A 5G Trial of Polar Code

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***Abstract*—Channel polarization based on Polar code has attracted more attentions since it was firstly proposed by Arıkan in 2008. It is attractive owing to its structural property which makes the encoding process at the transmitter easy to be implemented. At the same time, Polar code is coming to industry due to its novel optimized decoding algorithms. But until now, Polar code has not yet been verified in trial. In this paper, Polar code will be verified in a 5G trial conducted jointly by Huawei and NTT DOCOMO. For comparison purpose, Turbo code in LTE is introduced as a baseline. Extensive tests are conducted with respect to configured air interface specifications such as frame structure and waveform. The effect of packet size on performance is also investigated. To obtain realistic testing results, besides the lab test by using a channel emulator, Over the Air (OTA) field trials are also conducted. Test results show significant performance gain of Polar code over Turbo code.**

Keywords- Channel polarization; Polar Code; CRC-Aided Successive Cancellation List (CA-SCL); Channel Emulator; filtered-OFDM (f-OFDM); Over the Air (OTA)

I. INTRODUCTION

Channel polarization has been firstly proposed in 2008 by Arıkan and in 2009, more researches have been done in another paper [1]. At the same time, a corresponding new channel coding scheme, Polar code developed based on channel polarization has been proposed in that paper.

Polar code is the first code family that has been proven to be able to achieve the symmetric capacity in binary-input discrete memoryless channels. Owing to its structural property, it does not need any optimizing search when constructing a Polar code at the transmitter. Therefore, Polar coding theory becomes an popular research area soon after, and Polar code becomes a competitive candidate coding scheme in future wireless communication systems, e.g., 5G system.

In recent years, much attention has been paid to the decoding of Polar code, especially on how to improve the decoding efficiency and achieve a comparable performance as ML algorithm simultaneously [2]. The Successive Cancellation (SC) decoding algorithm is redefined as a path search procedure in the code tree. By allowing more than one candidate paths to be searched during the searching procedure, one enhanced searching algorithm has been proposed, i.e., the Successive Cancellation List (SCL) which performs a width-first search on the code tree [3-8]. At the same time, to save the decoding time in the searching procedure, utilizing the prior message if the un-coded bit sequence can pass the Cyclic Redundancy Check (CRC), which is a general case in practical digital communication system, the performance of Polar code under the SCL decoding algorithm can be significantly improved. That is CRC-Aided Successive Cancellation List, i.e., CA-SCL [9].

In this paper, Polar code will be tested for the first time in a 5G trial conducted jointly by Huawei and NTT DOCOMO. During this trial, the performance of Polar codes is tested with different parameter settings such as different channel propagation conditions, block sizes, waveforms, and UE velocities. Performance comparison with Turbo code is shown for demonstration purpose. From these tests, we can obtain some first-hand results about the performance of Polar code by using prototypes in realistic environments. This paper gives a summary of the testing results and observations, which provides guidance on the selection of channel coding schemes for 5G.

The rest of the paper is organized as follows. In section II, the framework of Polar code in the 5G trial, test configurations, test environments and corresponding test results will be provided. The paper will be concluded in section III.

II. POLAR CODE IN 5G TRIAL SYSTEM

In this section, the framework of the Polar code in the 5G trial system is firstly described. For thorough testing and comparison, configurations including the specification of air interface, frame structure, setting using large and small packets, OFDM and filtered-OFDM (f-OFDM) waveforms will be introduced. To demonstrate the performance of Polar code, both channel emulator based and Over the Air (OTA) based test environments are conducted. Test results are provided to illustrate the performance gain of Polar code compared to Turbo code in LTE.

A. Framework of Polar Code in 5G Trial System

The following figure is shown for the framework of encoding and decoding using Polar code. At the transmitter, it will use Polar code as channel coding scheme. Same as in Turbo coding module, function blocks such as segmentation of Transmission Block (TB) into multiple Code Blocks (CBs), rate matching (RM) etc. are also introduced when using Polar code at the transmitter. At the receiver side, correspondingly, de-RM is firstly implemented, followed by decoding CB blocks and concatenating CB blocks into one TB block. Different from Turbo decoding, Polar decoding uses a specific decoding scheme, SCL to decode each CB block. For the encoding and decoding framework of Turbo, interested readers can refer to 3GPP specifications [10, 12].

The computational complexity of a SCL decoder depends on the list size. For a list size of 32, its computational complexity without any reduction scheme is still lower than an 8-iteration Turbo decoder [11].

