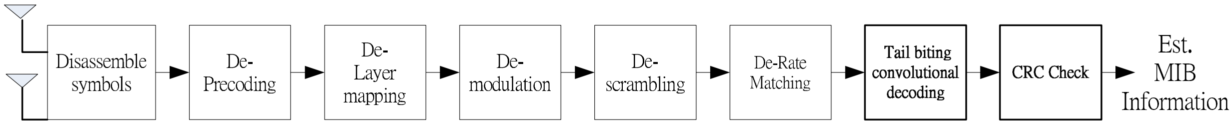

Fig. 2: Flow Chart of PBCH Receiver.

front of $\mathbf{r}$ such that the resultant $(N + nF + nB)$-bit vector is

$$\tilde{\mathbf{r}} = (r_{N-nF-2}, \cdots, r_{N-1}, r_0, r_1, \cdots, r_{N-1}, r_0, \cdots, r_{nB-1}),$$

and is briefly illustrated in Fig. 3.

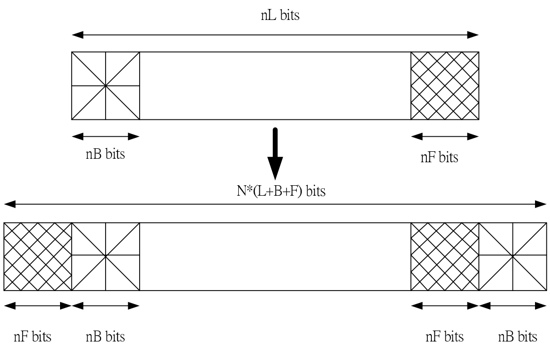

Fig. 3: Idea of Circular Decoding Algorithm

Next, $\tilde{\mathbf{r}}$ is decoded using the ordinary Viterbi algorithm with slight modifications such as equal-probable initial states and tracing back from the best state. The output sequence has length $F + L + B$ and the first F bits and last B bits will be discarded to obtain the final decoded information block of length L.

Obviously, the selection of F and B values should tries to reach a balance between the performance and complexity tradeoff.

B. Reduced Search Space Decoder

The main idea of the reduced search space decoder contains two parts: 1) jointly decode convolutional and CRC codes and 2) limit the search space only to the unknown information.

In the current spec, 24-bit MIB content are encoded by the CRC encoder to form a 40-bit CRC-coded vector, which is later encoded by tail-biting encoder to 120-bit tail-biting codeword. Furthermore, the current spec states that only 14 bits of the 24-bit MIB content are unknown to the receiver. Since the CRC encode and tail-biting encode are deterministic, there are only 2^{14} possible solutions[1] that should be determined in the receiver.

At least the reduced search space decoder, which searches only 2^{14} solutions and find the optimal solution, can be implemented by brute force comparison. Each of the 2^{14} candidates is encoded by CRC encoder and tail-biting encoder to generate the corresponding 120-bit codeword. All 2^{14} codewords are compared with the received vector to find the optimal solution.

C. Proposed Decoder

We introduce one PBCH decoder taking into consideration that 10 out of 24 MIB bits are reserved in the current LTE spec [3]. The main difference between tail-biting convolutional code and the zero-tail convolutional code is the knowledge of initial/end state in the trellis. Although tail-biting encoder is used in the LTE standard [5], the tail-biting decoder of PBCH may be enhanced by taking into consideration the 10 spare bits and the circular property of tail-biting convolutional code.

Fig. 4 shows the flow chart of the proposed PBCH receiver. We first cyclic right shift the received 120 soft values so that the initial state of the decoding trellis are ensured to be all zero state. Therefore, Viterbi decoding algorithm for zero-tail trellis can be used to generated the 40-bit estimated message vector. After that, simply cyclic left shift the message vector return the estimation of the 40-bit CRC-coded vector ready for CRC check.

