ISBN 978-93-84422-80-6
13th International Conference on Electronics and Communication (ICEC-17)
Pattaya (Thailand) Dec. 28-29, 2017

Detection Performance of LTE PUCCH

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***Abstract*:** *In much practical system, it is necessary to detection the existence of a UE transmitting PUCCH. In this paper a PUCCH detection algorithm is presented based on the reference signal. The performance of the presented algorithm is evaluated by simulation.*

Keywords: *PUCCH, RS, detection.*

1. Introduction

LTE is a widely used wireless standard based on OFDM techniques [1]. In an LTE system, PUCCH is used for the transmission of feedback information from a UE to eNodeB.

In many practical environments, for several purpose, it is necessary for an eNodeB to check the existence of the UE transmitting PUCCH. In this paper, a PUCCH detection algorithm is presented based on the RS of PUCCH. With the presented algorithm, a UE compete the received power of the RS of PUCCH and decides the existence of the PUCCH transmission based on it.

The performance of the presented algorithm is evaluated based on numerical simulation. The results show that reliable PUCCH detection performance can be obtained using the presented algorithm,

2. System Model

In this section, a system model is presented. In the model, there is an eNodeB and a UE communicating each other. The eNodeB tries to detect the existence of an uplink signal based on the control signal transmitted from the UE.

The control information is transmitted on uplink resources assigned for PUCCH. The control information includes channel-state information, hybrid-ARQ acknowledgements and scheduling request by the PUCCH transmission. There are several PUCCH transmission formats depending on the type of the control information. PUCCH consists of two resource blocks (RBs) located at the edge of a system bandwidth. Each slot of the subframe is composed of time multiplexed control data symbols and demodulation reference signals (DM-RS). Fig. 1 shows the structure of PUCCH format 1a/1b for a normal CP [2].

Reference signals (RSs) are included in PUCCH for coherent demodulation. The sequence $c_{i,m}(t)$ of an RS is determined by the subframe number *m* and the cell ID *i* [3]. The sequence are not orthogonal each other, if their cell IDs are different. Each UE transmits PUCCH using a sequence $c_{i,m}(t)$ for the time duration T_s of a subframe. The power of RS $c_{i,m}(t)$ is normalized to satisfy $\frac{1}{T_s}\int_0^{T_s}\left|c_{i,m}(t)\right|^2 dt = 1$ for all i, m.

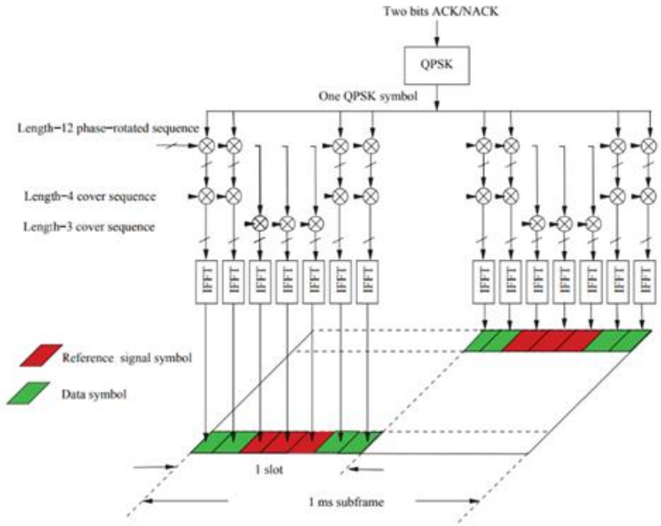

Fig. 1: The structure of PUCCH format 1a/1b for normal CP

Let us denote by γ_i the channel response between the eNodeB and the *i*-th UE. The channel is assumed to be slow time-varying such that its channel response γ_i is a constant during a subframe. It is also assumed that the channel is frequency-flat. Without loss of generality, the channel gains $g_i = |\gamma_i|^2$ is normalized to satisfy $\mathbb{E}(g_i) = 1$ [4]. For a Rayleigh fading channel, the PDFs $f_G(g = g_i)$ of channel gain is expressed as

$$f_G(g) = \exp(-g), \qquad \text{for } g \geq 0, \tag{1}$$

Where g is an independent channel gain [5].

If each UE transmits the RS of PUCCH with transmission power P_i, then the energy consumed for the RS transmission is $E_s = q \cdot P_i \cdot T_s$, where q is the ratio of the RS per subframe. At eNodeB, the received signal can be expressed as

$$r_m(t) = \sqrt{g_i \cdot P_i} \cdot c_{i,m}(t) + n(t), \qquad \text{for } 0 \leq t \leq T_s, \tag{2}$$

where $n(t)$ is an additive white Gaussian noise with power spectral density $N_0/2$.

In this paper, let us consider two possibilities, one is the case when a UE transmits PUCCH using assigned sequence $c_{i,m}(t)$. The other is the case when UE transmits PUCCH using the sequence $c_{j,m}(t)$, where another is different from the assigned one. An eNodeB accumulates the received energies of *N* subframes. Then, it computes the decision variable Z_i, which is expressed as

$$Z_i = \frac{1}{N}\sum_{m=1}^{N}\left|\frac{1}{\sqrt{T_s}}\int_0^{T_s} r_m(t) \cdot c_{i,m}^{*}(t)\,dt\right|^2 \tag{3}$$

For an eNodeB, there are two hypotheses to test. The hypotheses denoted as H_1 and H_0. H_1 is the hypothesis when a UE transmits PUCCH using the assigned sequence $c_{i,m}(t)$. H_0 is the hypothesis when a UE transmits PUCCH using a sequence $c_{j,m}(t)$ $(j \neq i)$, which is different sequence from assigned one.

