Performance Evaluation of Physical Random Access Channel in 5G New Radio

Gweon-Do Jo*, Young Ha Lee*

* ETRI(Electronics and Telecommunications Research Institute), South Korea

gdjo@etri.re.kr

Abstract— **This paper presents performance evaluation results of physical random access channel in 5G new radio standard defined in 3GPP, which was derived from simulation assumptions such as preamble formats, wireless channel, signal-to-noise ratio. We assumed sampling rate of 61.44 Msps, 30 kHz subcarrier spacing, 3.7 GHz center frequency, and 40 MHz system bandwidth in the simulation. As the official performance requirements for new radio physical random access channel is not available yet at the moment, which is being discussed in the 3GPP meeting and by email, this paper refers to the requirements described in 3GPP release-13. Simulation results indicates that the performance of NR PRACH defined in 3GPP release 15 meets the requirements in release 13 at least in additive white Gaussian noise and extended typical urban channel.**

***Keywords*—5G, new radio, random access**

I. INTRODUCTION

The global cellular ecosystem is governed by the 3GPP standardization body. Although LTE, which is recognized as a successful global mobile telecommunication standard developed in 3GPP, is still evolving and expected to be used for many years to come, 5G radio access known as New Radio (NR) has been standardized to meet future requirements. 5G NR is addressing three communication service types such as mobile broadband (eMBB), cellular IoT for massive machine-type communication (mMTC), ultra-reliable low latency communication (URLLC). Basic functionalities for 5G were already included in the 3GPP standards Release 15, which will be more enhanced in upcoming Release 16 i.e. “5G phase 2”.

Regarding random access procedure, the overall protocol sequence would be almost same in LTE and NR. Once a user equipment (UE) is synchronized to the downlink transmission after the cell search procedure, it is able to initiates the random access procedure to establish synchronization between the UE and the gNB. Random access procedure is based on the transmission of random access preamble that is randomly selected from all available preambles assigned to the UE. The transmission of random access preamble takes place on the physical random access channel (PRACH) [1]–[3].

The gNB is able to detect multiple random access attempts from different UE’s. The response message shall be scheduled on downlink shared channel (DL-SCH). The uplink of the UE is time synchronized and beam established after successful initial access procedure. The random access procedure may also be used by a UE in connected state to request resources for uplink transmission or to recover the uplink (re-establishing uplink synchronization and recovering from beam failure) [4].

The objective of the work in this paper is to evaluate the performance of NR PRACH and compare it to that of LTE because the performance requirements for NR PRACH has not been release from 3GPP yet, which is being discussed in the 3GPP meeting and by email [5], [6].

The rest of the paper is organized as follows: Section II introduces features of preambles on NR PRACH. Section III presents simulation parameters, results and the performance analysis. Performance over wireless channel models such as AWGN and extended typical urban (ETU) are provided and compared to performance requirements on LTE PRACH. We make concluding remarks with discussion issues for further studies in Section IV.

II. PHYSICAL RANDMOM ACCESS CHANNEL

Similar to LTE, NR PRACH is used to carry random access preamble from UE towards gNB and it helps gNB to adjust uplink timings of the UE. The major difference between LTE RACH and NR RACH would be the support for beamforming which would be supported by default in mmWave in NR. When NR UE is operating in beamforming mode, it shall detect and select a best beam for NR RACH process. When a suitable beam pair in one of the transmission directions is determined, the same pair can then be used also in the opposite transmission direction in the view of beam correspondence [4], [7], [8].

As well known, 3GPP NR adopted a flexible OFDM numerology with subcarrier spacing, which ranges from 15 kHz up to 240 kHz, just to support a wide range of deployment scenarios, from large cells up to small cells supporting high data rate with mmWave [4].

As shown in Table 1 & 2, NR random access preamble supports two different sequence lengths with more various format configurations than those of LTE, which helps in wide deployment scenarios. Each cell is allowed to use a single preamble format. There are 64 preambles defined in each time -frequency PRACH occasion [1], [7].