To be specified, we illustrate the content of 40-bit CRC-coded vector before and after right cyclic shift in Fig. 5. Note that the last 6 bits (i.e., the begin/end state of the trellis) corresponds to the CRC part, which makes the receiver unaware of the initial/end state of the trellis. However, if we

[1]The number of solutions can be further reduced if, for example, we take into consideration that only 6 system bandwidth choices are illustrated by 3 bits. However, the difference between those further search space reduction is limited.

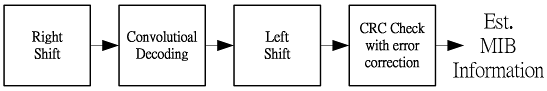

Fig. 4: Flow chart of the Proposed PBCH Decoder.

right cyclic shift $3 \times 16 = 48$ bits of the 120 soft values which corresponds to right cyclic shift the input codeword by 16 bits, the last 6 bits are spare bits which are zeros according to the current spec [3].

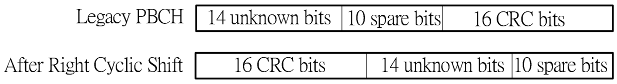

Fig. 5: Content of 40-bit CRC-coded Vector Before and After Right Cyclic Shift.

IV. Simulation results

In this section, we compare the simulation results for different decoders. Our simulation assumption based on the 3GPP standard (see table 9.5.1.1-1 of [1]) and is summarized in table II. Besides, the parameters $B = F = 40$ are chosen for the circular Viterbi decoder.

As observed from Fig. 6, the reduced search space decoder provide the best performance. By only searching the optimal solution within 2^{14} candidates provides about 4.6 dB performance gain compared with the legacy circular Viterbi decoder. However, the complexity of the reduced search space decoder with 14 unknowns bits is very high and may need further study to reduce the complexity before its usage for low-cost devices.

Compared the proposed decoder with the legacy circular Viterbi decoder, we see about 1.0 dB performance gain for the proposed decoder. Furthermore, the decoding complexity of the proposed decoder is smaller that the circular Viterbi decoder. For example, for $L = 40$, and $B = F = 40$, the decoding complexity of the proposed decoder is just about 1/3 of that of the circular Viterbi decoder.

Notably, the reason why the proposed receiver can have better performance and lower complexity compared with the legacy circular Viterbi decoder is the knowledge of the spare bits.

TABLE II: Simulation Assumption

Parameter	Value
System Bandwidth	1.4 MHz
Carrier frequency	2.0 GHz
Antenna configuration	2x2, low correlation for FDD
Channel model	EPA
Modulation Mode	QPSK
Channel Estimation	Perfect channel estimation
Performance target	1 percent miss probability

V. Conclusion

The current 3GPP discussion focuses on the coverage enhancement of MTC in LTE. In this work, we focus on the improvement of the PBCH coverage by proposing a different

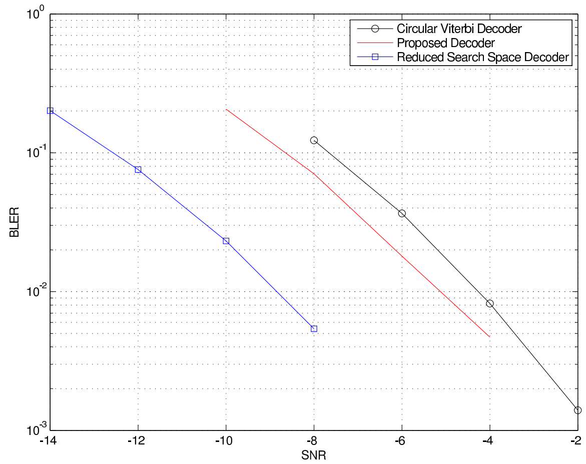

Fig. 6: Performance Comparison for Different Decoders Under 3GPP Simulation Settings.

decoder. From the simulation results we observe performance gain compared with the legacy decoder design. Furthermore, the decoding complexity is also improved. We believe the proposed decoder are promising for PBCH coverage enhancement.

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