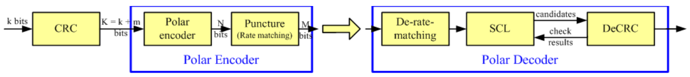

Fig.1. The framework of Polar code in the 5G trial system.

B. Test Configurations

In this sub-section, configuration parameters for tests are described. Mainly four configurations are considered: 1) specification of air interface; 2) frame structure; 3) settings for large and small packets; 4) OFDM waveform vs. f-OFDM waveform.

- Specification of Air Interface

The main specifications of air interface are listed in Table 1.

Table 1. Specifications of air interface

Configuration Item	Value
Carrier Frequency	2.3GHz
Carrier Spacing	15KHz
System Bandwidth	20MHz
Wave Form	OFDM vs f-OFDM
Modulation and Coding	Same as LTE
Antenna Configuration	eNB: 2T2R UE: 1T2R
MIMO Mode	DL: SFBC UL: SIMO
Application Type	Full Buffer

The carrier frequency, carrier spacing, system bandwidth, waveform, modulation and coding scheme, antenna configuration at both eNB and UE, MIMO mode for downlink (DL) and uplink (UL) etc. are described.

- Test Frame Structure

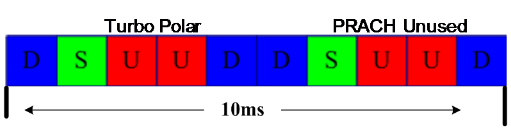

Fig.2. Test frame structure design.

In order to compare Polar code with Turbo code, the frame structure as shown in Figure 2 is used. Without loss of generality, it is fine to use either UL or DL transmission for testing. For simplicity, UL transmissions are tested for comparison in the trial. As shown in Figure 2, Turbo code and Polar code are arranged in two consecutive UL sub-frames in one 10ms radio frame. The 2nd sub-frame uses Turbo code and the 3rd sub-frame uses Polar code for UL channel coding. For UL synchronization purpose, the 7th sub-frame is reserved for Physical Random Access Channel (PRACH). As a result, the 8th UL sub-frame is not used to make the same transmission opportunity for both Polar and Turbo coding algorithms. The pros of this design is to try to minimize the impact of the fast fading channel on Turbo code and Polar code in one snap-shot. DMRS based channel estimation, e.g., MMSE, is used for both Polar and Turbo coding for a fair enough performance comparison.

- Settings for Large and Small Packets

The impact of packet size on Polar code and Turbo code is investigated. In the testing, two different numbers of resource block (RB) with 3 modulation coding set (MCS) levels for each RB configuration are used. The corresponding packet size supported is shown in Table 2.

Table 2. Settings for large and small packets

MCS Index	Modulation	Edge UE 4 RBs (Small Packet)		Center UE 100 RBs (Large Packet)	
		TB Size [bit]	Coding Rate	TB Size [bit]	Coding Rate
1	QPSK	144	0.136	3624	0.137
11	16QAM	680	0.322	17568	0.332
22	64QAM	1864	0.588	46888	0.592

From Table 2, the TB size (TBS) in 100 RBs case even with the smallest MCS level is far larger than that in 4 RBs case with the largest MCS level.

In the 5G trial test, we allocate the center 100 RBs in the 20MHz bandwidth to 1 UE, named as "Center UE" with "Large Packet", and, the edge 4 RBs are allocated to 1 UE, named as "Edge UE" with "Small Packet".

In the 5G trial test, all above scenarios will be tested for performance comparison.

- OFDM Waveform vs. f-OFDM Waveform

In the comparison test, two waveforms will be considered. One is classical OFDM waveform and the other is f-OFDM waveform. The following three configurations are given in the following Figures. 3, 4, and 5.

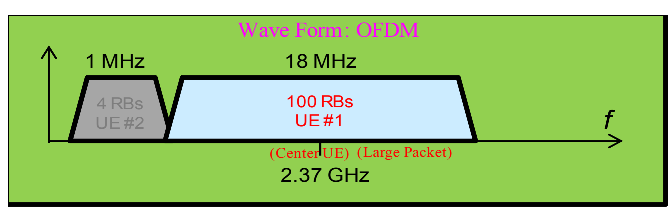

Fig.3. OFDM mode (Center UE with Large Packet).

In the first configuration as shown in Figure 3, only one Center UE is active. The center 100 RBs are allocated to the Center UE. OFDM waveform, the same as that in LTE UL system was used.

