Performance comparison of DTX detection schemes for 5G NR PUCCH

Young-Hoon Kim, Hyungsik Ju, Chan Bok Jeong, Moon-Sik Lee
Future Mobile Communication Research Division
Electronics and Telecommunications Research Institutes
Daejeon, South Korea
{yhkim23, jugun, nineplus, moonsiklee }@etri.re.kr

***Abstract*—The detection of discontinuous transmission (DTX) at the receiver is required, along with the demodulation of the uplink control information (UCI) that is transmitted on the 5G New Radio (NR) Physical Uplink Control Channel (PUCCH). Two feasible detection schemes of the DTX for 5G NR PUCCH format 0 are considered and the performance comparisons of these are carried out by the computer simulations under several situations. The simulation results show that these meet the performance requirements described in the 3GPP standards.**

***Index Terms*—PUCCH, DTX, 5G, NR**

I. Introduction

5G New Radio (NR) wireless communication systems have been continuously deploying since the first commercialized service was successfully introduced. Moreover, many different architectures for 5G NR are considered for offering the flexible and effective usages such as the functional splits of the wireless communication systems and Integrated Access Backhauled Networks (IAB) [1], [2]. In the near future, we will see the distinctive use cases: enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), and ultra-reliable and low-latency communication (URLLC) [3].

A device (also known as User Equipment, UE) carries the uplink control information (UCI) on the Physical Uplink Control Channel (PUCCH) [4]. Depending on the type of the information on the UCI, the various PUCCH formats are provided. Several studies are found for PUCCH of long-term evolution (LTE) and 5G NR [5]–[11].

The generalized likelihood-ratio test (GLRT) detection algorithm in [5] and the joint detection algorithm based on minimum mean square error (MMSE) detection in [6] were proposed for LTE PUCCH. In [7]–[9], the several candidates of the PUCCH designs for 5G NR were compared and studied. The new semi-blind detection algorithms for 5G NR PUCCH was proposed in [10]. However this approach can be applied only for PUCCH format 1 and format 2.

In this paper, we focus only on the detection of 5G NR PUCCH format 0 that is quite different from the other formats. Two different feasible detection schemes of the discontinuous transmission (DTX) for 5G NR PUCCH format 0 are considered and the performance comparisons of these are done by the computer simulations under several situations. In section II, the transmission and reception of the 5G NR PUCCH format 0 are described and the performance metrics are introduced. In section III, the computer simulations are carried out and the results are compared for the several situations. The final section concludes the paper.

II. System description

Unlike the other uplink channels such as the physical uplink shared channel (PUSCH) and the physical random-access channel (PRACH), there is no corresponding upper layer channels for PUCCH (see Fig. 1). A UE transmits uplink control information (UCI) on PUCCH to carry L1/L2 control information such as hybrid automatic repeat request (HARQ) acknowledgements (ACK), channel state information (CSI) for DL-SCH transport block, and uplink scheduling request for uplink shared data channel (UL-SCH). UCI can be transmitted on PUCCH using five different formats for various situations and scenarios [3], [11]. Short-PUCCH such as format 0 and format 2 can be transmitted in short-duration (1 or 2 OFDM symbols). On the other hand, long-PUCCH such as format 1/3 and 4 can be transmitted occupying from 4 to 14 OFDM symbols (see Tbl. I). Whenever the number of bits of UCI is

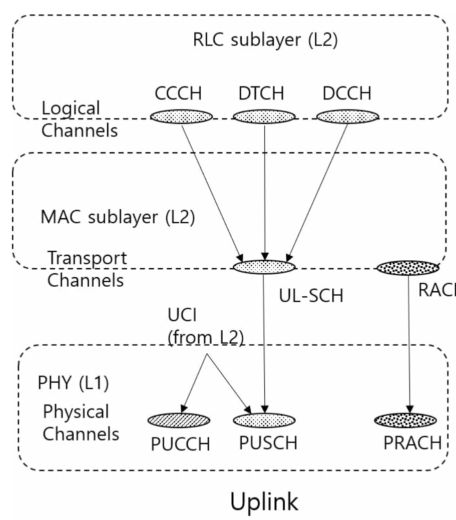

Fig. 1. Mapping between UL channels [3].

less than equal to 2, format 0 and 1 should be used to carry only HARQ and Scheduling Request (SR). The other formats can be used to transmit UCI more than 2 bits for carrying CSI.

