Detection of PUCCH Format 0 and Performance Analysis for 5G NR Systems

Seongjin Ahn and Junhwan Lee
Satellite Communication Research Division
Electronics and Telecommunications Research Institute (ETRI)
Daejeon, Korea
sj.ahn@etri.re.kr

***Abstract*—In 5G New Radio, the physical uplink control channel (PUCCH) format 0 is a reference signal-less PUCCH carrying small uplink control information (UCI) payloads based on sequence selection. The PUCCH format 0 detection involves discontinuous transmission detection and UCI decoding, typically requiring a non-coherent sequence detector at the receiver. In this paper, we propose a detection method of PUCCH format 0 based on a new detection parameter. Through computer simulations, we evaluate the detection performance of the proposed method.**

***Keywords*—5G, PUCCH, UCI, DTX**

I. Introduction

The physical uplink control channel (PUCCH) in cellular communication systems plays a crucial role in conveying uplink control information (UCI). 5G New Radio (NR) defines five PUCCH formats, each supporting different amounts of UCI payload sizes and resource allocations [1]. Among the various PUCCH formats, PUCCH format 0 is a sequence based scheme carrying small UCI payloads, which contains up to two hybrid automatic repeat request acknowledgment (HARQ-ACK) bits and a scheduling request (SR) bit. Unlike other formats, PUCCH format 0 does not utilize any reference signals. Because of the sequence based structure and absence of the reference signal, PUCCH format 0 receiver generally requires a non-coherent detector. In the previous works, power and correlation based detection methods were presented and it was shown that the correlation based method is more effectively than the power based method [2]-[4].

In this paper, we propose a PUCCH format 0 detection method based on a new detection parameter. We employ the root mean square (RMS) of the correlation coefficients between the received sequence and the reference sequences as the detection parameter. The detection performance of the proposed method is evaluated through computer simulations.

II. System Model

In PUCCH format 0, UCI is transmitted using a cyclic shifted version of a predefined base sequence. The PUCCH format 0 sequence $x(n)$ is generated according to

$$x(lN_{sc}^{RB}+n) = r_{u,v}^{(\alpha,\delta)}(n) \tag{1}$$

$$l = \begin{cases} 0 & \text{for 1 OFDM symbol} \\ 0,1 & \text{for 2 OFDM symbols} \end{cases}$$

where $n = 0, 1, \dots, N_{sc}^{RB}-1$, $N_{sc}^{RB} = 12$ is the number of subcarriers per resource block, and $r_{u,v}^{(\alpha,\delta)}(n)$ is the low peak-to-average power ratio (PAPR) sequence with the sequence cyclic shift m_{cs} determined by the UCI bits [5]. When there is no SR or negative SR, $m_{cs} \in \{0, 6\}$ for one HARQ-ACK bit of $\{0, 1\}$ and $m_{cs} \in \{0, 3, 6, 9\}$ for two HARQ-ACK bits of $\{00, 01, 11, 10\}$. With positive SR, $m_{cs} \in \{3, 9\}$ for one HARQ-ACK bit of $\{0, 1\}$ and $m_{cs} \in \{1, 4, 7, 10\}$ for two HARQ-ACK bits of $\{00, 01, 11, 10\}$. $m_{cs} = 0$ for only positive SR transmission. The sequence $x(n)$ is mapped to a single allocated physical resource block (PRB) in the frequency domain and transmitted through a wireless channel after OFDM modulation.

III. Detection Method

The PUCCH format 0 detection is implemented by non-coherent sequence detector, which includes discontinuous transmission (DTX) detection and UCI decoding. In this section, we introduce a new detection parameter and process for the PUCCH format 0 receiver.

A. Detection Parameter

Let $Y_{r,s}$ denote the received sequence of the s-th OFDM symbol at the r-th receive antenna within the allocated PRB for PUCCH format 0. For each candidate m_{cs} value, the reference low-PAPR sequence $X_{m,s}$ is generated based on the UCI bits, where m is the index of the candidate m_{cs} value. Subsequently, the normalized correlation coefficient between $Y_{r,s}$ and $X_{m,s}$, $\rho_{r,s}^{m}$, is calculated as

$$\rho_{r,s}^{m} = \frac{\left|\sum_{k=1}^{N_{SC}^{RB}} Y_{r,s}(k)X_{m,s}^{*}(k)\right|}{\sqrt{E_{Y_{r,s}}E_{X_{m,s}}}} \tag{2}$$

where E_z is the energy of the sequence z and * denotes the complex conjugate. Theoretically, the maximum of $\rho_{r,s}^{m}$ is obtained when m_{cs} of the received sequence matches that of the reference sequence, while other cases yield low correlation values. To emphasize significant correlation values, we use the RMS of $\rho_{r,s}^{m}$ values as a detection parameter, R_m, computed as

$$R_m = \sqrt{\frac{1}{N_R}\frac{1}{N_S}\sum_{r=1}^{N_R}\sum_{s=1}^{N_S}{\rho_{r,s}^{m}}^2} \tag{3}$$

where N_R and N_S are the number of received antennas and the OFDM symbols, respectively.

