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Evaluation of Optimum NPRACH Performance in NB-IoT Systems

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Abstract – Narrowband-internet of Things (NB-IoT) is a low power wide area network that contributes strongly to the revolution and expansion of the internet of things (IoT). Here, we aim at improving the performance and reliability of NB-IOT. Given than random access is one of the most influential characteristics of NB-IoT system performance, a detailed study of the NB-IOT random access was conducted, taking into account random access channel (NPRACH) periodicity, number of collisions, number of users, random access preamble repetitions and time taken for all system users to finalize a random access procedure. Simulation results have shown that appropriately choosing NPRACH periodicity values can efficiently achieve uplink channel optimization between its two signals NPRACH and NPUSCH with an acceptable number of collisions and a high number of delivered packets. Short periodicities (40ms and 80ms) show optimal results in reducing the number of collisions for both low and high traffic while all users win NPRACH and start to send data to the base station after approximately 2 second. However, short periodicities waste more uplink resources in random access, minimizing resources remaining for data transmission. Medium-length periodicities (such as 160ms and 320ms) show a promising performance that balances the two uplink physical channels. Our results demonstrate that doubling the number of users (from 40 to 80) is not a considerable factor in choosing NPRACH periodicity with different repetition values. We further showed how to maximize the system performance by selecting certain NPRACH periodicity value for every preamble repetition scheme.

Index Terms – NB-IoT, LPWA, IoT, NPRACH, Random Access Periodicity.

1. INTRODUCTION

The internet-of-Things (IoT) has emerged as a recent hot research topic for it materializes the revolutionary idea of connecting everything around us via the internet. Low power wide area network (LPWAN) is an important type of IoT networks that accommodates a growing number of connected devices. The Narrow Band Internet of Things (NB-IoT), a type of LPWAN, was proposed by the 3rd Generation Partnership Project (3GPP) [1]. NB-IoT technology offers many advantages such as indoor coverage, low cost, long battery life, and wide communication range of about 20 kilometers, making it a perfect fit for future IoT network requirements.

Many studies have examined NB-IoT performance in terms of scheduling, deployment scenarios, and downlink and uplink transmission [2, 3, 4 and 5]. In [6], the authors introduced a mathematical model for narrowband uplink channel in terms of network throughput. The study in [7] presents the first open-source simulator tool for modelling the NB-IoT, which implements uplink transmission and supports single-Tone and Multi-Tone configurations and random access procedure. The study in [8] presents the narrow band random access channel model with different preamble repetitions values and number of collision using stochastic geometry to improve the random access success probabilities. However, no study has examined NB-IoT random access details. Here, we extensively study the NPRACH performance for NB-IoT system by examining the effect of the system important parameters such as NPRACH periodicity, number of collisions, number of users, and random access preamble repetitions. Our results show that choosing medium-length NPRACH periodicity values can efficiently achieve up-link channel optimization between its two signals NPRACH and NPUSCH with an acceptable number of collisions and high throughput.

The rest of the paper is organized as follows. Section 2 describes detailed NB-IoT technology. The main random

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access classes in the NB-IoT 5g-simulator are presented in Section 3. In Section 4, we present and discuss the simulation results. Finally, Section 5 concludes the paper.

2. NB-IOT TECHNOLOGY

Integration of NB-IoT into the existing cellular network is expected to be a smooth operation. NB-IoT resembles the LTE (Long-Term Evolution) upper layer and introduces minor modifications to the physical layer. The NB-IoT systems need to operate on 180 kHz bandwidth .The spectrum is occupied with 15 kHz and 3.75 kHz which spans over 12 and 48 sub-carriers respectively.

The Uplink channel is the main focus of this manuscript. Figure 1 shows the uplink channel structure (narrowband physical uplink channel and narrowband physical random access channel) [8], with more details given in the next section.

- Narrowband Physical Random Access Channel (NPRACH).
- Narrowband Physical Uplink Shared Channel (NPUSCH).