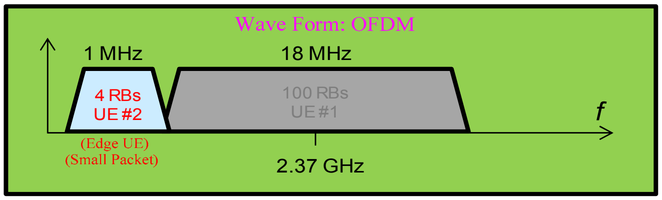

Fig.4. OFDM mode (Edge UE with Small Packet).

In the second configuration as shown in Figure 4, only one Edge UE is active. 4 RBs locating at the edge band are allocated to the Edge UE. OFDM waveform, the same as that in LTE UL system was used.

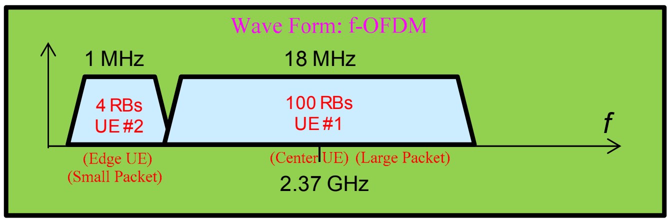

Fig.5. F-OFDM mode (Center UE with Large Packet and Edge UE with Small Packet).

In the third configuration as shown in Figure 5, both of the two UEs are active. One is a Center UE with Large Packet service and the other is an Edge UE with Small Packet service.

It is noted that there are two edge bands each with 1MHz bandwidth in a 20MHz system. One is at upper edge band and the other is at lower edge band. In the comparison test, we only use the lower 1MHz edge band as shown in Figure 5. Different with OFDM based waveform, here we use f-OFDM waveform to generate the baseband signal.

C. *Test Environments*

In this sub-section, test environments will be described.

For the comparison test, the following two environments will be configured. The first one is to use channel emulator to do the comparison test and the second one is to do direct OTA field trial.

- Channel Emulator based Test

The comparison test is firstly done in lab environments. The detailed configured framework is shown in Figure 6.

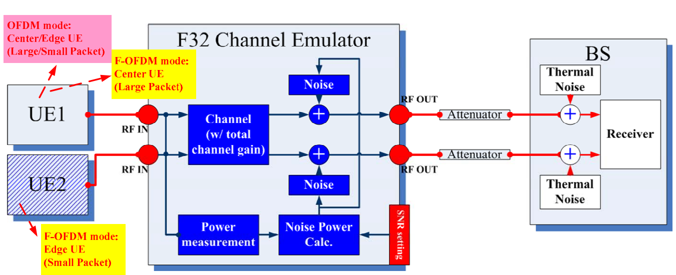

Fig.6. Comparison test using channel emulator.

In this figure, a channel emulator is used to emulate channel conditions. Firstly, it measures the power of input signal at "RF IN" port, then it generates noise power based on the measurement, the channel gain of wireless channel and the SNR according to external settings.

When testing OFDM based waveform, only one UE, UE1 (Center UE with Large Packet) or UE2 (Edge UE with Small Packet) is in active mode and the other UE is in inactive mode. But when testing f-OFDM based waveform, both UEs are in active mode.

- OTA Field Trial

The comparison test is then done in OTA field trial. The OTA test environments are shown in Figure 7.

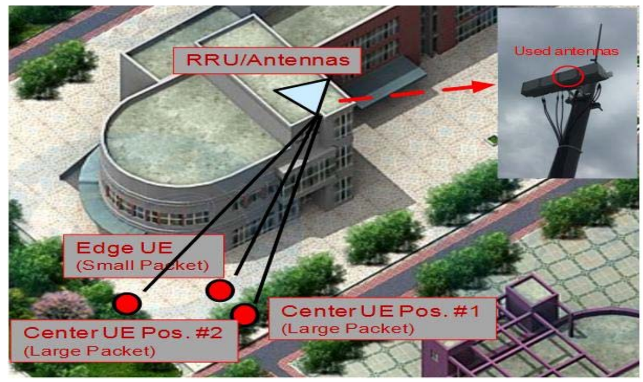

Fig.7. OTA field trial.

In this figure, the antenna height is about 20m or so including the height of building and the tower. Only one pair of cross-polarized antennas (2 transmit antennas) has been used. Base Band Unit (BBU) is put in lab and is connected to Radio Remote Unit (RRU) (located at top of building) via fiber and it is about in 10km distance. Two kinds of UEs, one Center UE with Large Packet and the other Edge UE with Small Packet are deployed on the open square. A more detailed UE is shown in Figure 8.

