Performance Analysis of Resource Unit Configurations for M2M Traffic in the Narrowband-IoT System

Renato Caminha Juaçaba Neto, Emanuel Bezerra Rodrigues and Carina Teixeira de Oliveira

***Abstract*— The massive amount of low-end uplink traffic of Machine to Machine (M2M) communications are a key aspect of what 5G will be. In this context, Narrowband-IoT (NB-IoT) is described as the next step to allow Long Term Evolution (LTE) support for this type of traffic. This new technology provides support to massive amounts of ultra-low-end devices while occupying the frequency space of a single LTE resource block. This work studies the NB-IoT uplink, which allows multi-tone and single-tone transmissions. These types of transmissions result in configurations of resource units for NB-IoT devices that have different durations and frequency occupations. We present extensive simulations results that provide insight into the behavior of the configurations. Based on these simulations, we discuss the best resource configurations to be used by NB-IoT. We also defend the feasibility of NB-IoT for higher tier traffic.**

***Keywords*— M2M, LTE, NB-IoT, Performance Evaluation, Uplink Schedulers.**

I. INTRODUCTION

The Long Term Evolution (LTE) standard is considered the leading technology for cellular networks [1]. Since its 10th release in 2010, the standard provides connectivity at the 4G level. However, one of the main requirements to consider LTE as a 5G cellular technology is related to its ability to provide support to Machine to Machine (M2M) communications, also known as Machine Type Communications (MTC).

According to Ghavimi *et al* [2], M2M consists of massive amounts of disposable devices with limited mobility that sporadically transmit small data reports. The M2M traffic is expected to compose a considerable portion of the 5G traffic as part of the Internet of Things (IoT) scenario.

Recent related work has begun to address LTE extensions to provide M2M support, such as the introduction of the LTE Category 0 and the Enhanced MTC [3]. The Third Generation Partnership Project (3GPP), responsible for the LTE, defined a new feature on its 13th release called Narrowband Internet of Things (NB-IoT). Lin *et al* [4] provide an in-depth description of this feature.

The aim of NB-IoT is to provide connectivity to massive amounts of ultra-low-end M2M devices and to be easily deployable on an existing LTE carrier, reducing its time to market [5], [6].

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The flexibility of deployment of NB-IoT is due to the three modes defined in the standard:

- The first mode is called standalone. It is designed to be used on refarming legacy technologies;
- The second mode is called guardband and it inserts the NB-IoT carrier inside the guard band space of an existing LTE carrier;
- The last mode is called inband. It defines the NB-IoT carrier in the space of a Resource Block (RB) of an existing LTE carrier.

The high scalability of devices is explained by two features: the several configurations of Resource Units (RU) for uplink and the possibility to deploy several NB-IoT carriers on the same LTE carrier.

The NB-IoT uplink is capable of sharing the uplink bandwidth to allow multiple transmissions on the frequency space of one RB. This is possible by the usage of multi-tone and single-tone transmissions that define different types of RU [5].

These RU configurations occupy different numbers of subcarriers of the NB-IoT carrier and last for different amounts of time. More subcarriers per RU result in faster transmissions but less simultaneous transmissions [7].

There are performance assessments for NB-IoT such as the work of Ratasuk *et al* [6] that states that NB-IoT is capable of handling the aimed performance targets of its design and others that are made available by 3GPP. But these do not show details of the different RU configurations and the upper bound of the applications that it can handle.

In this paper, we provide a performance analysis on the scalability of the NB-IoT standard under a M2M traffic with heavier data flow in comparison to NB-IoT intended traffic. We evaluate different RUs configurations to provide a better understanding of the capacities of the technology and assess its ability to support this traffic.

Our results provide evidence that some RU configurations behave far better than others for high-end traffic and that these configurations make NB-IoT feasible for this traffic.

II. SYSTEM MODEL

In our study, we assume a single cell with support to inband deployment of NB-IoT that doesn't receive any interference from nearby cells. The base station may deploy multiple NB-IoT carriers on its LTE carrier to split the NB-IoT users among them.

In this section, we discuss about the traffic model and the aspects of NB-IoT considered in this study.

A. Traffic model

The 3GPP project provides an expected traffic model for NB-IoT as daily or hourly reports of 80 bytes. Hovewer, in this work, we analyze the limits of this technology using a different set of applications.

