Coexistence Study between NB-IoT and cdma2000 Systems

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ABSTRACT

Narrowband Internet of things (NB-IoT) is a new communication system standard for future applications of Internet of things, which is expected to operate over 850MHz band. However, the existing cdma2000 system also operates over adjacent band, so the coexistence study between the two systems has significant value. In this paper, the uplink and downlink performance simulations of coexistence between NB-IoT in stand-alone mode and cdma2000 system are studied, including both coordinated and uncoordinated deployment scenarios. To capture the dynamic distribution of users, Monte Carlo method is adopted. The simulation results show that the interference between the two systems is not quite severe in coordinated case. In addition, some deployment suggestions are proposed to achieve better coexistence between the two systems.

KEYWORDS

coexistence, interference, NB-IoT, cdma2000

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1 INTRODUCTION

Narrowband Internet of things (NB-IoT) has been a hot topic in the 3rd generation partnership project (3GPP) since it was introduced in Rel-13 due to its advantage of wide coverage (20dB improvement over GSM), long battery life (over 10 years) and massive connections (50k per cell) [1]. NB-IoT is based on existing long term evolution (LTE) functionalities and intends to achieve Internet of things through narrowband guard band and standalone. *In-band mode* can utilize any resource block (RB) within a LTE carrier. The unused RB within the guard-band of a LTE carrier can be applied for *guard band mode*. *Standalone mode* can be deployed on the spectrum which is currently used by GSM/EDGE radio access network (GERAN) systems.

Since NB-IoT is built on cellular network and only occupies 180kHz of bandwidth, it can be deployed directly in existing cellular network. Due to the benefit of large coverage of radio signals in low frequency, the NB-IoT system is expected to be deployed around the frequency band of 850MHz, which is used by legacy cdma2000 system in mainland China. Therefore, the two systems operating over adjacent frequency bands may be interfered with each other and the coexistence study between NB-IoT and cdma2000 systems is of great importance.

There is a lot of literature focused on coexistence study between two different systems. In [2], the authors studied the coexistence issue between WiMAX and WCDMA systems and proposed several mitigation methods as well. The coexistence study between WCDMA and HSDPA systems was presented in [3], which also investigated the impact of deployed environments on the system performance. In [4], the research on coexistence analysis between TD-LTE and WCDMA systems in multimode terminals was conducted. In [5], the problem of coexistence between LTE and NB-IoT systems in standalone mode was discussed and a novel evaluation method about adjacent channel leakage ratio (ACLR) was introduced in consideration of large difference in system bandwidth between the two systems. However, most of the literature did not address the interference issue between cdma2000 and NB-IoT systems. In this paper, we will study the coexistence over 850MHz band between cdma2000 and NB-IoT systems in standalone mode.

The rest of this paper is organized as follows. Section II describes the system model including cell layout, network deployment and interference scenarios. The related simulation methodology is presented in Section III. The simulation results and discussions as well as deployment suggestions are presented in Section IV. Finally, Section V provides some concluding remarks.

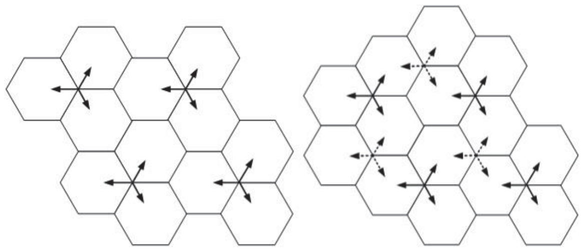

Figure 1: Network deployment scenarios with coordinated case (left) and uncoordinated case (right)

2 SYSTEM MODEL

In this paper, we will evaluate the coexistence performance in adjacent band situation between cdma2000 and NB-IoT systems and both the uncoordinated and coordinated deployment scenarios will be considered. However, given that cdma2000 system and NB-IoT system transmit and receive over different frequencies, the uplink and downlink frequency interval of the two systems is quite big [6]; besides, the specification has strictly regulated the spurious radiation over the designated receiving frequency band. Therefore, the interference between base stations (BSs) and between user equipments (UEs) could be neglected. In this paper, we will study the following four coexistence scenarios for both coordinated and uncoordinated cases:

(1) NB-IoT BSs as aggressor, cdma2000 UEs as victim;
(2) cdma2000 BSs as aggressor, NB-IoT UEs as victim;
(3) NB-IoT UEs as aggressor, cdma2000 BSs as victim;
(4) cdma2000 UEs as aggressor, NB-IoT BSs as victim;

2.1 Cell Layout

A layout of 2-tier 19 cells is considered in the simulation, and each cell contains three identical hexagonal sectors. Besides, the wrap technique is applied in order to eliminate the boundary effect.