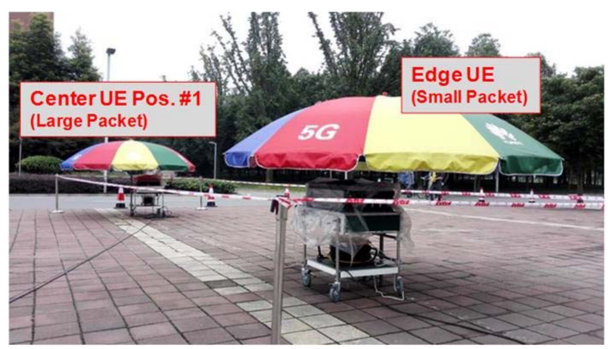

Fig.8. UEs in OTA field trial.

The distance between the Center UE and the Edge UE is about 10m. The downlink Cell-specific Reference Signal (CRS) based SNR of each UE is about 17dB or so in the OTA test.

In the OTA comparison test, the impact of channel propagation condition of the Center UE is also investigated. The propagation environment is designed as shown in Figure 9.

Fig.9. Different locations of center UE in OTA field trial.

When the bus is present, it is marked as "Center UE Pos. #2-1" and it is marked as "Center UE Pos. #2-2" when the bus is absent. This test is to observe the impact of different propagation conditions on the comparison test. In both conditions, the downlink CRS based SNR of the Center UE is kept at about 17dB or so.

D. *Test Results*

In this sub-section, the comparison of test results will be provided. The detailed test items using the channel emulator and the OTA field trial could be different.

- Channel Emulator based Test

In channel emulator based comparison test, there are three test items.

Item1: Comparison between Polar code and Turbo code with different channel models

In this test item, Polar code and Turbo code based on different channel models, AWGN, EPA-3kmph and ETU-3kmph, are investigated and compared.

100 RBs case:

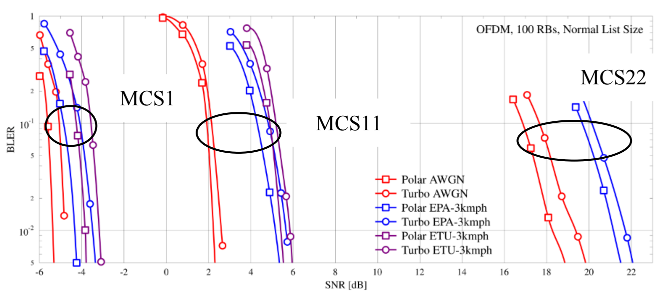

Fig.10. OFDM waveform, 100 RBs: AWGN/EPA-3kmph/ETU-3kmph.

The following is observed from Figure 10:

- Polar code achieves performance gain compared with Turbo code in all three channel models.
- The performance gain at 1% BLER operation point is
  - 0.57 ~ 1.1 dB in AWGN channel,
  - 0.5 ~ 0.82 dB in EPA-3kmph channel, and
  - 0.42 ~ 0.63 dB in ETU-3kmph channel,

  respectively.

4 RBs case:

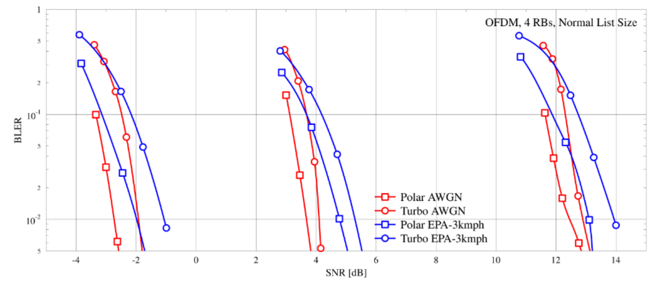

Fig.11. OFDM waveform, 4 RBs: AWGN/EPA-3kmph

The following is observed from Figure 11:

- Polar code achieves performance gain compared with Turbo code in two channel models.
- The performance gain at 1% BLER operation point is
  - 0.42 ~ 0.8 dB in AWGN channel
  - 0.5 ~ 0.91 dB in EPA-3kmph channel.
- Some cross-over between curves of the same coding scheme with different channel models occurs at large BLER level, which may be caused by the inaccurate SNR estimation in 4 RBs case.