This work was supported by Institute of Information & communications Technology Planning & Evaluation (IITP) grant funded by the Korea government(MSIT) (No. RS-2024-00359235, Development of Ground Station Core Technology for Low Earth Orbit Cluster Satellite Communications)

TABLE I. SIMULATION PARAMETERS [6]

Parameter	Value
Subcarrier spacing	30kHz for FR1, 120kHz for FR2
Channel bandwidth	100MHz
Number of UCI information bits	1
Number of PRBs	1
First PRB prior to frequency hopping	0
First PRB after frequency hopping	The largest PRB index - (Number of PRBs - 1)
Intra-slot frequency hopping	N/A for 1 symbol, Enabled for 2 symbols
Group and sequence hopping	neither
Hopping ID	0
Initial cyclic shift	0
First symbol	13 for 1 symbol, 12 for 2 symbols
Number of TX/RX antennas	1/2
Propagation condition	TDLC300-100 Low for FR1, TDLA30-300 Low for FR2

B. *DTX Detection and UCI Decoding*

The DTX detection is performed by comparing the maximum of R_m against a predefined detection threshold. If the maximum R_m is less than the threshold, the received signal is determined as DTX. Otherwise, PUCCH format 0 transmission is assumed, and then UCI bits are decoded by deriving m_{cs} corresponding to the index m that yields the maximum R_m. We derive the detection threshold through simulations to ensure that the DTX to ACK probability does not exceed 10^{-2}.

IV. SIMULATION RESULTS

The performance metrics for PUCCH format 0 include the DTX to ACK probability and the ACK missed detection probability, both of which are required not to exceed 10^{-2} [6]. In this section, we evaluate the detection performance of the proposed method by comparing that of the conventional correlation based method from the MATLAB 5G toolbox in [7]. We consider tapped delay line (TDL) channels in frequency ranges (FR) 1 and FR 2. The detailed simulation parameters are provided in Table I [6].

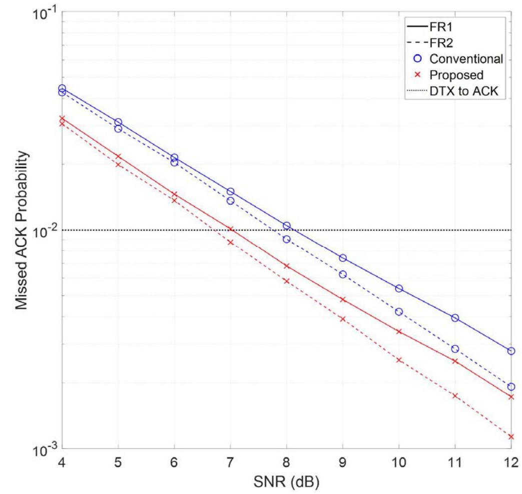

Fig. 1. Missed ACK probability versus SNR for 1 OFDM symbol

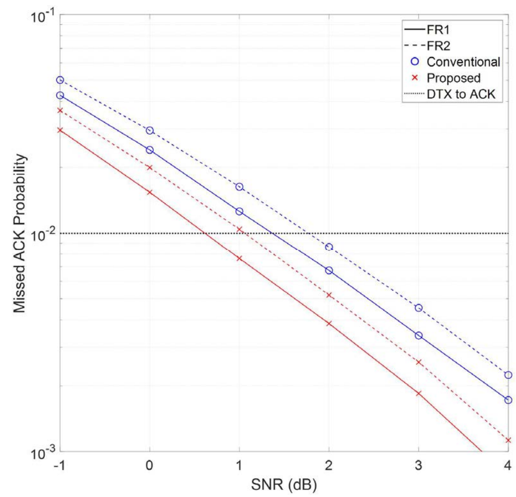

Fig. 2. Missed ACK probability versus SNR for 2 OFDM symbols

Fig. 1 shows the ACK missed detection probability versus signal-to-noise ratio (SNR) for 1 OFDM symbol. The detection thresholds to achieve the DTX to ACK probability of 10^{-2} are set to 0.487 and 0.5 for the conventional and the proposed methods, respectively. The proposed method provides a gain of approximately 1.1 dB at the missed ACK probability of 10^{-2} in both FR1 and FR2 over the conventional method. Fig. 2 shows the ACK missed detection probability versus SNR for 2 OFDM symbols. The detection thresholds are set to 0.417 and 0.439 for the conventional and the proposed methods, respectively. The proposed method achieves a gain of approximately 0.7 dB at the missed ACK probability of 10^{-2} in both FR1 and FR2. Both methods satisfy the minimum required SNR to achieve the ACK missed detection probability of 10^{-2} specified by [6]: 9.2 dB for 1 OFDM symbol in both FR1 and FR2, and 3.5 dB and 3.8 dB for 2 OFDM symbols in FR1 and FR2, respectively.

V. CONCLUSIONS

In this paper, we proposed a detection method of PUCCH format 0 based on a new detection parameter for 5G NR systems. The RMS of the normalized correlation coefficients between the received sequence and the reference low-PAPR sequences was employed for the detection parameter. Through simulations, we showed that the proposed method meets the minimum performance requirements of NR PUCCH format 0, outperforming the conventional method.

REFERENCES

[1] *NR; Physical channels and modulation*, 3GPP, document TS 38.211, V.18.7.0, June 2025.

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

[3] Y.H. Kim, H.S. Ju, C.B. Jeong, and M.S. Lee, "Performance comparison of DTX detection schemes for 5G NR PUCCH," *in Proc. International Conference on Information anc Communication Technology Convergence* (*ICTC*), Jeju, Korea, Oct. 2020, pp. 1391–1394.

[4] S. Tadavarty and N.K. Chavali, "Performance analysis of 5G NR PUCCH format 0 receiver," *in Proc. India Council International Conference* (*INDICON*), Guwahati, India, Dec. 2021, pp. 1–5.

[5] *NR; Physical layer procedures for control*, 3GPP, document TS 38.213, V.18.7.0, June 2025.

[6] *NR; Base Station (BS) radio transmission and reception*, 3GPP, document TS 38.104, V.18.10.0, June 2025.

[7] The MathWorks Inc., *5G Toolbox version*: *24.2* (*R2024b*). Accessed: Oct. 22, 2024, Available: http://www.mathworks.com.