2.2 Network Deployment

The network deployment in simulation includes uncoordinated case and coordinated case. As shown in Figure 1, identical cell layouts are applied for both cases. For uncoordinated deployment, we consider the worst case in which NB-IoT BSs are located at the edge of cdma2000 cells, whereas for coordinated deployment, NB-IoT BSs are co-located with cdma2000 BSs.

2.3 ACIR

Adjacent channel interference power ratio (ACIR) reflects the total interference level caused by a source to an adjacent channel receiver due to the imperfections of transmitter and receiver, which can be expressed as

$$ACIR = \frac{1}{\frac{1}{ACLR} + \frac{1}{ACS}}, \tag{1}$$

where ACLR is defined as the ratio of the transmit power of the transmitter to the power received by the receive filter on the adjacent channel, and adjacent channel selectivity (ACS) denotes the ratio of the power attenuation of the receiver filter over the specified channel to the attenuation on the adjacent band [7].

However, as for NB-IoT and cdma2000, ACLR and ACS are defined for their respective bandwith sizes. Considering the huge bandwith difference between the two systems, NB-IoT ACLR would not accurately reflect the interference experienced over the whole cdma2000 bandwith. Therefore, a new term is introduced which is called effective ACLR in [5]. The effective ACLR is defined as

$$ACLR_e = ACLR - 10 \cdot log_{10}(B_{victim}/B_{aggressor}), \tag{2}$$

where B_{victim} is the bandwith of the victim system, and $B_{aggressor}$ is the bandwith of the aggressor system. As a result, ACIR in (1) should be corrected as

$$ACIR_e = \frac{1}{\frac{1}{ACLR_e} + \frac{1}{ACS}}. \tag{3}$$

3 EVALUATION METHODOLOGY

In this section, evaluation methodology used in our coexistence study will be presented in details. In order to simulate the dynamic distribution of users, Monte Carlo method is used. Multiple snap-shots are needed to simulate dynamic systems. In each snap-shot, UEs are dropped randomly in simulation area and then the coupling path loss (CL) between each UE and each BS is calculated. Each UE will choose a BS with the largest link gain as its serving BS in a given snap-shot. Finally, we will calculate SINR value after power control is complemented in cdma2000 system. The final statistics will be collected when the two systems operate steadily or the number of power control iterations meets the threshold.

3.1 Propagation model

The urban macro cell propagation model in TR 36.942 is used to calculate the link loss between UE and BS [8].

$$\begin{aligned} L(d) =& 40(1 - 4 \cdot 10^{-3}\Delta h_b)\log_{10}(d) - 18\log_{10}(\Delta h_b) \\ &+ 21\log_{10}(f) + 80, \end{aligned} \tag{4}$$

where Δh_b in meters denotes the difference between the average rooftop height and the antenna height of BS which corresponds to 15m, the distance d in kilometers is the distance between UE and BS, and the carrier frequency is denoted by f in MHz.

After obtaining the link loss between a UE and a BS, CL is defined as $\max(PL - G_{TX} - G_{RX}, MCL)$, where G_{TX} and G_{RX} denote the transmitted and received antenna gains, respectively, MCL is the minimum coupling loss which is equal to 70dB, and PL is defined as the sum of link loss and log-normally distributed shadowing fading.

3.2 SINR

cdma2000 is a self-interference system, which means that it not only experiences the interference from inter-cell interfering signals, but also suffers from the interference from intra-cell interfering signals. Since multi-user detection (MUD) is used in cdma2000 uplink, the intra system interference could be suppressed to some extent, and we use β to denote the interference reduction factor. Therefore, SINR in uplink can be expressed as [7]

$$SINR_{UL} = \frac{G_p \cdot S}{(1-\beta) \cdot I_{own} + I_{other} + N_0}, \tag{5}$$

where G_p is defined as processing gain, S is the received signal, and N_0 is thermal noise. I_{own} is the interference caused by intra-cell users of cdma2000 system except the target user, I_{other} is the interference generated by users of other cdma2000 cells and users of NB-IoT system, let $\beta = 0$. Specifically, I_{other} is expressed as:

$$\begin{aligned} I_{other} &= I_{cdma2000}^{other\_cells} + I_{NB-IoT}^{all\_cells} \\ &= \sum_i P_{cdma2000\_RX}^i + \sum_j (P_{NB-IoT\_RX}^j / ACIR_e). \end{aligned} \tag{6}$$

Similarly, SINR in cdma2000 downlink is expressed as

$$SINR_{DL} = \frac{G_p \cdot S}{\alpha \cdot I_{own} + I_{other} + N_0}, \tag{7}$$

where $\alpha = 0.2$ is the orthogonality factor due to the imperfect orthogonal between downlink code channel resulting from multipath propagation. The definition of G_p, S, N_0, I_{own} and I_{other} is similar to the uplink. Besides, the calculation of I_{own} and I_{other} of downlink should take the pilot channel into account.