Item2: Comparison between Polar code and Turbo code with different mobility speeds

In this test item, Polar code and Turbo code based on different mobility speeds are compared.

100 RBs case:

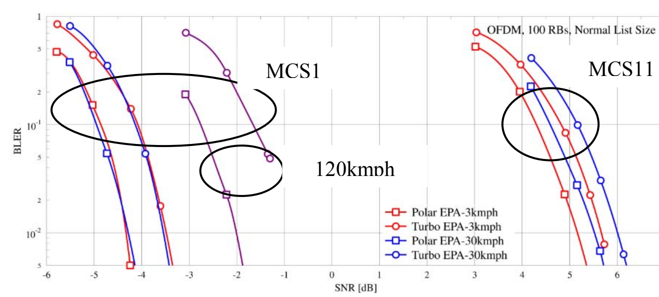

Fig.12. OFDM waveform, 100 RBs: EPA-3kmph/EPA-30kmph.

The following is observed from Figure 12:

- The velocity of 30kmph level has minor impact on the performance at low MCS level, and has larger impact at high MCS level such as MCS 11.
- The performance is worse in 120kmph but the mobility has almost the same impact on Polar codes and Turbo codes.

Item3: Comparison between Polar code and Turbo code with f-OFDM

In this test item, Polar code and Turbo code based on f-OFDM waveform are compared.

100 RBs case:

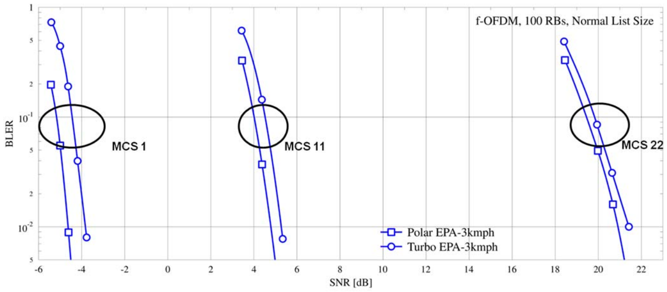

Fig.13. F-OFDM waveform, 100 RBs: EPA-3kmph.

The following is observed from Figure 13:

- When f-OFDM waveform is used, the coding gain of Polar code is still observed compared with Turbo code.
- The performance gain at 1% BLER operation point is
  - 0.48 ~ 0.8 dB in EPA-3kmph channel.

- OTA field trial

In OTA comparison test, MCS 11 and MCS 22, each with 100 RBs and 4 RBs are tested respectively.

MCS 11, 100 RBs case:

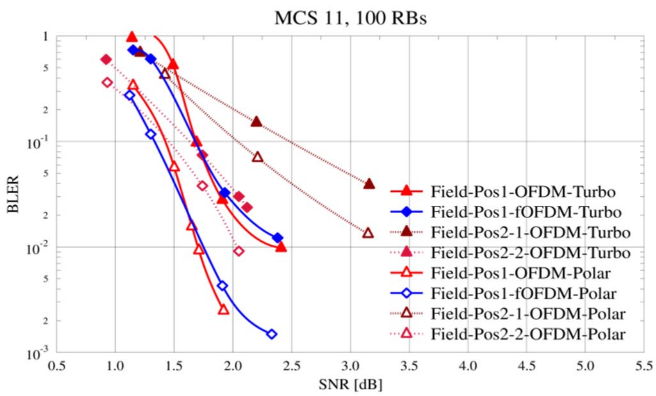

Fig.14. 100 RBs: OTA field test, OFDM/F-OFDM (Different UE Positions).

The following is observed from Figure 14:

- OFDM waveform: Polar code has about 0.7 dB gain compared with Turbo code at 1% BLER operation point.
- F-OFDM waveform: Polar code has about 0.5 dB gain compared with Turbo code at 1% BLER operation point.
- In the OTA field trial, several different UE positions are tested. The following is observed:
  - The propagation conditions in the OTA field trial have significant impact on the results.
  - BLER curves with different slopes are obtained with different environments but the relative performance gain is still kept.