We use the traffic models defined by Maia *et al* [8] for M2M, which is split into two categories: Time Driven (TD) and Event Driven (ED).

The TD traffic emulates sensor applications that generate uplink traffic in between constant intervals. On the other hand, the ED traffic emulates applications that send reports every time a random event happens.

Regarding Human Type Communication (HTC), we utilize video streaming, VoIP, and Constant Bit Rate (CBR). Table I provides a summary of the simulated applications.

TABLE I
SUMMARY OF APPLICATIONS MODELS.

Application	Description	Maximum Delay Allowed
M2M Time Driven	Data reports of 125 bytes being generated in constant intervals between 50ms and 5s	Same as inter package interval
M2M Event Driven	Data reports of 125 bytes being generated by a Poisson process of mean 0.02 reports per TTI	50 ms
Video	H.264 with 128 Kbps	150 ms
VoIP	G.795	100 ms
Constant Bit Rate (CBR)	Throughput of 128 Kbps with data reports of 256 bytes	300 ms

All applications are associated with a Quality of Service (QoS) parameter that determines the maximum delay allowed per report. This delay is measured from the time the report is generated until it's received by its destination. If any report surpasses this delay, it is dropped because the information is no longer considered important.

Each device hosts a single application. Also, M2M devices are tuned to the NB-IoT carrier, while HTC devices are tuned to the LTE carrier. Besides, to provide scenarios closer to reality, we consider scenarios where several applications coexist.

Based on the Ericsson mobility report [9], all devices are split into 30% HTC and 70% M2M. Applications M2M are split 30% and 70% of the total M2M for ED and TD, respectively. HTC are split 35%, 45% and 20% of the total of HTC, for CBR, Video, and VoIP, respectively.

B. NB-IoT Model

We adopted a simple but equivalent version of NB-IoT that focuses on the MAC layer but takes into consideration the limitations of the PHY layer to make our model comparable to a full model. These limitations are justified due to the objetive of this work.

Transmission Repetitions: The use of repetitions to increase the coverage of the standard was not considered, since there is no widely accepted strategy for choosing the number of repetitions.

Control Data: The effects of control data are not considered. Even if it affects the available resources for data, it has been shown that the control mechanisms of NB-IoT can support a number of devices far larger than the expected number of devices for our traffic models [6].

Adaptive Modulation and Coding (AMC) module: The AMC module is a key aspect of the measurement of the real performance of NB-IoT because. According to its definition, NB-IoT does not support the same modulation and coding schemes of LTE and also has smaller block sizes in comparison with LTE [10].

Subcarrier Spacing: NB-IoT is able to function in two different subcarrier spacing configurations, 15kHz and 3.75kHz, resulting in 12 or 48 subcarriers per NB-IoT carrier, respectively. Our model only considers the 15kHz configuration because it is the same configuration of LTE and allows seamless integration.

III. RESOURCE ALLOCATION OF NB-IOT

In this section, we provide an overview of the several uplink RU configurations and resource allocation aspects of NB-IoT.

As mentioned before, the high scalability is achieved by using multi-tone and single-tone transmissions on the uplink.

Multi-tone transmission is only possible with subcarrier spacing of 15 kHz and in groups of 3, 6 and 12 subcarriers. Single-tone transmissions allow the maximum amount of simultaneous transmissions per NB-IoT carrier but result in larger RU in the time domain.

A subcarrier spacing of 15 kHz allows 12 subcarriers in the spectrum of 180 kHz and is the same spacing of conventional LTE, which allows seamless integration on the LTE carrier.

The 3.75 kHz subcarrier spacing adopts a different numerology from LTE, resulting in interference between the NB-IoT and LTE carrier, but results in 48 subcarriers.

A. Resource Unit Configurations

Table II displays the possible RU configurations according to the NB-IoT specification [7]. Configurations 1 and 5 represent single-tone and configurations 2, 3 and 4 represent multi-tone.

TABLE II
NB-IOT RESOURCE UNIT CONFIGURATIONS.

	Subcarrier Spacing	Subcarrier grouping	Resource unit duration
Configuration 1	15 kHz	1	8 ms
Configuration 2	15 kHz	3	4 ms
Configuration 3	15 kHz	6	2 ms
Configuration 4	15 kHz	12	1 ms
Configuration 5	3.75 kHz	1	32 ms

The amount of data sent by the RUs is the same for all RU configuration because of the RUs have the same amount of symbols. But as we can see, each configuration results in different durations and amounts of subcarriers per RU.