The long sequence uses four preamble formats like LTE. These formats are designed to support large cell deployment in sub 6 GHz range. Each format corresponds to a specific numerology (1.25 kHz or 5 kHz). A long preamble with 1.25

kHz subcarrier spacing occupies six resource blocks (1.08 MHz), while a preamble with 5 kHz subcarrier spacing occupies 24 resource blocks (4.32 MHz) in the frequency domain [4].

Short preambles are based on a sequence length L = 139. Nine formats are defined in short preamble sequence. These formats are to support small cell deployment and mmWave frequency range. These preamble formats are used for both FR1 (sub-6 GHz) and FR2 (mmWave) ranges. Subcarrier spacing of 15 or 30 KHz are applicable in FR1, while subcarrier spacing of 60 or 120 KHz are for FR2 [7].

Regardless of the preamble numerology, a short preamble always occupies 12 resource blocks in the frequency domain. For example, a short preamble occupies 4.32 MHz in case of 30 kHz subcarrier spacing. One major difference compared to long preamble is that short preamble can be transmitted multiple times (i.e. multiple RACH occasions exist) within a single RACH slot because short preamble spans only a few OFDM symbols [4].

TABLE 1. LONG PREAMLE FORMATS

Format	L_{RA}	Δf^{RA}	N_u	N_{CP}^{RA}
0	839	1.25 kHz	24576κ	3168κ
1	839	1.25 kHz	$2 \cdot 24576\kappa$	$2 \cdot 21024\kappa$
2	839	1.25 kHz	$4 \cdot 24576\kappa$	4688κ
3	839	5 kHz	$4 \cdot 6144\kappa$	3168κ

TABLE 2. SHORT PREAMLE FORMATS

Format	L_{RA}	Δf^{RA}	N_u	N_{CP}^{RA}
A1	139	$15 \cdot 2^{\mu}$ kHz	$2 \cdot 2048\kappa \cdot 2^{-\mu}$	$288\kappa \cdot 2^{-\mu}$
A2	139	$15 \cdot 2^{\mu}$ kHz	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$576\kappa \cdot 2^{-\mu}$
A3	139	$15 \cdot 2^{\mu}$ kHz	$6 \cdot 2048\kappa \cdot 2^{-\mu}$	$864\kappa \cdot 2^{-\mu}$
B1	139	$15 \cdot 2^{\mu}$ kHz	$2 \cdot 2048\kappa \cdot 2^{-\mu}$	$216\kappa \cdot 2^{-\mu}$
B2	139	$15 \cdot 2^{\mu}$ kHz	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$360\kappa \cdot 2^{-\mu}$
B3	139	$15 \cdot 2^{\mu}$ kHz	$6 \cdot 2048\kappa \cdot 2^{-\mu}$	$504\kappa \cdot 2^{-\mu}$
B4	139	$15 \cdot 2^{\mu}$ kHz	$12 \cdot 2048\kappa \cdot 2^{-\mu}$	$936\kappa \cdot 2^{-\mu}$
C0	139	$15 \cdot 2^{\mu}$ kHz	$2048\kappa \cdot 2^{-\mu}$	$1240\kappa \cdot 2^{-\mu}$
C2	139	$15 \cdot 2^{\mu}$ kHz	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$2048\kappa \cdot 2^{-\mu}$

Unlike the LTE, 5G new radio supports many options for preamble transmission in physical random access channel especially for short preambles. This paper focuses on the performance evaluation of short preambles with 30 kHz subcarrier spacing.

III. PERFORMANCE EVALUATION

A. Simulation Model

We carried out link level simulation on preamble format B1 assuming sampling rate of 61.44 Msps, 30 kHz subcarrier spacing, 3.7 GHz center frequency, and 40 MHz system bandwidth. The preamble format B1 are illustrated in Figure 1. The basic structure for preamble generation and preamble detection, as illustrated in Figure 2, was assumed in the simulation.