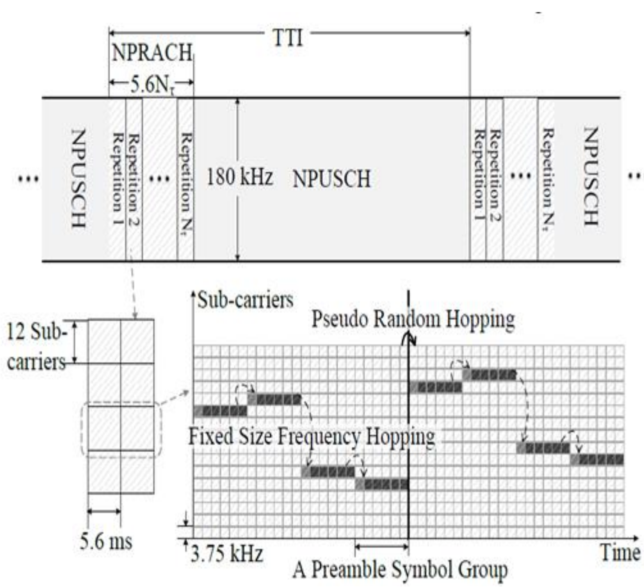

Figure 1 Structure of NPUSCH and NPRACH

2.1. Narrowband Physical Random Access Channel (NPRACH)

A new user equipment (UE) can establish a connection with the NB-IoT network through a preamble transmission over NPRACH, which in turn triggers the random access procedure. There are two preamble formats (Format 0 and 1) with duration of 5.6ms or 6.4ms respectively. According to different IoT device coverage requirements, the preamble can be repeated over the set {1- 2- 4- 8- 16- 32- 64- 128} [9].

A preamble consists of four symbol groups as shown in Figure 1. If the preamble is received at the base station without collisions, the base station sends back a response (RAR) message over physical downlink shared channel (NPDSCH). Then the UE sends message 3 indicating the data volume it wants to transmit. Finally, the base station automatically sends message 4 back to the UE to activate it and start the data transmission process [10].

We here study the NPRACH periodicity, which is known as NPRACH transmission time interval (TTI), (see Figure 1) over the set (40ms, 80ms, 160ms, 240ms, 320ms, 640ms, 1280ms, 2560ms).

2.2. Narrowband Physical Uplink Shared Channel (NPUSC)

After the allocation of the Physical Random Access Channel, all the uplink resources are dedicated for data transmission over NPUSCH, Single or multi-tone transmission configurations can be used in transmission, according to the scheduling strategy, the base station dedicates some resources to each UE [11]. NPUSCH resource unit configuration is illustrated in Table 1.

NPUSH format	Spacing Δ f	Number of subcarriers	Number of slots
Format 1	3.75 kHz	1	16
	15 kHz	1	16
		3	8
		6	4
		12	2
Format 2	3.75 kHz	1	4
	15 kHz	1	4

Table 1 NB-IoT Resource Unit Configuration

3. NB-IOT 5G-SIMULATOR

The 5g-simulator [7] is an open-source simulator for NB-IoT, developed by modifications to the well-known LTE simulation tool. The 5g-simulator implements many features, including uplink communications, random access procedure, scheduling algorithms such as round-robin and first-in-first-out, and Single-Tone and Multi-Tone transmission configurations with different subcarrier spacing and number of tones. The 5g-simulator further supports both uplink subcarrier spacing 3.75 kHz and 15 kHz, in this simulator, the cell is divided into 11 or 14 equally wide concentric zones (see Figure 2), each zone is denoted by a different Modulation and Coding process (MCS) [7].

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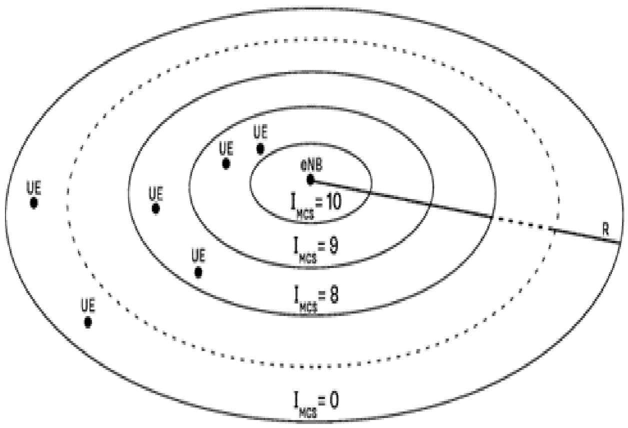