TABLE I
5G PUCCH FORMATS [4]

PUCCH format	Number of OFDM symbols	Number of UCI bits
0	$1 \sim 2$	≤ 2
1	$4 \sim 14$	≤ 2
2	$1 \sim 2$	> 2
3	$4 \sim 14$	> 2
4	$4 \sim 14$	> 2

TABLE II
m_{CS} VALUE FOR HARQ/SR TRANSMISSION OF FORMAT 0 [12, SEC.9.2.6]

	HARQ value			
Transmission Type	{0,0}	{0,1}	{1,0}	{1,1}
No SR/1 bit HARQ	0	6	-	-
SR/1 bit HARQ	3	9	-	-
No SR/2 bits HARQ	0	3	6	9
SR/2 bits HARQ	1	4	7	10

A PUCCH format for a UE can configured done by the Radio Resource Control (RRC) signaling from gNB (Next generation nodeB). The resource configuration for the UE PUCCH format can be defined by several RRC parameters such as *intraSlotFrequencyHopping*, *startingPRB*, *secondHopPRB*, *noofSymbols*, and *startingSymbolIndex* (see Fig. 2).

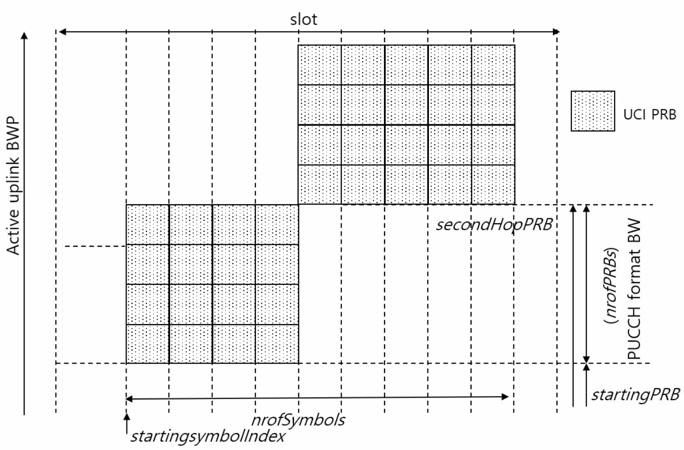

Fig. 2. PUCCH resource allocation and related RRC parameters [12].

Different functions for different formats are defined in [4]. Therefore, different performance requirements for different formats are provided in [13]. A PUCCH format 0 is one of simplest and basic format among these. A PUCCH format 0 can be used during RRC connection, because the UE has only HARQ-ACK information bit [12] and can be used under the situation when the low latency is needed [11].

PUCCH format 0 sequence is generated according to

$$x(l \cdot N_{\mathrm{sc}}^{\mathrm{RB}} + n) = r_{u,v}^{(\alpha,\delta)}(n) \tag{1}$$
$$n = 0, 1, \cdots, N_{\mathrm{sc}}^{\mathrm{RB}} - 1$$
$$l = \begin{cases} 0 & \text{for 1 OFDM symbol,} \\ 0, 1 & \text{for 2 OFDM symbols} \end{cases}$$

where $r_{u,v}^{(\alpha,\delta)}(n)$ is low peak-to-average power ratio (PAPR) sequence defined in [4] with m_{CS} depending on UCI bits (see Tbl. II) and $N_{\mathrm{sc}}^{\mathrm{RB}}$ is the number of subcarriers per resource block. There are 4 possible different Low-PAPR sequences for one OFDM symbol transmission and 8 orthogonal candidates for two OFDM symbol transmission at the receiver side of gNB. Therefore, the received sequences are correlated with these sequences:

$$C_m = \frac{1}{N_r} \sum_{r=0}^{N_r - 1} \left| \frac{1}{N_{\mathrm{sc}}^{\mathrm{RB}}} \sum_{k=0}^{N_{\mathrm{sc}}^{\mathrm{RB}} - 1} R_r(k) \cdot X_m^*(k) \right|^2 \tag{2}$$

where N_r is the number of the RX branch, $R_r(k)$ is the received PUCCH sequence in the frequency domain, and $X_m^*(k)$ is the conjugated sequence that $m = m_{\mathrm{CS}}$. The demodulated UCI bits can be obtained by finding m that provides the maximum of C_m.

There are two performance metrics for NR PUCCH format 0. DTX to ACK probability is the probability that ACK is detected when nothing was transmitted to gNB. The other metric is the ACK missed detection probability. The followings are the performance requirements described in [13]:

- DTX to ACK probability $< 1\%$
- Missed ACK probability $< 1\%$

The DTX with DRX is one of the most important schemes to save a UE battery life. There are several approaches for detection of the DTX of the UE such as [5], [6], [10]. However, most of the approaches cannot be applied for the PUCCH format 0 becuase these approches are based on the known pilot symbols at the gNB. Therefore, we will evaluate the peformance of the detection of the DTX for two basic approaches for the PUCCH format 0 case in this paper.