Two important performance measures are detection probability P_D and false alarm probability P_{FA}. PUCCH is detected when the decision variable Z_i is larger than the detection threshold η under H_1. A false alarm occurs when the decision variable Z_i is larger than the detection threshold η under H_0. Therefore, detection probability P_D and false alarm probability P_{FA} are expressed as

$$P_D = \Pr\{Z_i \geq \eta | H_1\}, \tag{4}$$

https://doi.org/10.17758/ERPUB.P0121716

$$P_{FA} = \Pr\{Z_i \geq \eta | H_0\}. \quad (5)$$

3. Numerical Result

In this section, simulation results are presented. Fig. 2 and 3 show the detection probability P_D versus false alarm robability P_{FA}. PUCCH is transmitted over a Rayleigh fading channel. To obtain the results, PUCCH format 1a/1b is considered for uplink signal transmission with a normal CP. If an LTE system uses a normal CP, there are 7 OFDM symbols in a slot. The results are obtained for several N and E_s/N_0 values.

Fig. 2 shows the detection probability P_D versus the false alarm probability P_{FA} with $N = 1$. From the figure, if can be observed that the detection performance improves as E_s/N_0 increases. The detection probability of PUCCH is about 73% with 0.0 dB E_s/N_0, when the false alarm probability is $P_{FA} = 10^{-3}$. To achieve detection probability higher than 80%, E_s/N_0 should be larger than 2.0 dB.

Fig. 3 shows the detection probability P_D versus the false alarm probability P_{FA}, when E_s/N_0 is 0.0 dB. From the figure, it can be observed that the detection probability increases as N value increases. The detection probability of PUCCH is about 85% with N=2 for the false alarm probability of $P_{FA} = 10^{-3}$ with N=2. To obtain detection of PUCCH higher than 90%, N should be larger than 4.

4. Conclusions

In this paper, a simple PUCCH detection algorithm is presented. The presented algorithm is based the received power of the RS of PUCCH. Numerical results show that reliable PUCCH detection performance can be achieves with the presented algorithm.

5. Acknowledgment

This research was supported by Projects for Research and Development of Police science and Technology under Center for Research and Development of Police science and Technology and Korean National Police Agency funded by the Ministry if Science, ICT and Future Planning (PA-A000001).

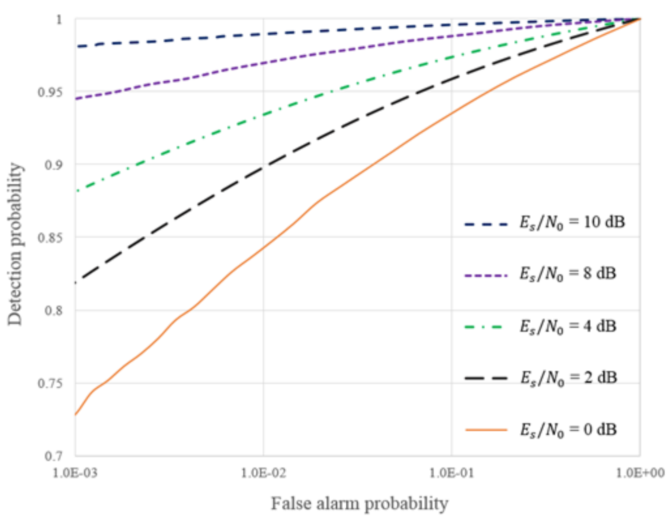

Fig. 2: Detection probability versus false alarm probability ($\boldsymbol{N}$=1).

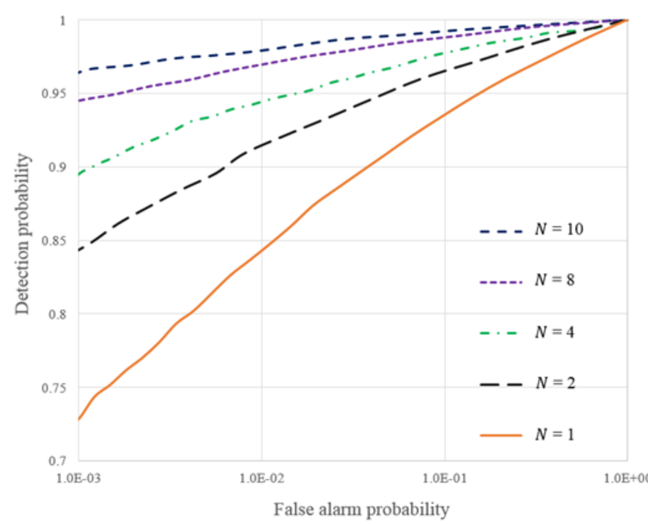

Fig. 3: Detection probability versus false alarm probability ($\boldsymbol{E_s/N_0 = 0}$ **dB**).

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