Figure 2 Distribution of MCS Indexes in a Cell

Random access procedure can be divided into two classes:

- UE-NB-IoT-Random-Access
- ENB-NB-IoT-Random-Access

Where the random access sequence works as follow:

1. UE-NB-IoT-Random-Access: Start-Ra-Procedure () method initializes the procedure by sending a random access preamble through UE-NB-IoT-Random-Access: SendMessage1 () method. A preamble is randomly chosen among all the available preambles once NPRACH resource is available.
2. ENB-NB-IoT-Random-Access: Check-Collision () scans all the preambles to find collisions. If a collision is detected, it will tell the end-user to try to send another preamble in the next NPRACH occurrence. If no collision occurs, it will send a Random Access Response to the end-user, through ENB-NB-IoT-Random-Access: SendMessage2 ().
3. The mobile terminal will receive the response (Message 2) and send the third message through UE-NB-IoT-Random-Access: Send-Message 3 ().
4. Upon receiving Message3, the base station automatically sends to the end-user the last message. ENB-NB-IoT-Random-Access: Send-Message4 ().
5. At this stage, the random access process is finalized the end-user is now activated and starts to transmit.

4. SIMULATION RESULTS AND ANALYSIS

The 5g-simulator, described in the previous section, has been used to evaluate NB-IoT system performance under different NPRACH periodicity values (40, 80, 160, 240, 320, 640, 1280, and 2560ms) with the simulation parameter values in Table 2. Distinguishable performances among the schedulers in the 5g-simulator can only be observed by using sufficiently large packets. For this reason, we selected a packet size of 256 bytes throughout the study. With this packet size, and when the request per second is greater than 20, the difference in performance between scheduling policies becomes more noticeable. As Round Robin (RR) guarantees lower delays compared to First-in-first-out for most of the users, we chose the RR policy for our simulation.

Cell radius	1 km
Duration	20 s
Packet size	256 byte
Requests per second	80-160
Transmission type	Single-tone
Subcarrier spacing	3.75KHZ
Scheduling algorithm	Round Robin

Table 2 Simulation Settings

We utilized the Single-Tone mode throughout the experiments as, using the 5g-simulator, the authors showed that the Single-Tone mode is capable of handling a higher number of transmission requests. More users can be scheduled at the same time during a TTI compared to the Multi-Tone configuration. The goodput is indeed improved.

The NPRACH periodicity is configurable in the 5g-simulator, making it easy to study the effect of its change. However, the number of preamble repetitions is not similarly configurable in the NB-IoT-Random-Access class. We thus modified the simulator so that the repetition effect can be studied. As detailed in the next section, the modification we made are as follows in (1) and (2). Preamble repetition values were examined over the set (1, 2, 4, 8, 16, 32, 64, and 128).

(1) $$Preamble\ Duration = 5.6\ ms$$

(2) $$Channel\ resources\ for\ NPRACH = 5.6 * repetition\ value$$

- NPRACH periodicity effect on number of collisions and system delay.
- Comparison of the total number of collisions for the different NPRACH periodicities.
- Comparison of NPRACH End sub-frame (total time taken until all UE win RACH and start to send data).
- NPRACH periodicity for different Preamble repetition value.

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4.1. NPRACH Periodicity Effect on Number of Collisions and System Delay

Tables [3 through 10] show the effect of different periodicity values on the number of collisions and the NPRACH End sub-frame, the time where all users are active and able to transmit data to the base station for two traffic scenarios (80 and 160 request per second).

As shown in Table 3, at periodicity =40ms, in the two traffic scenarios, all users finished random access procedure and start sending packets at sub-frame 2040. This indicates that duplicating the number of users does not affect the performance, and as the random access resources become available every 40ms, a few users compete to send preamble at the same period, which causes little number of collisions (about 2-4).

