PERFORMANCE EVALUATION OF CHANNEL-ADAPTIVE RANDOM ACCESS WITH DISCONTINUOUS CHANNEL MEASUREMENT FOR NB-IOT

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Abstract - Performance of channel-adaptive random access with discontinuous channel measurement is evaluated by simulation for NarrowBand Internet-of-Things (NB-IoT)systems.To evaluate the performance, a Time Division Duplex (TDD) based NB-IoT system is assumed. The results show that performance gain can be obtained using channel-adaptive random access scheme for NB-IoTsystems.

Index Terms - Random access, NB-IoT,Internet-of-Things (IoT), channel measurement.

I. INTRODUCTION

Narrowband Internet-of-Things (NB-IoT) has established in the 3rd generation partnership project (3GPP) for massive number of low-cost and low-throughput devices [1].In [1], NB-IoT physical random access channel (NPRACH) is defined, which is different from PRACH of legacy long term evolution (LTE) systems. One of the important design issues is coverage enhancement for NPRACH, since maximum transmission power of NB-IoT devices is very low. To extend coverage of NPRACH, repetition transmission is considered up to 128 times [1]. However, it requires large transmission power,which is proportional to the number of repetition. To reduce transmission power of random access, channel-adaptive random access has been proposedfor TDD based wireless systems [2]. In TDD wireless systems, it is possible to assume that the channel of uplink is the same as that of downlink by channel reciprocity [3]. Withchannel-adaptive random access, after an UE estimates uplink channel quality by measuring downlink channel, it transmits a random access packet only when a transmission condition is satisfied. To reduce power consumption required for channel measurements, discontinuous channel measurement has been proposed for channel-adaptive random access[4], where an UE can measure the downlink channel for only predetermined time intervals. With channel-adaptive random access, NPRACH can achieve to extend coverage with the same transmission power. To apply channel-adaptive random access to NPRACH, a TDD-based NB-IoT system is assumed, which has been discussed in 3GPP specification meetings[5][6]. In this paper, Performance of channel-adaptive random access with discontinuous channel measurement is evaluated by simulation for NB-IoT systems. The rest of this paper is organized as follows. In Section II, a system model is described for performance evaluation. In Section III, the performance results are presented. Finally, conclusion is drawn in Section IV.

II. SYSTEM MODEL

A. NB-IoT physical random access channel (NPRACH)

In an NB-IoT system, NPRACH is based on SC-FDMA with frequency hopping.An NPRACH band consists of 12, 24 36, or 48 subcarriers for each coverage class, where subcarrier spacing is 3.75 kHz.The number of orthogonal preamble sequences is the same as the number of subcarriers in an NPRACH band.Each orthogonal preamble sequence has unique frequency hopping pattern.

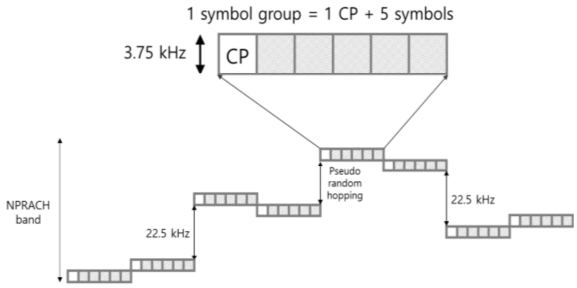

Fig. 1. NPRACH resource structure

Fig. 1 shows an example of NPRACH resource structure.In NPRACH, a symbol group is defined on a single subcarrier, which is composed of a single cyclic prefix (CP) and five consecutive symbols without gaps.The length of CP of 66.7 μsand 266.7 μs can be supported for 15 km and 35 km cell radius, respectively.Each symbol has a duration of 266.7μs, which is the same as the length of long CP.A preamble consists of 4 symbol groups as a basic unit.It can be repeatedly transmitted $2^i (i = 0, \cdots, 7)$ times to enhance coverage. Frequency hopping for NPRACH is constrained within 12 subcarriers and its hopping pattern is defined in [1].Single subcarrier hopping is applied before transmission of the 2nd and the 4th groups and 6 subcarrier hopping is applied before transmission the 3rd group.In the case of repetition

transmission, pseudo-random hopping is applied between consecutive preambles.

B. Channel-adaptive random access with discontinuous channel measurement for NB-IoT

Let us consider an NB-IoT system that operates TDD mode.An eNodeB transmits periodic pilot signals with power large enough to measurethe downlink channel accurately.An UE discontinuously measures the downlink channel for only predetermined time intervals as in [4].