Unlike cdma2000 system, there is not intra-cell interference due to the strict orthogonality between NB-IoT channels. As a result, SINR of NB-IoT is defined as

$$SINR = \frac{P_{RX}}{I_{other} + N_0}, \tag{8}$$

where P_{RX} is the received power, I_{other} is the interference generated by users of cdma2000 and users of NB-IoT in other cells which use the same frequency band as the target user.

3.3 Power Control

For NB-IoT system, no power control is used in downlink, and a BS transmits signal with the maximum power. Open power control is used in uplink, the power control is done as follows

$$P_{TX} = P_{max} \times \min\{1, \max[R_{min}, (\frac{CL}{CL_{x-ile}})^{\gamma}]\}, \tag{9}$$

where P_{max} presents the maximum transmit power, and R_{min} denotes the minimum power reduction ratio. CL is the path coupling loss. CL_{x-ile} is the x-percentile CL value. $0 \le \gamma \le 1$ is the balancing factor. In our simulation, we set $\gamma = 1$, and the CL_{x-ile} values are specified in Table 1.

For cdma2000 system, power control is used in both uplink and downlink. Our goal is to adjust the transmit power so that SINR at the receiver meets the target SINR. The specific power control for cdma2000 system is given as follows

Table 1: Power control parameter of NB-IoT system.

UL Bandwith	3.75kHz	15kHz	60kHz
CL_{x-ile} (dB)	141	135	129

Table 2: Simulation Parameters.

Parameter	NB-IoT	cdma2000
Bandwith	0.18MHz	1.23MHz
Antenna model	$A(\theta) = -\min[12(\frac{\theta}{\theta_{3dB}})^2, 20]$	
antenna gain	BS: 20dBi, UE: 0dBi	
Inter-site distance	750m	750m
Frequency reuse	1	1
Number of scheduled UE per sector (DL)	1	capacity, E_b/N_0=5.5dB
Number of scheduled UE per sector (UL)	3	capacity, E_b/N_0=4dB
Noise figure	BS: 5dB, UE: 9dB	
Log-model shadowing	10dB	10dB
Shadowing correlation	inter-cell 0.5; intra-cell 1	
Process gain	-	21dB

$$P_{TX} = \max(P_{min}, \min(P_{max}, P_{old} + SINR_{target} - SINR_{current})), \tag{10}$$

where P_{TX} is the transmit power after the present power control. P_{max} and P_{min} present the maximum transmit power, respectively. P_{old} is the latest transmit power before the present power control. $SINR_{target}$ is the target SINR at the receiver, whereas $SINR_{current}$ is the SINR measured before the present power control.

3.4 Performance Evaluation Criteria

Different performance criteria are used for NB-IoT and cdma2000 system. For NB-IoT system, SINR distribution is studied, from which we can obtain the SINR loss at some specific points. It is required that the average of SINR loss is less than or equal to 1dB [6]. On the other hand, for cdma2000 system, capacity loss no more than 5% is the criteria for coexistence. Specifically, the uplink capacity of cdma2000 is estimated based on an increase in thermal noise by 5.5dB, while the downlink capacity of cdma2000 is estimated according to 95% users achieving target of $(E_b/N_0 - 0.5)$ dB. First, we simulate a single cdma2000 system and record the single-system capacity C_{single}; then we simulate again after introducing NB-IoT system and obtain the multi-system capacity C_{multi}. The capacity loss can be expressed as

$$C_{loss} = 1 - \frac{C_{multi}}{C_{single}}. \tag{11}$$

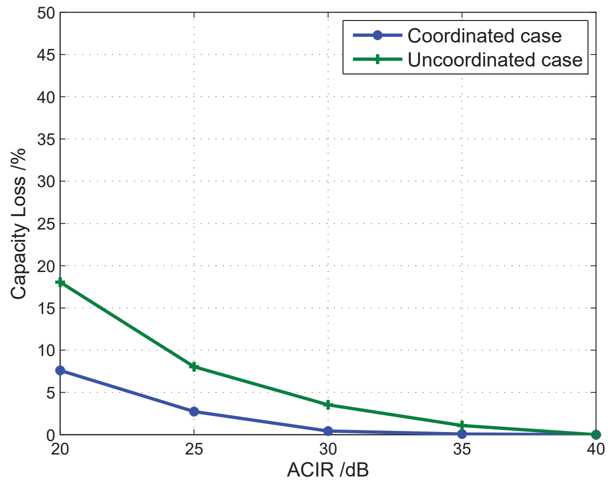

Figure 2: NB-IoT aggressor, cdma2000 victim (DL)