The first approach is using the signal power and the other one is based on the correlation value obtained from (2). The detection of the DTX is done by comparing the measured value to the reference value. These reference values can be obtained by premeasuring.

III. SIMULATION RESULTS

In this section, two detection schemes of the DTX for PUCCH format 0 have been simulated. Fig. 3 shows the TX and RX processing for the computer simulation. The major parameters used in the simulations are summarized in Tbl. III. The propagation condition of a channel model, a maximum Doppler frequency, and the desired delay spread is TDLA30-300 Low for FR2 (see [13]). In this link level simulation, DTX threshold values for two detection algorithms are chosen to maintain at below 10^{-2} for DTX to ACK probability. Fig. 4 shows the missed ACK probability with two different DTX schemes for using only 1 OFDM symbol. The performances of two algorithms of alg0 (based on the power) and alg1 (based

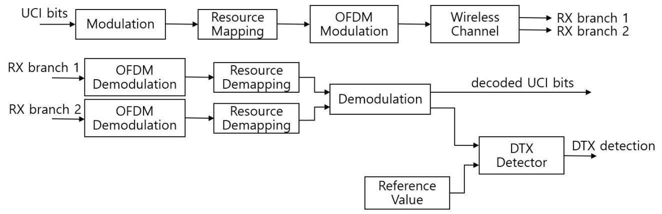

Fig. 3. TX and RX processing for PUCCH format 0.

on the correlation) with 1 RX branch and 2 RX branch cases are compared. The required SNRs for the both scheme with 2 RX branches that meets the missed ACK performance are below than the given required SNR 9.2dB described in [13]. The performance of the correlation-based scheme (alg1) is much better than the power-based scheme. From Fig. 4, it is observed that the RX diversity gain of the correlation-based algorithm is bigger than the RX diversity gain of the power-based algorithm.

Fig. 5 shows the performance comparisons of two algorithms with two OFDM symbols when the intra slot frequency hopping is used and is not used. Both algorithms can get the diversity gain, however the required SNR for the power based scheme does not meet the required SNR 3.8dB described in [13].

The reason for the better performance of the correlation based algorithm is due to the processing gain of the Low-PAPR sequnce correlation under the fading channel. Howerver, the power based algorithm shows the increased power estimation error and DTX detection error with a physical resource block (PRB) when a UE transmits the sequence.

TABLE III
TEST PARAMETERS [13]

Parameter	Value	Remark
Channel BandWidth	100 Mhz	
SCS	120 KHz	Subcarrier Spacing
FFT size	1024	
No. of TX	1	
No. of RX	2	
nrofBits	1	No. of UCI bits
nrofPRBs	1	No. of PRB size [12, 9.3]
startingPRB	0	[12, 9.3]
intraSlotFrequencyHopping	enabled	N/A for 1 symbol [12, 9.3]
secondHopPRB	65	[12, 9.3]
initialCyclicShift	0	[4]
startingSymbolIndex	12 or 13	[12, 9.3]
No. of OFDM symbols	1 or 2	[12, 9.3]

IV. CONCLUSION

In this study, we evaluate the performance of the two detection approaches of DTX for 5G NR PUCCH format 0 under the various situations. The DTX is one of the most important functionality to save the battery life for a UE. Therefore, the detection of DTX is essential at the receiver side of the gNB.