MCS 11, 4 RBs case:

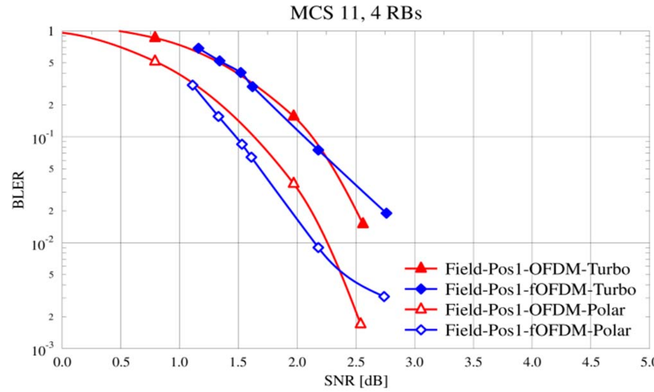

Fig.15. 4 RBs: OTA field test, OFDM/f-OFDM (UE Position 1 only).

The following is observed from Figure 15:

- OFDM waveform: Polar code has about 0.4 dB gain compared with Turbo code at 1% BLER operation point.
- F-OFDM waveform: Polar code has about 0.7 dB gain compared with Turbo code at 1% BLER operation point.

MCS 22, 100 RBs case:

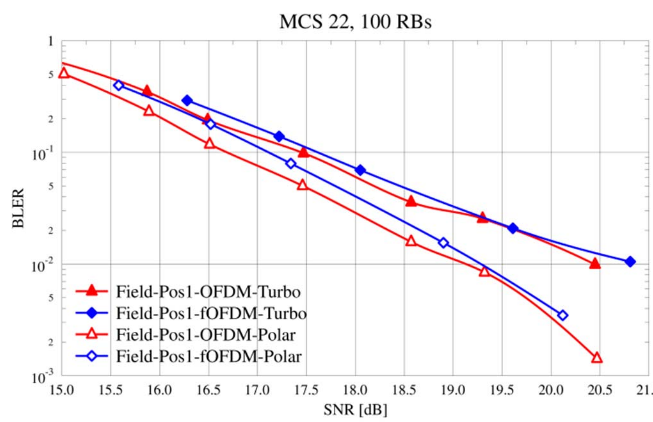

Fig.16. 100 RBs: OTA field test, OFDM/f-OFDM (UE Position 1 only).

The following is observed from Figure 16:

- OFDM waveform: Polar code has about 1.2 dB gain compared with Turbo code at 1% BLER operation point.

  F-OFDM waveform: Polar code has about 1.2 dB gain compared with Turbo code at 1% BLER operation point.

MCS 22, 4 RBs case:

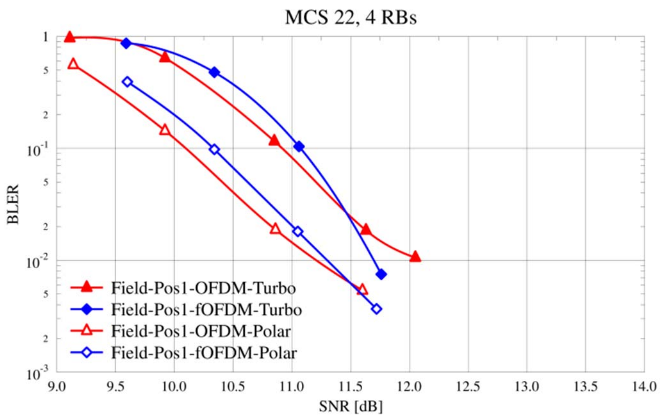

Fig.17. 4 RBs: OTA field test, OFDM/f-OFDM (UE Position 1 only).

The following is observed from Figure 17:

- OFDM waveform: Polar code has about 0.8 dB gain compared with Turbo code at 1% BLER operation point.
- F-OFDM waveform: Polar code has about 0.5 dB gain compared with Turbo code at 1% BLER operation point.

III. Conclusions

In this paper, Polar code has been extensively tested for the first time in a 5G joint trial collaboration project beween Huawei and NTT DOCOMO. Various configurations including the specifications of the air interface, frame structure, settings for large and small packets, OFDM and f-OFDM waveforms have been tested for a thorough verification. For the test environments, both channel emulator and OTA field trials are conducted for performance comparison. When using the channel emulator, the impact of different channel models, different mobility speeds and with and without filtering OFDM has been investigated. In the OTA field trial, two MCS levels, MCS 11 and MCS 22, each with 100 RBs and 4 RBs cases are tested respectively. At the same time, the impact of changing the location of Center UE to get different propagation conditions has also been investigated. For both channel emulator based test and OTA test with various configurations, the Polar code always achieved performance gains over Turbo code. As a conclusion, Polar code is an attractive channel coding scheme which is expected to be beneficial to near future wireless communication systems, e.g., 5G system.

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