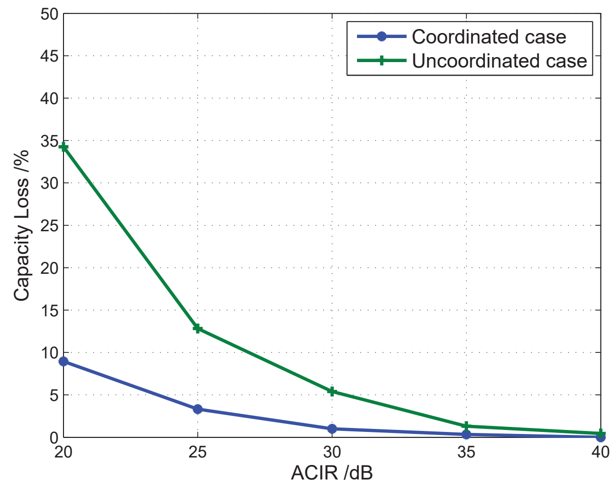

Figure 3: NB-IoT aggressor, cdma2000 victim (UL)

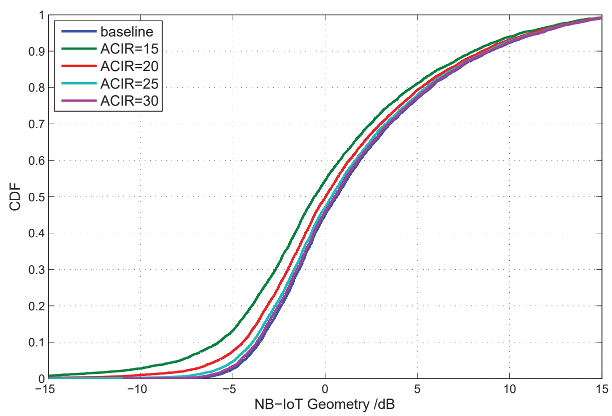

Figure 4: cdma2000 aggressor, NB-IoT victim (DL, uncoordinated)

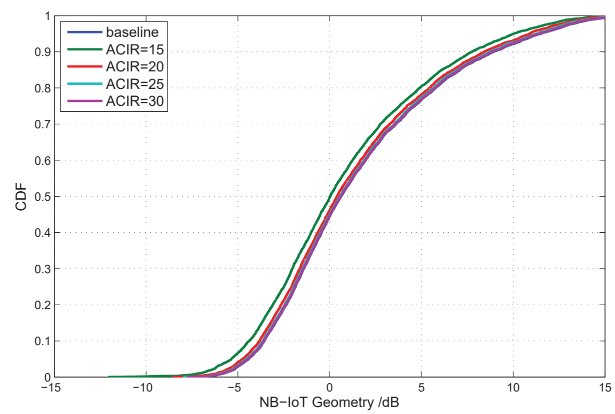

Figure 5: cdma2000 aggressor, NB-IoT victim (DL, coordinated)

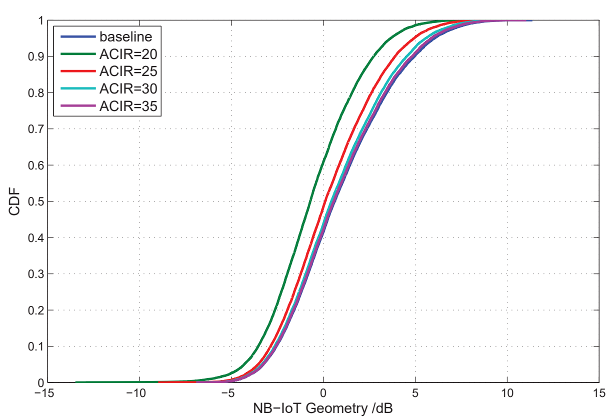

Figure 6: cdma2000 aggressor, NB-IoT victim (UL, uncoordinated)

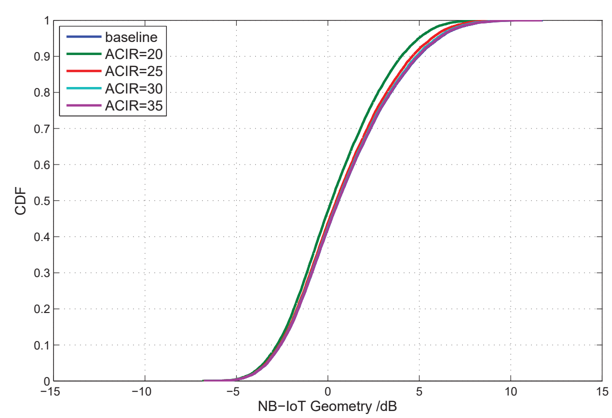

Figure 7: cdma2000 aggressor, NB-IoT victim (UL, coordinated)

Table 3: Required ACIR Value for Different Cases.