	Number of users: 80		Number of users: 160	
SF number	Number of users win NPRACH	Number of Collisions	Number of users win NPRACH	Number of Collisions
1040	1	0	3	0
1080	4	0	3	2
1120	1	0	5	0
1160	3	0	6	0
1200	3	2	9	4
1240	5	2	12	0
1280	6	0	5	2
1320	2	0	9	0
1360	2	0	8	0
1400	3	0	4	0
1440	2	0	2	2
1480	1	0	5	0
1520	7	0	8	2
1560	3	0	6	0
1600	2	0	7	2
1640	4	0	5	2
1680	3	0	10	0
1720	6	0	8	2
1760	2	0	4	0
1800	2	0	5	0
1840	4	0	6	2
1880	-	-	5	0
1920	4	0	6	2
1960	4	2	10	2
2000	4	2	9	0
2040	2	0	-	-
Total	80	8	160	24

Table 3 NPRACH performance for periodicity=40ms and number of users = 80 and 160

Increasing the periodicity to 80ms (Table 4) still has the same effect for the two traffic scenarios where all the users finish the random access procedure after 2080ms. Compared with 40ms, number of collision still the same for low traffic and increased to total of 68 (24 at the high traffic). As the periodicity increase and the number of users increases, more users compete for random access at the same period, so the number of collisions increases.

	Number of users: 80		Number of users: 160	
SF number	Number of users win NPRACH	Number of Collisions	Number of users win NPRACH	Number of Collisions
1040	1	0	3	0
1120	5	0	6	2
1200	8	0	11	10
1280	6	3	17	8
1360	7	0	19	4
1440	5	0	6	6
1520	8	0	13	6
1600	5	0	15	4
1680	5	2	13	4
1760	8	2	12	4
1840	8	0	11	6
1920	4	0	9	8
2000	8	2	19	6
2080	2	0	6	0
Total	80	9	160	68

Table 4 NPRACH Performance for Periodicity=80ms and Number of Users = 80 and 160

As the periodicity increased to 160ms (Table 5), the two traffic scenarios differ in random access end sub-frame, which increased to 2400ms (with a difference of 320ms between the two traffic scenarios). This is due to the increased number of collisions as more users compete for sending preamble at the same period.

	Number of users: 80		Number of users: 160	
SF number	Number of users win NPRACH	Number of Collisions	Number of users win NPRACH	Number of Collisions
1120	6	0	8	3
1280	10	7	23	14
1440	8	8	23	14
1600	15	6	21	19
1760	21	0	22	22
1920	10	0	21	25
2080	10	0	23	19
2240	-	-	15	4
2400	-	-	4	0
Total	80	21	160	120

Table 5 NPRACH Performance for Periodicity=160ms and Number of Users = 80 and 160

At periodicity of 240ms (Table 6), the NB-IoT system becomes clogged with a high number of collisions (up to 226 at high traffic compared to 31 for low traffic). It is also noticeable that the number of collisions increases in small amounts for low traffic (8-9-21-31) as the periodicity increase (40-80-160-240). Number of collisions increases in greater amounts for higher traffic (24-68-120-226). Also the increased number of users and collisions at high traffic require more time to finish random access.

	Number of users: 80		Number of users: 160	
SF number	Number of users win NPRACH	Number of Collisions	Number of users win NPRACH	Number of Collisions
1200	14	0	22	8
1440	13	5	24	22
1680	13	12	18	43
1920	20	10	17	62
2160	16	4	26	53
2400	4	0	27	26
2640	-	-	14	12
2880	-	-	12	0
Total	80	31	160	226

Table 6 NPRACH Performance for Periodicity=240ms and Number of Users = 80 and 160

At periodicity of 320ms (Table 7), the users at the high traffic require more time (about 1280ms difference) to send random access preamble successfully. Meanwhile, the number of collisions is still low for the low traffic scenario (37 compared to 263 for the high traffic scenario).

	Number of users: 80		Number of users: 160	
SF number	Number of users win NPRACH	Number of Collisions	Number of users win NPRACH	Number of Collisions
1280	15	8	27	18
1600	16	14	27	40
1920	30	9	19	70
2240	13	6	23	64
2560	6	0	25	39
2880	-	-	16	23
3200	-	-	16	7
3520	-	-	5	2
3840	-	-	2	0
Total	80	37	160	263

Table 7 NPRACH Performance for Periodicity=320ms and Number of Users = 80 and 160

As the NPRACH periodicity increased to 640ms (Table 8), the difference between random access finishing times for the two traffic scenarios increased to 2560ms compared with 1280ms for 320ms periodicity, which is apparently due to the increase in the number of collisions (363 and average of 40 collisions at each NPRACH period).