A sub-carrier spacing of 30 kHz in PRACH is used for robustness towards Doppler spread in high speed scenarios, whereas 15 kHz for slow speed scenarios. Overall link budget is not so strongly affected by subcarrier spacing. The higher subcarrier spacing shall require wider noise bandwidth for the same PRACH preamble resource allocation, whereas it may improve detection performance for a given SNR since the preamble duration is shorter and fewer coherent detection groups are required [9], [10].

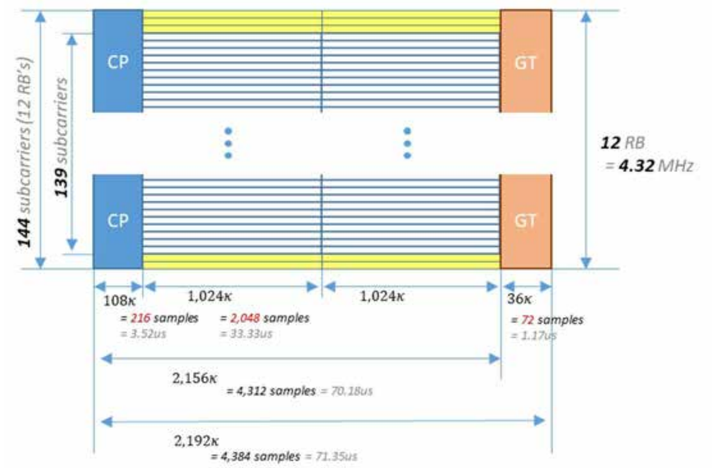

Figure 1. Preamble format B1

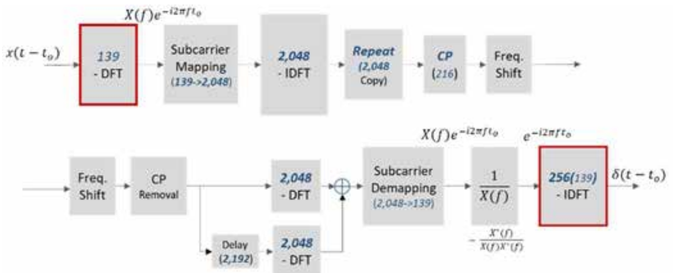

Figure 2. The structure for preamble generation and detection

B. Performance Requirements

3GPP has not announced the performance requirements for NR PRACH yet, which is being discussed in the meeting and by email. The requirements shall be written in TS38.104 and TS38.141 in the near future. As the performance requirements are not available at the moment, this paper refers to the requirements described in documents for LTE, especially for 3GPP release-13.

The performance requirement of PRACH for preamble detection is determined by the two parameters: The probability of false detection of the preamble (P_{fa}) and the probability of detection of preamble (P_d). The false alarm probability is the conditional total probability of erroneous detection of the preamble (i.e. erroneous detection from any detector) when input is only noise. The performance is measured by the required SNR to achieve the probability of detection, P_d of 99%. And the false alarm rate P_{fa} shall be 0.1% or less [6].

Table 1 shows the performance requirement regarding LTE PRACH missed detection for normal mode defined in 3GPP release 13. The probability of detection shall be equal to or exceed 99% for the SNR levels listed in the table.

TABLE 3. PRACH MISSED DETECTION REQUIREMENTS FOR NORMAL MODE

Number of RX antennas	Propagation conditions and correlation matrix	Frequency offset	Required SNR [dB]
			Burst format 2
2	AWGN	0	-16.4
	ETU 70 Low	270 Hz	-10.0