It is assumed that the resource for NPRACH is allocated immediately after a downlink resource block which contains pilot signals.For example, because NPBCH is periodically transmitted every 10 ms interval, pilot signals in NPBCH can be used to measure the downlink channel for channel-adaptive random access transmission.In this case, no additional power consumption is required to measure the downlink channel. Based on channel reciprocity, a remote station can estimate the uplink channel by measuring the corresponding downlink channel.With channel-adaptive random access, an UE transmits a random access packet only when an uplink channel gain g is larger than or equal to a predetermined threshold g_{th}. Because of frequency hopping for NPRACH, each symbol group is transmitted with different subcarrier.Denote by $h_i(t)$ the channel response of the i-th symbol group.Then, the uplink channel gain g experienced a preamble is expressed as

$$g = \sum_{i=1}^{4} |h_i(t)|^2. \quad (1)$$

If a preamble is transmitted N_{rep} times, the total channel gain is $g_{tot} = N_{rep} g$ .Without loss of generality, the channel gain is normalized to satisfy $E(g) = 1$ and average path-loss is assumed to be 1.

When an UE transmits a random access packet, it selects a preamble sequence among possible orthogonal preamble sequences.Let $s_i(t)$ a preamble sequence in the i-th symbol group for time duration T_p, which is normalized to unit power.A preamble is transmitted with relative gain $\sqrt{P}$ .At aneNodeB, received signal of the i-th symbol group can be expressed as

$$r_i(t) = \sqrt{P} h_i(t) s_i(t) + n_i(t), \quad (2)$$

where $n_i(j)$ is an AWGN for the i-th symbol groupwith power spectral density of $N_0/(2 \cdot 4)$.

Two transmission power allocation schemes are considered as in [2], which are constant and channel inversion power allocations.With constant and channel inversion power allocations, a preamble is transmitted with relative gains $\sqrt{P_{R1}}$ and $\sqrt{\frac{P_{R2}}{g}}$, respectively, when the uplink channel gain g is larger than or equal to g_{th}.Here, P_{R1} and P_{R2} are constants to satisfy an average transmission power constraint.

TheeNodeB decides whether an UE has transmitted a random access packet or not, based on the received energy for packet transmission time interval $N_{rep} T_p$.The eNodeB computes the received energy for a search window of size W $(W \geq 1)$ .Then, the maximum value Z of decision variables Z_j's $(1 \leq j \leq W)$ is computed as

$$Z = \frac{1}{T_p} \sum_{i=1}^{4 \cdot N_{rep}} \left| \int_0^{T_p} r_i(t) s_i^*(t) dt \right|^2 \quad (3)$$

where $s_i^*(t)$ indicates complex conjugate of the signal for the i-th symbol group.

The eNodeB decides the hypothesis H_1, when Z is larger than or equal to a detection threshold η .Otherwise, The eNodeB decides the hypothesis H_0.With these hypotheses, false alarm and detection probabilities are expressed as

$$P_{FA} = Pr\{Z \geq \eta | H_0\}, \quad (4)$$

$$P_D = Pr\{Z \geq \eta | H_1\}. \quad (5)$$

When a random access packet is transmitted, average transmission power of a preamble is denoted by $P_{avg|H_1}$.With the constant and channel inversion power allocation schemes, $P_{avg|H_1}$ is computed as

$$P_{avg|H_1} = P_{R1}, \quad (6)$$

$$P_{avg|H_1} = P_{R2} E\left(\frac{1}{g}\right). \quad (7)$$

III. NUMERICAL RESULTS

In this section, performanceof channel-adaptive random access with discontinuous channel measurement is evaluated for NB-IoT environments.

Table 1. Parameters for simulation

Number of subcarriers	12
Subcarrier spacing	3.75 kHz
Length of cyclic prefix	266.7 μs
Symbol length	266.7 μs
Fading channel	Single-path independent Rayleigh fading channel
Doppler frequency f_D	5.0 Hz
Channel measurement interval	200 ms
Number of repetition N_{rep}	1,2, 4 (conventional random access) 1, 2 (channel-adaptive random access)
False alarm probability P_{FA}	10^{-3}
Search window size W	20

Table 1 presents the parameters used for the simulation. The NPRACH operates with 12 subcarriers and 3.75 kHz subcarrier spacing. The length of both a CP and a symbol is266.7 μs. A single-path independent Rayleigh fading channel is considered with Doppler frequency of 5.0 Hz. Channel measurement interval is set to 200 ms, which is the inverse of Doppler frequency. A preamble can be repeatedly transmitted 1, 2, 4 times for conventional random access and 1, 2 times for channel-adaptive random access. The detectionthreshold η is set to

satisfy $P_{FA} = 10^{-3}$ with the search window size of 20.The results are obtained with the outage probability $P_o = Pr\{g < g_{th}\}$ of 0.4 and 0.7.