For the periodicity of 1280ms (Table 9), users require much more time to finish random access procedure because of the increased number of collisions. Finally the 2560ms periodicity (Table 10) shows the worst system scenario where the users at the low traffic require 12800ms to finish the random access procedure and 23040ms for those at the high traffic. Of note is also the increased number of collisions (146 and 593 for the two traffic scenarios).he system performance is almost similar for the first 80 users.

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SF number	Number of users: 80		Number of users: 160	
	Number of users win NPRACH	Number of Collisions	Number of users win NPRACH	Number of Collisions
1280	15	8	27	18
1920	20	35	21	95
2560	18	27	20	92
3200	23	4	19	73
3840	4	0	24	49
4480	-	-	24	25
5120	-	-	16	9
5760	-	-	7	2
6400	-	-	2	0
Total	80	74	160	363

Table 8 NPRACH Performance for Periodicity=640ms and Number of Users = 80 and 160

SF number	Number of users: 80		Number of users: 160	
	Number of users win NPRACH	Number of Collisions	Number of users win NPRACH	Number of Collisions
1280	15	8	27	18
2560	22	43	20	113
3840	18	25	18	95
5120	23	2	22	73
6400	2	0	23	50
7680	-	-	27	23
8960	-	-	12	11
10240	-	-	8	3
11520	-	-	3	0
Total	80	78	160	386

Table 9 NPRACH Performance for Periodicity=1280ms and Number of Users = 80 and 160

Figure 3 shows the cumulative number of users who gain random access at each available NPRACH for different periodicities where total system users are set to 80 users. NB-IoT system performance for periodicity 40, 80 and 160ms is almost similar, where all users can gain random access and start to send data after 2.08 second. Most of the users can access the random procedure once data packets are generated because of the diminishing intervals between the random access periods. As the NPRACH periodicity tends to increase, more users will be waiting for the next available random access resources. With the increase in waiting users' number, number of collisions increases and a large portion of users do not succeed in finishing the random access procedure causing a further delay until all users can finish random access.

SF number	Number of users: 80		Number of users: 160	
	Number of users win NPRACH	Number of Collisions	Number of users win NPRACH	Number of Collisions
2560	15	65	17	143
5120	18	47	16	127
7680	24	23	24	103
10240	12	11	22	81
12800	11	0	21	60
15360	-	-	24	63
17920	-	-	22	14
20480	-	-	12	2
23040	-	-	2	0
Total	80	146	160	593

Table 10 NPRACH Performance for Periodicity=2560ms and Number of Users = 80 and 160

The increase in delay is a simple rate where it increases to values of 2.4 and 3.8 seconds for 320ms and 640ms of periodicities respectively, then doubling to 6.4 and 12.8 for higher periodicities Thus, we recommend that NPRACH periodicity should be set to as small values as possible.

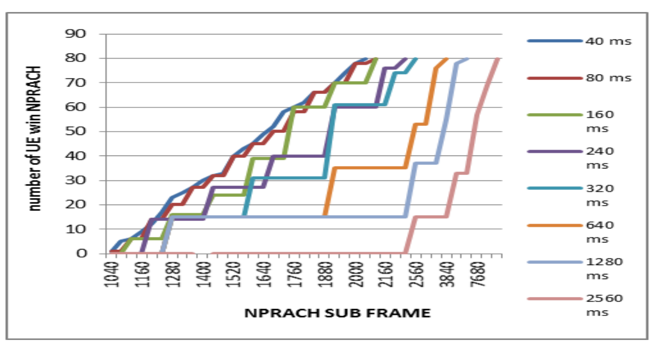

Figure 3 Cumulative Number of Users Who Win Random Access at Each Available NPRACH (Total System Users=80)

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The effect of increasing the number of users was then studied and the results are summarized in Figure 4. More users competing for completion of the random access procedure at the same period leads to an increase in the number of collisions and similarly an increase in delay rates especially for 640, 1280 and 2560ms periodicities Delay rates increased to 6.4, 11.5 and 23.04 seconds compared to 2, 2.08 and 2.4 seconds for 40, 80 and 160ms, respectively. Collectively, these results suggest that the greater the number of users, the more important is the periodicities are set to short times.