B. NB-IoT Packet Schedulers

In accordance with the LTE standard, the schedulers are independent entities of the base station, which also applies to NB-IoT. It also inherits the same uplink and downlink format from LTE, SC-FDMA and OFDMA, respectively.

Downlink works the same way LTE downlink works, but with only one RB. NB-IoT uplink is a different due to the use of single-tone and multi-tone transmissions.

Uplink schedulers can allocate RU using any configuration but need to comply with the constraint of SC-FDMA of allocating resources that are located next to each other [11]. It is also possible to use several configurations at the same time, depending on the scheduler.

For subcarrier spacing of 3.75kHz, the scheduler must use configuration 5. But if the subcarrier spacing is 15kHz, the scheduler can choose configurations 1 through 4. It can, for example, use configurations 1 to maximize the number of simultaneous transmissions or use configuration 4 to make transmissions quicker.

IV. SIMULATION RESULTS

In this section, we evaluate two aspects of NB-IoT: the performance of all RU configurations using three schedulers and the effect of the number of NB-IoT carriers over the LTE carrier.

The graphs presented in this section display the behavior of the scenario under increasing amounts of devices. The horizontal axis displays the total amount of simulated devices, which results in the sum of all applications, M2M and HTC.

These graphs were generated using a modified version of the LTE-Sim simulator [12] to include the NB-IoT features.

A. Simulation Parameters

1) Schedulers utilized: For NB-IoT, we decided to consider three different scheduling algorithms: Round Robin (RR), Maximum Throughput (MT) and Proportionally Fair (PF). They were chosen to provide a mix of fairness and throughput focused algorithms to the NB-IoT carrier. The LTE carrier always uses the PF scheduler and the average throughput used by the PF scheduler is calculated by a moving window average of size 100.

Resources are distributed by finding the device with the best metric for the PF and MT schedulers or by choosing the next user for RR. Devices can only receive one RU at a time to maximize the distribution of resources among the devices.

2) Evaluation Metrics: We generated graphs for metrics like Jain's Fairness Index [13], aggregated cell throughput, average user throughput and delivery ratio for all simulations. Due to space constrictions, in this paper, we display only Jain's Fairness Index and Delivery Ratio, since these metrics display values for the main objectives of M2M networks. The delivery ratio is calculated in a aggregated matter.

B. Performance of M2M applications on NB-IoT

For this subsection, we simulated all configurations with all schedulers of RU that have subcarrier spacing of 15 kHz. We expect to achieve a better understanding of the behavior of the configurations. Due to the large amount of curves, we provide the legend for the graphs in Table IV.

TABLE III

SUMMARY OF SIMULATION PARAMETERS.

Parameter	Value	
Number of cells	1 cell of 500m radius	
LTE Carrier Bandwidth	3 MHz (15RB)	
UE Mobility	Static devices	
Signal model	Urban Macrocell	
Path Loss Model	$128.1 + 37.6\ log10(d)$	
Shadowing Model	LogNormal Distribution $\mu = 0db\quad \sigma = 6db$	
Fast Fading Model	Jakes Model [14]	
Device transmit power	Constant 23dBm	
NB-IoT deployment mode	Inband	
Scheduler for LTE carrier	Proportionally Fair	
Proportion of applications	M2M Event driven	20%
	M2M Time driven	50%
	CBR	10%
	Video streaming	14%
	VoIP	6%
Repetitions per scenario	30	
Confidence Interval	95%	
Duration of simulations	5s	

TABLE IV

LEGEND FOR GRAPHS

Legend	Scheduler	Configuration
	MT	1
		2
		3
		4
	PF	1
		2
		3
		4
	RR	1
		2
		3
		4

Figure 1 presents the overall delivery ratio achieved by the NB-IoT carrier. As we can see, configuration 4 proves to be better than other configurations with all schedulers, followed by configuration 3. Nevertheless, configurations 1 and 2 show far worse performance compared to other configurations.