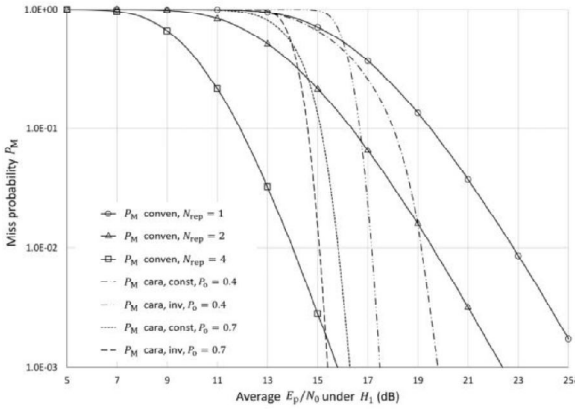

Fig. 2. Detection performance comparison of conventional random access and channel-adaptive random access with $N_{rep} = 1$.

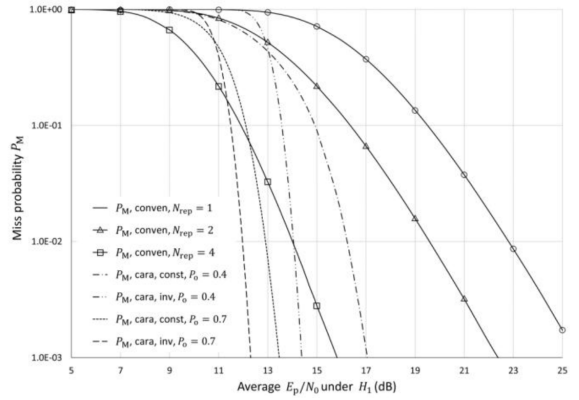

Fig. 3. Detection performance comparison of conventional random access and channel-adaptive random access with $N_{rep}=2$.

Fig. 2 and 3 present performance of channel-adaptive random access with discontinuous channel measurement, compared to those of conventional random access for different N_{rep} values. With conventional random access, it is possible to observe improved detection performance, asN_{rep} is increased.

Fig. 2 presents the miss probability $P_M = 1 - P_D$ versus E_p/N_0 for channel-adaptive random access with $N_{rep} = 1$. Compared to the performance of conventional random access with $N_{rep} = 1$, about 3.7 dB and 7.1 dB performance gains are obtained with channel-adaptive random access using constant power allocation for the miss probability P_M of 10^{-2}, when g_{th} is set to satisfy$P_o = 0.4$ and 0.7, respectively. In the case of channel inversion power allocation, about 5.7 dB and 7.9 dB performance gains are obtained, when g_{th} is set to satisfy$P_o = 0.4$and 0.7, respectively.

Fig. 3 presents the miss probability P_M versus E_p/N_0 for channel-adaptive random access with $N_{rep} = 2$. Compared to the performance of conventional random access with $N_{rep} = 2$, about 3.5 dB and 6.9 dB performance gains are obtained with channel-adaptive random access using constant power allocation for the miss probability P_M of 10^{-2}, when g_{th} is set to satisfy$P_o = 0.4$ and 0.7, respectively. In the case of channel inversion power allocation, about 5.8 dB and 8.0 dB performance gains are obtained, when g_{th} is set to satisfy$P_o = 0.4$and 0.7, respectively. From the results, channel-adaptive random access with discontinuous channel measurement can achieve improveddetection performance compared to conventional random access, even with the smaller number of repetition transmission.

CONCLUSION

Performance has been evaluated by simulation for channel-adaptive random access with discontinuous channel measurement in NB-IoT environments.NPRACH is based on SC-FDMA with frequency hopping.In this paper, it is assumed that an NB-IoT system operates TDD mode. With this assumption, it can be assumed that a downlink channel is the same as a corresponding uplink channel, based on channel reciprocity.Then, channel-adaptive random access schemecan be easily applied to NPRACH.With channel-adaptive random access using discontinuous channel measurement in NB-IoT, performance gain can be achieved compared to conventional NPRACH.

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REFERENCES

[1] Evolved Universal Terrestrial Radio Access (E-UTRA);Physical channels and modulation, 3rd Generation Partnership Project (3GPP) TS 36.211, Jun. 2017.

[2] H. Moon and S. Choi, "Channel-adaptive random access for TDD based wireless systems," IEEE Trans. Veh. Technol., vol. 60, no. 6, pp. 2730−2741, July 2011.

[3] H. Holma and A. Toskala, LTE for UMTSUMTS: OFDMA and SC-FDMA Based Radio Access. Hoboken, NJ: Wiley, 2009.

[4] H. Moon, "Channel-adaptive random access with discontinuous channel measurements," IEEE J. Sel. Areas Commun., vol. 34, no. 5, pp. 1704−1712, May2016.

[5] "On the TDD support for NB-IoT," R1-160011, 3GPP TSG-RAN1 AH-NB-IoT, Nokia, Budapest, Hungary, Jan. 2016.

[6] "Considerations of TDD NB-IoT," R1-160181, 3GPP TSG-RAN1 AH-NB-IoT, Alcatel-Lucent, Budapest, Hungary, Jan. 2016.

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