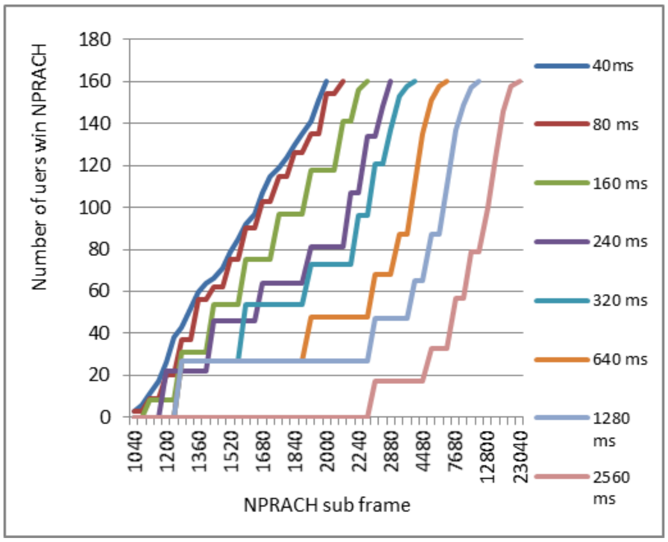

Figure 4 Cumulative Number of Users Who Win Random Access at Each Available NPRACH (Total System Users=160)

4.2. Comparison of the Total Number of Collisions for the Different NPRACH Periodicities

From Table 11 and Figure 5, it is noticeable that the members of the sets {40, 80}, {160,240,320} and {640, 1280} act as alternatives to each other as they endure approximately similar number of collisions. The 2560ms periodicity stands as an outlier for the collision number but still follow the exponential growth trend.

For low traffic (80 request per second), as the NPRACH Periodicity increases, the number of collisions increases. NPRACH Periodicities of 40ms-320ms have approximately similar effect where the collisions vary between 8 and 37, where NPRACH periodicity (640ms- 2560ms) has a bad effect on the number of collisions which varies between 74 and146.

For high traffic as 160 requests per second, as the periodicity decreases, the NB-IoT network performance improves with a small number of collisions compared with longer periodicities.

NPRACH Periodicity	Total number of collisions (N0. Of users: 80)	Total number of collisions (NO. of users: 160)
40ms	8	24
80ms	9	68
160ms	21	120
240ms	31	226
320ms	37	263
640ms	74	363
1280ms	78	386
2560ms	146	593

Table 11 Comparison of the Total Number of Collisions According to Number of Users 80 and 160 with Different NPRACH Periodicity Scenarios

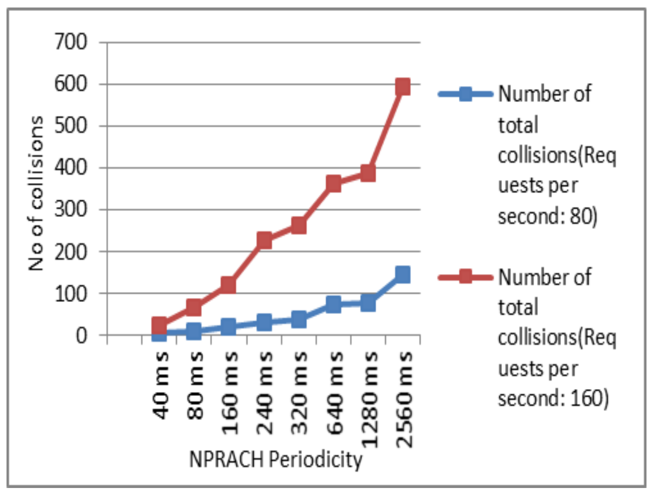

Figure 5 Comparison of the Total Number of Collisions According to Number of Users 80 and 160

4.3. Comparison of NPRACH End Sub-Frame (Total Time Taken Until All UE Win RACH and Start to Send Data)

As shown in Table 12 and Figure 6, all users gain RACH at sub-frame number 2040 for NPRACH periodicity of 40ms, and take much longer time as the periodicity increases, reaching 12800 sub-frame when 2560ms periodicity was chosen. As the traffic increases, short periodicities (40ms-240ms) still has a similar effect and shorter time until all users can gain RACH and higher, while longer periodicities (320ms-2560ms) require much more time until all users can successfully send preamble due to increased number of collisions as the intervals between random access periods tend to increase.