The good performance of configuration 4 can be explained by the small duration of the RU. A larger RU duration makes it easier for the report to be dropped due to the QoS requirement. We use Equation 1 to better explain the situation. Observe that it must be satisfied for a report to be transmitted.

$$\left\lceil \frac{Report\ Size * 8}{Transport\ Block\ Size} \right\rceil \leq \left\lfloor \frac{App\ Max\ Delay}{RU\ Duration} \right\rfloor \quad (1)$$

According to this equation, only the Transport Block Size (TBS) and the RU duration are variable in our simulations. The other values are taken from our applications models. The

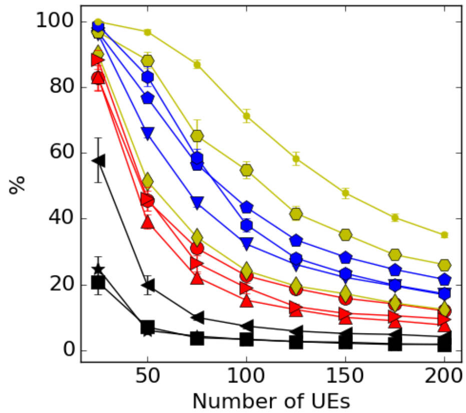

Fig. 1. Delivery Ratio of the NB-IoT carrier

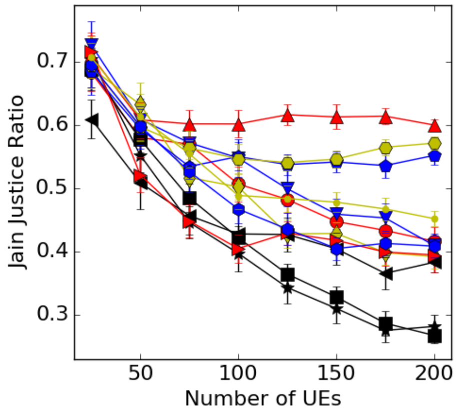

Fig. 2. Overall justice index

TBS depends on the channel quality and it is defined by the AMC module.

The left size of the equation represents the amount of RUs that the device needs to transmit its report, assuming that the channel quality of the device remains the same. The right side represents the amount of RUs of a specific RU configuration that a device can receive before its QoS requirement expires.

This equation provides a simple view of the situation because the TBS may vary a lot depending on the scenario, RU configurations can be dynamic and devices can receive more than one RU at the same time.

Nevertheless, this equation can provide some insight on the behavior of the simulation. Observe that the value of the right side of the equations decreases if we increase the duration of the RU, which means that there are less opportunities for the device to be allocated an RU.

As for the left side, we can see that small TBS results in low values and larger TBS result in larger values. This means that the worse the channel quality of a device, the more RUs a device will require.

It is possible for a device to not be able to transmit in some configurations. Imagine a device running an event driven application and the scheduler is using the configuration 1.

This results in the value of the right side of the equation to equal to six using our definitions. If this device is in poor channel quality, even if it receives the next 6 RUs, it may not be able to finish transmitting the report due to the QoS restriction. This shows that some configurations are not feasible for devices with bad channel conditions.

Now we plot the Jain's justice index achieved by the simulated scenarios, as displayed in figure 2. This graph shows that the PF scheduler has the best performance in respect to justice with RU configuration 2, 3 and 4.

From these two figures, we can argue that the use of PF with configuration 4 is the best usage of NB-IoT in these scenarios because it has a good performance in delivery ratio while keeping a good fairness index.

Now observe figures 3 and 4 show the delivery rate of the M2M applications separately.

From these, we can see that a single carrier of NB-IoT can see that TD applications have a far lower decrease in performance if compared to ED applications. This can be easily explained by the fact that ED applications generate a lot more traffic than time driven applications and TD applications have behavior far more relatable to the behavior of the intended traffic of NB-IoT.