Interference Scenarios	ACIR values	
	unco-	co-
NB-IoT aggressor, cdma2000 victim (DL)	28dB	23dB
NB-IoT aggressor, cdma2000 victim (UL)	30dB	24dB
cdma2000 aggressor, NB-IoT victim (DL)	20dB	15dB
cdma2000 aggressor, NB-IoT victim (UL)	25dB	20dB

4 SIMULATION RESULTS

In this paper, we will study the system performance when NB-IoT system coexists with cdma2000 system. Except for some parameter assumptions already mentioned above, other simulation parameters are shown in Table 2.

This section is divided into two parts. In the first part, the impact of different deployment scenarios on system performance is discussed; while in the second part, some deployment suggestions are proposed according to the simulation results.

4.1 Different Deployment Scenarios

Figure 2 and Figure 3 show the relationship between ACIR value and cdma2000 capacity loss in downlink and uplink, respectively. It is obvious that the capacity loss of cdma2000 in uncoordinated scenario is larger compared to coordinated scenario under the same conditions. That is, the system performance of cdma2000 in uncoordinated cases is worse than that of in coordinated cases when it coexists with NB-IoT system. Since the edge users of cdma2000 system may be located in the cell center of NB-IoT for uncoordinated case, the power of the interfering signal from NB-IoT is rather high, resulting in significant inter-system interference.

Figure 4 and Figure 5 show the SINR distribution with different ACIR values when cdma2000 BSs interfere with NB-IoT UEs in uncoordinated cases and coordinated cases, respectively. As shown in Figure 4, the interference from cdma2000 BSs to NB-IoT UEs in uncoordinated case has much impact on the edge users of NB-IoT. On the one hand, the edge users of NB-IoT may be located in the cell center of the cdma2000 for uncoordinated case, and the link loss between the users and cdma2000 BSs is rather small. On the other hand, the transmit power of cdma2000 BSs to their edge users is quite large after power control in order to compensate for link loss. Both of them result in significant interference to the edge users of NB-IoT. On the contrary, as shown in Figure 5, the interference from cdma2000 BSs in coordinated case is relatively balanced to NB-IoT UEs, resulting from equivalent link loss between a NB-IoT BS to a target UE and the coordinated cdma2000 BS to the UE in coordinated case.

Figure 6 and Figure 7 show the SINR distribution with different ACIR values when cdma2000 UEs interfere with NB-IoT BSs in uncoordinated cases and coordinated cases, respectively. The SINR values mainly distribute from -5dB to 8 dB. The range of SINR distribution in Figure 7 is 10dB smaller than that of in Figure 5, which results from power control in NB-IoT uplink and the power of received signal is limited. Besides, as shown in Figure 6, the interference from cdma2000 UEs to NB-IoT BSs in uncoordinated case has much impact on the users in NB-IoT cell center. For a specific NB-IoT BS, the interference received from cdma2000 UEs (i.e., I_{other} in (8)) is a constant, and for a UE served by the BS, the larger P_{RX} is, the greater the impact of I_{other} on its SINR value.

4.2 Deployment Suggestions

Based on the simulation results and coexistence criteria, we propose the required ACIR values for different coexistence scenarios in Table 3. As can be seen from Table 3, when NB-IoT coexists with cdma2000 over adjacent band, the required ACIR values in coordinated cases are lower than those in uncoordinated cases. In order to realize better coexistence performance of NB-IoT and cdma2000 systems, it is suggested to deploy the base stations of the two systems at the same location.

5 CONCLUSIONS

The coexistence study between NB-IoT system and other cellular network is a valuable topic since NB-IoT is overlaid in the existing cellular network. In this paper, we have studied the interference coexistence between NB-IoT and cdma2000 systems over 850MHz band for uncoordinated and coordinated cases. The simulation results show that the coexistence performance in coordinated case is much better than that of in uncoordinated case regardless of the interference scenarios, and the ACIR value of 25dB is enough to achieve good coexistence for coordinated case.

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