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NPRACH Periodicity	End sub-frame (NPRACH) (Number of users: 80)	End sub-frame (NPRACH) (Number of users: 160)
40ms	2040	2000
80ms	2080	2080
160ms	2080	2400
240ms	2400	2880
320ms	2560	3840
640ms	3840	6400
1280ms	6400	11520
2560ms	12800	23040

Table 12 Comparison of NPRACH End Sub-Frame When All Users Win Random Access According to the Number of Users 80 and 160 with Different NPRACH Periodicity Scenarios

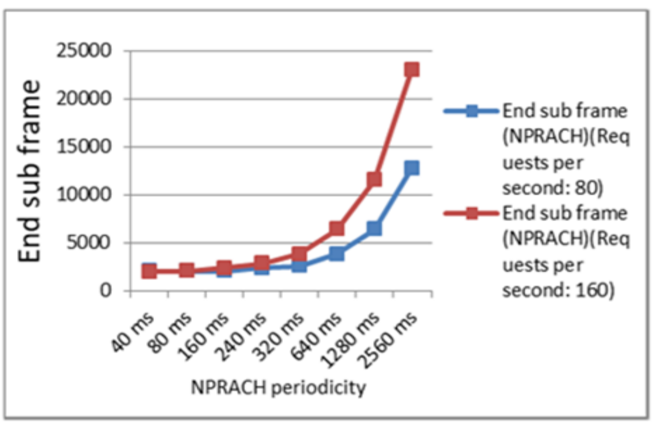

Figure 6 Comparison of NPRACH End Sub-Frame When All Users Win Random Access (users 80 - 160)

4.4. NPRACH periodicity for different Preamble repetition value

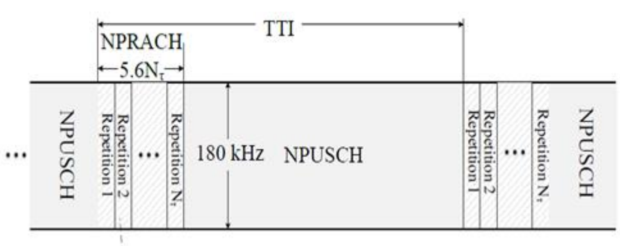

Figure 7 NB-IoT uplink channel structure

According to different IoT device coverage requirements, the random access preamble can be repeated from the set (1- 2- 4- 8- 16- 32- 64- 128). Since only two signals are defined in the uplink (NPRACH and the NPUSCH as shown in Figure 7), channel optimization between those two signals is an important issue. In a TTI, the repetition value (Nτ) determines the assigned channel resources for NPRACHs (2), and the least channel resources for data transmission (NPUSCHs) (3).

(1) $\textit{Channel resources for NPUSCH}\ \mathrm{T(NPUSCH)} = \mathrm{TTI} - 5.6 * N\tau$

We run the 5g-simulator for 5 seconds with all different NPRACH periodicities for each repetition value to determine which one achieves the maximum number of delivered packets, with two traffic scenarios, low traffic with UE= 40 (Table 13) and high traffic with UE=80 (Table 14).

Number of repetition	NPRACH periodicity							
	40	80	160	240	320	640	1280	2560
1	100	100	105	103	103	99	79	48
2	87	99	105	103	103	99	81	48
4	53	87	104	101	101	99	81	48
8	0	54	98	102	100	98	83	48
16	0	0	47	89	98	94	75	48
32	0	0	0	10	59	89	76	48
64	0	0	0	0	0	40	65	45
128	0	0	0	0	0	0	31	37

Table 13 Number of Delivered Packets According to the Different Number of Repetition and Different NPRACH Periodicity and Number of UE =40