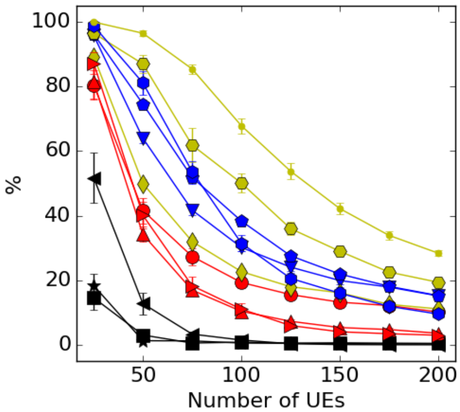

Fig. 3. Delivery rate of event driven applications

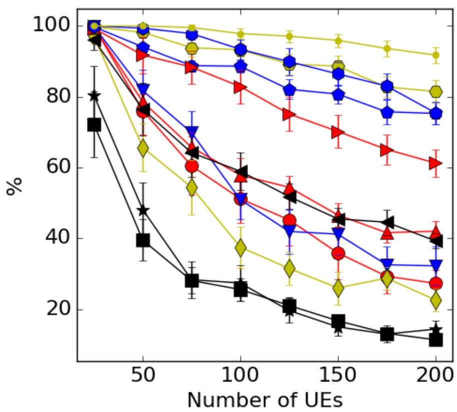

Fig. 4. Delivery rate of time driven applications

This shows that NB-IoT can support this type of TD applications to a considerable amount, especially if you consider more than one carrier, but this type of ED traffic suffers in terms of performance due to its greater throughput. The feasibility of NB-IoT to provide support to this tier of applications can greatly increase if the QoS requirements of them can be loosened to equal that of the intended QoS of NB-IoT devices.

C. Effect of NB-IoT over conventional LTE

We have shown that one NB-IoT carrier is capable of handling a considerable amount of higher end M2M devices but, in case of inband deployment, requires that an RB from conventional LTE be reserved for it. In this section, we provide simulation data of conventional LTE under an increasing amount of NB-IoT inband deployments.

In these scenarios, we still contain the same three conventional applications, video streaming, VoIP and CBR, in the same proportions as the previous simulations. NB-IoT devices are not simulated because these do not intervene with the LTE carrier. We use the PF scheduler.

Since not every RB of an LTE carrier can be allocated for inband deployment of NB-IoT, we limited our simulations to the limit of deployments for each LTE carrier bandwidth [7]. This limitation is due to the mechanism of cell search and initial synchronization of the NB-IoT device.

Figures 5 and 6 show the delivery ratio for scenarios with a small and large cell bandwidth of 3MHz and 10 MHz, respectively.

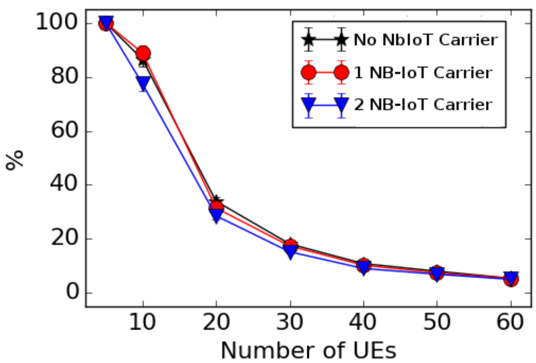

Fig. 5. Delivery ratio of 3MHz scenarios

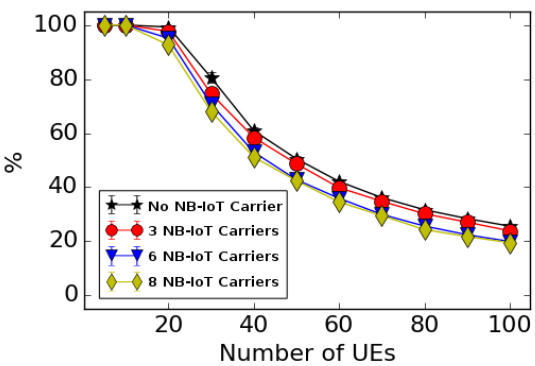

Fig. 6. Delivery ratio of 10MHz scenarios

The 3MHz bandwidth was chosen because its the lower possible value that accepts an inband deployment and the 10MHz bandwidth was chosen because of its average size from the available bandwidths.

From these figures we can see that both bandwidths can handle a considerable amount of NB-IoT carriers without losing considerable performance. That shows the scalability of NB-IoT and can justify the use of multiple NB-IoT inband carriers to be used to support M2M.

V. Conclusion

In this article, we present an analysis of the different configurations of RU that the NB-IoT standard is capable of use. We simulate scenarios with three different schedulers and four RU configurations.

Our results show that configurations with lower durations result in better performance for higher end applications. We also show that NB-IoT can be used for higher end M2M applications, especially if multiple carriers are available.

For future work, we plan to try different algorithms to schedule NB-IoT resources exploring more scheduling metrics and dynamic uses of the RU configurations. Also, we will compare the use of NB-IoT for high-end M2M in contrast to the use of conventional LTE and other features for high-end M2M.

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