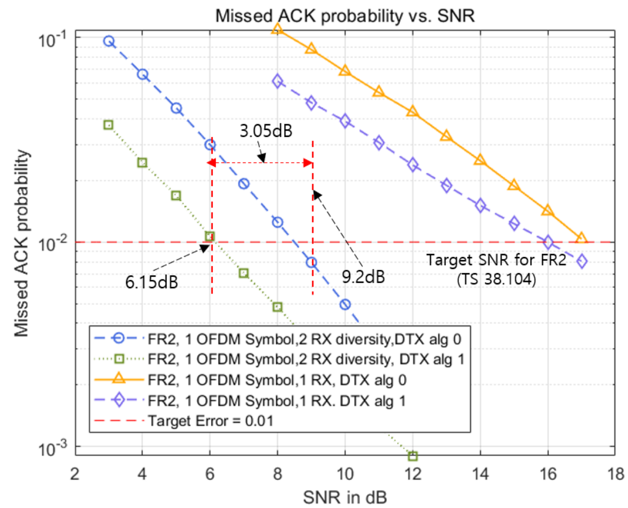

Fig. 4. Missed ACK detection probability for 1 OFDM symbol

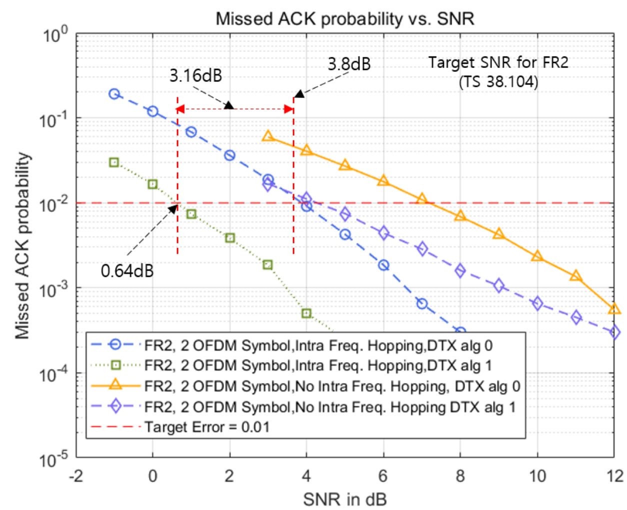

Fig. 5. Missed ACK detection probability for 2 OFDM symbols

Since the transmission of the UCI on the PUCCH format 0 is quite different from the other formats, the performance requirements for the PUCCH format 0 is throughly studied in this paper. Two approaches for the detection of the DTX are introduced and intensive computer simulations are carried out. Simulation results shows that these two schemes for the 5G NR PUCCH format 0 satisfy the performance requirements. Two schemes are feasible and promising for the various deployments of 5G NR gNB such as the regular gNB, DU and IAB.

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REFERENCES

[1] L. M. P. Larsen, A. Checko, and H. L. Christiansen, "A survey of the functional splits proposed for 5g mobile crosshaul networks," *IEEE Communications Surveys Tutorials*, vol. 21, no. 1, pp. 146–172, Oct. 2019.

[2] M. Polese, M. Giordani, T. Zugno, A. Roy, S. Goyal, D. Castor, and M. Zorzi, "Integrated access and backhaul in 5g mmwave networks: Potential and challenges," *IEEE Communications Magazine*, vol. 58, no. 3, pp. 62–68, Mar. 2020.

[3] E. Dahlman, S. Parkvall, and J. Sköld, *5G NR: The next generation wireless access technology*. Academic Press, 2018.

[4] 3GPP, *NR; Physical channels and modulation*, 3GPP TS 38.211, Rev. V15.5.0, Mar. 2019.

[5] Y. Wu, D. Danev, and E. G. Larsson, "On ack/nack messages detection in the lte pucch with multiple receive antennas," in *2012 Proceedings of the 20th European Signal Processing Conference (EUSIPCO)*, Oct. 2012, pp. 994–998.

[6] J. Zhang, H. Zhao, Y. Peng, and L. Zhao, "A joint detection algorithm for pucch," in *2014 Sixth International Conference on Ubiquitous and Future Networks (ICUFN)*, 2014, pp. 226–230.

[7] L. Wang, Y. Matsumura, K. Takeda, X. Hou, and S. Nagata, "Uplink control channel for 5g new rat," in *2017 11th International Conference on Signal Processing and Communication Systems (ICSPCS)*, Dec. 2017, pp. 1–7.

[8] Y. Matsumura, L. Wang, K. Takeda, and S. Nagata, "5g new rat uplink control channel for small payloads," in *2017 11th International Conference on Signal Processing and Communication Systems (ICSPCS)*, Dec. 2017, pp. 1–5.

[9] L. Kundu, G. Xiong, and J. Cho, "Physical uplink control channel design for 5g new radio," in *2018 IEEE 5G World Forum (5GWF)*, Jul. 2018, pp. 233–238.

[10] Y. Du, W. He, and H. Long, "An improved semi-blind detection algorithm for nr pucch," in *2019 IEEE 5th International Conference on Computer and Communications (ICCC)*, Dec. 2019, pp. 66–71.

[11] S. Ahmadi, *5G NR Architecture, Technology, Implementation, and Operation of 3GPP New Radio Standards*. Academic Press, 2019.

[12] 3GPP, *NR; Physical layer procedures for control*, 3GPP TS 38.213, Rev. V15.5.0, Mar. 2019.

[13] *NR; Base Station (BS) radio transmission and reception*, 3GPP TS 38.104, Rev. V15.9.0, Mar. 2020.