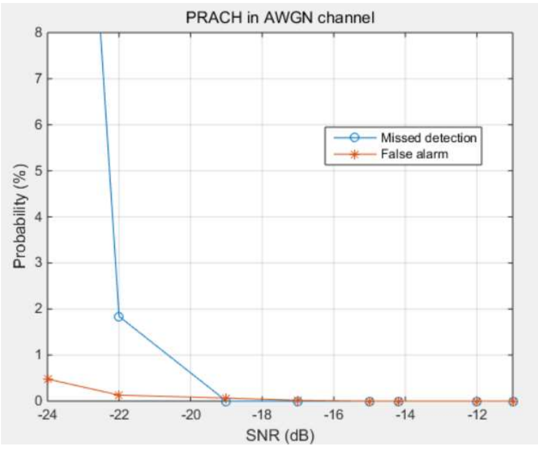

Figure 3. Simulation results (AWGN channel)

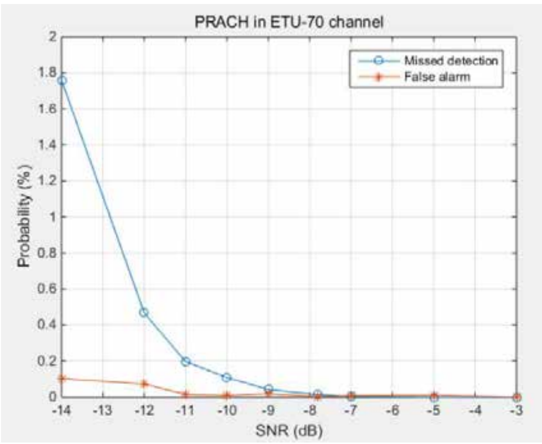

Figure 4. Simulation results (ETU channel)

C. Evaluation Results

We tried 60,000 preamble transmissions for each SNR in the simulation to get a result in the figure. Figure 3 and 4 shows missed detection probabilities and false alarm probabilities according to configured SNR's in AWGN and ETU channel, respectively.

In AWGN and -16.4 dB SNR, Figure 3 shows 99.99% detection probability and 0.17% false alarm rate, which stays above 99% detection probability and below 0.1% false alarm rate. We see more than 2 dB SNR margin in the figure.

In ETU 70 Low and -10 dB SNR, Figure 4 shows 99.89% detection probability and 0.01% false alarm, which stays above 99% detection probability and below 0.1% false alarm rate. We see more than 2 dB SNR margin in the figure.

IV. CONCLUSIONS

We evaluated the PRACH in 5G new radio standard defined in 3GPP by using link level simulator. AWGN and ETU wireless channel were considered in this paper. Simulation results indicates that the performance of NR PRACH defined in 3GPP release 15 meets the requirements at least in AWGN and extended typical urban channel defined in 3GPP release 13.

The probability of detection and false alarm is highly related to the detection threshold in the preamble receiver in gNB. It shall be beneficial to set the threshold adaptive to the channel environment and number of concurrent access from multiple UE's. Novel threshold adjustment schemes are to be investigated in the future study.

ACKNOWLEDGMENT

This work was supported by Institute for Information & communications Technology Promotion(IITP) grant funded by the Korea government(MSIT) (No. 2017-0-00724, Development of Beyond 5G Mobile Communication Technologies (Ultra-Reliable, Low-Latency, and Massive Connectivity) and Combined Access Technologies for Cellular-based Industrial Automation Systems).

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Gweon-Do Jo received the B.S. degree in electronics engineering and M.S. degree in mobile communications from Chonnam University, Gwang-ju, Korea, in 1991 and 1994, respectively, and the Ph.D. degree in computer and communication engineering from Chungbuk National University, Cheongju, Korea, in 2005. Since February 1994, he has been with Electronics and Telecommunications Research Institute (ETRI), Daejeon,Korea, where he has engaged in the research and development of third- and fourth-generation mobile communication systems and software-defined radio (SDR). He is currently the Principal Engineer with the Internet Research Division, ETRI. His current research interests include digital pre-distortion for power amplifier linearization, IQ data compression, beam space MIMO antenna system, and 5G new radio system.

Young Ha Lee