Number of repetition	NPRACH periodicity							
	40	80	160	240	320	640	1280	2560
1	186	188	204	202	167	167	107	28
2	162	188	204	202	197	167	106	28
4	95	159	201	200	200	172	105	28
8	0	92	183	193	188	168	104	28
16	0	0	80	164	176	154	104	29
32	0	0	0	17	110	146	104	29
64	0	0	0	0	0	73	84	27
128	0	0	0	0	0	0	45	22

Table 14 Number of Delivered Packets Due to the Different Number of Repetition and Different NPRACH Periodicity and Number of UE =80

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The comparison in Table 15 shows that, if the number of required repetitions is small {1, 2, 4}, the reserved uplink resources Channel for NPRACH is limited (2) and the least channel resources for data transmission (NPUSCHs), so as shown medium periodicity such as 160ms provides better performance, as the number of collisions is small, more packets are delivered.

Our results show that the longer periodicities provides better performance despite the increase in the number of collisions, as data transmission requires more resources to increase the number of delivered packets. Specifically, as the number of repetitions increases, more uplink resources are required for the random access. With short periodicities, no resources will remain for data transmission. For higher number of repetition: 8, 16, and 32, periodicities of 240, 320, and 640ms becomes more suitable, respectively, Finally for 64 and 128 repetitions, it is more effective to set the periodicity to 1280ms -2560ms .

Almost the same performance replicates with the two traffic scenarios of 40 and 80 users for different NPRACH periodicities and different repetitions, this shows that increasing the number of users is not a considerable factor in choosing the NPRACH periodicity.

Number of repetition	Number of UE =40	Number of UE =80
1	160	160
2	160	160
4	160	160
8	240	240
16	320	320
32	640	640
64	1280	1280
128	2560	1280

Table 15The Most Effective NPRACH Periodicity for Different Preamble Repetition Values and Number of Users 40 and 80

5. CONCLUSION

This article provides a thorough study of the NPRACH performance for NB-IoT system, taking into account the effect of the network pivotal parameters such as NPRACH periodicity, number of collisions, number of users, random access preamble repetitions and time taken until all system users can finalize random access procedure and start to send data. The goal is to determine the optimum values for NPRACH Periodicity that achieve a good balance between NPRACH and NPUCH data transmission time to increase the number of delivered packets and ensure users access to the random access procedure as soon as possible to avoid high delay rates.

Short periodicities of 40ms and 80ms optimally reduced the number of collisions for both low and high traffic, and the entire user gained NPRACH and starts to send data to the base station after approximately 2 seconds. However, more uplink resources were wasted in random access, reducing the remaining resources for data transmission, therefore, we do not recommend these periodicities as a best policy.

In contrast, when a long periodicity was chosen (such as 1280ms and 2560ms), there has been a significant increase in the number of collisions as more users compete for random access at the same NPRACH period and most users required much longer time to gain random access (about 13 seconds and up to 23 seconds for higher traffic) which has a negative effect on the packet delay times. Additionally, more NPUSCH resources were wasted as the users could not access the random procedure.

We recommend the utilization of medium-length periodicities (such as 160ms and 320ms) as they achieved a good balance between the two uplink physical channels NPRACH and NPUSCH with an acceptable number of collisions and a high number of delivered packets.

For best coverage, preamble can be repeated up to 128 times so it was necessary to illustrate the repetition effect and indicate the optimum periodicity value for each number of repetitions. If the number of required repetitions is small {1, 2, 4}, 160ms is the optimum periodicity.

As the number of repetitions increases, longer periodicities showed better performance. Finally our results showed that doubling the number of users from 40 to 80 does not significantly affect the NB-IoT system performance with different repetition values, so the number of users is not considered as a factor in choosing the NPRACH periodicity.

5.1. Abbreviations

LTE: Long-Term Evolution; NPRACH: narrowband physical random access channel; NB-IoT: Narrowband Internet of Things; 3GPP: 3rd Generation Partnership Project; NPUSCH: Narrowband Physical Uplink Shared Channel; IoT: Internet-of-Things; LPWAN: low power wide area network; RACH: random access channel; 5G: Fifth generation; UE: user equipment; PRB: Physical Resource Block; MCS: Modulation and Coding process; eNB: evolved Node-B; TTI: transmission time interval; RU: resource unit; RR: Round Robin.

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