Implementation of NB-IoT Power Saving Schemes in ns-3

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ABSTRACT

Narrowband IoT (NB-IoT) is a Low Power Wide Area Network (LPWAN) radio technology standard that uses a subset of the Long-Term Evolution (LTE) specification issued by the 3rd Generation Partnership Project (3GPP). NB-IoT focuses specifically on extended coverage, long battery life and support for a large number of connected devices. Since the ns-3 simulator is already a popular platform for LTE research purposes, it can be adapted for NB-IoT simulations. In this paper, we present the ns-3 design and implementation details of power saving schemes for NB-IoT to evaluate the device's energy consumption and latency. The important features of power saving schemes include Power Saving Mode (PSM), extended Discontinuous Reception (eDRX) and Idle mode paging. We have validated our implementation by running and analyzing various experiments. The implemented code is available as open source.

CCS CONCEPTS

• **Networks** → **Network simulations**; • **Software and its engineering** → *Simulator / interpreter*.

KEYWORDS

NB-IoT, Power Saving Schemes, eDRX, PSM

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1 INTRODUCTION

NB-IoT is a mobile radio access technology that aims to support energy constrained IoT devices using the existing LTE deployed infrastructure. The NB-IoT specification was completed in June 2016 by the 3GPP. Moreover, several network operators, such as Orange, Vodafone and Telia, have already announced the support of this technology in different countries. IoT devices are usually battery-powered, and many IoT use-cases need them to operate for several years without battery replacement. To this end, NB-IoT introduces several techniques to reduce energy consumption and extend their battery lifetime. However, limited research has been done to evaluate the energy consumption of NB-IoT for a variety of use cases. Researchers often rely on simulators and analytical models to evaluate the performance of any network technology. The ns-3 is one of the most popular simulators, where some NB-IoT features have previously been implemented on top of LTE code[1]. The code defines the data structures and functions to send new MIB (Master Information Block) and SIB (System information block) messages periodically according to NB-IoT specification. Additionally, Soussi *et al.* [4] have implemented other features such as limiting the number of resource blocks to one, modifying the physical error model to adopt lower Modulation and Coding Schemes (MCS), separating the subframes for control and data channels and including cross subframe delays for both channels. However, many other features still need to be implemented.

In this paper, we present some improvements to the existing implementation of Soussi *et al.* [4]. We have implemented power saving features of NB-IoT with the objective to evaluate the power consumption and downlink latency of the devices. The new features include the addition of new power saving states and User Equipment (UE) transition logic. In our previous work, we already evaluated the effect of these features on the energy consumption of the UE [5]. In this paper, we instead detail their implementation in ns-3 and validate them. The implemented code with these extended features is publicly available as open source[2].

The rest of this paper is structured as follows: Section 2 provides a brief overview of the User Equipment states. Its implementation details are described in Section 3. In Section 4, we present the validation results. Finally, conclusions are discussed in Section 5.

2 OVERVIEW OF USER EQUIPMENT STATES

In this section, the NB-IoT power saving states for the UE are discussed. The Radio Resource Control (RRC) layer controls communications between a UE and an Evolved NodeB (eNB) at the radio interface to setup, modify and release resources. This RRC protocol has two states: RRC Connected and RRC Idle, as shown in Figure 1. The UE needs to be in RRC Connected state for active data communication. However, this state consumes more energy compared to RRC Idle. For this reason, if the eNB initiates an RRC Release message to UEs, the UEs should transit to the RRC Idle state. The RRC Release message is sent when the RRC inactivity timer expires, which is a network operator specified parameter. This timer is controlled by the eNB which restarts it after a data packet transmission. A UE in the RRC Idle state can always switch to connected state whenever it receives the Uplink (UL) grant or the Downlink (DL) notification. The RRC Idle state consists of two power saving modes: (i) Extended Discontinuous Reception Mode (eDRX) or sleep, and (ii) Power Saving Mode (PSM) or deep sleep.

[1] https://github.com/TommyPec/ns-3-dev-NB-IOT
[2] https://github.com/imec-idlab/NB-IoT

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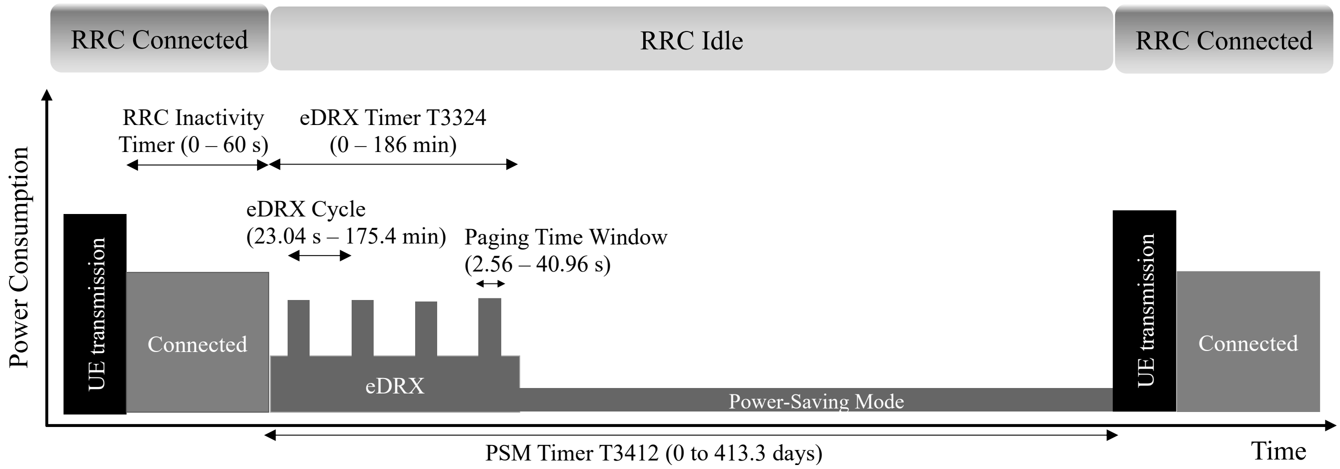


Figure 1: Overview of the NB-IoT UE Duty Cycle States

While the UE is in the eDRX state, it can listen to the DL control channel *Narrowband Physical Downlink Control Channel* (NPDCCH), to receive the DL data notification or the UL data grant from the eNB. This listening mechanism is referred as paging. In the PSM state, the UE turns off its radio and becomes unreachable by the network, but stays registered to it. As in the eDRX state the UE listens to NPDCCH, better DL latency is achieved while more energy is consumed compared to the PSM state. The remainder of this section discusses these two features in more detail.

2.1 Extended Discontinuous Reception

The eDRX is an extension of the DRX procedure with longer timer values to achieve further improvement in the energy consumption. It is designed to save energy while waiting for any DL data. The timer T_{3324} defines the eDRX state time for the UE. It can vary from 0 to 186 minutes [1]. During this period, the UE monitors the channel for paging messages at the interval of the eDRX cycle, which can be set up to 175.4 minutes [6]. An eDRX cycle consists of a Paging Time Window (PTW) time (between 2.56 and 40.96 seconds) followed by a sleep time [2]. During paging, if the UE receives the DL data notification from the eNB, it will switch to the Connected state and the eNB will reset the RRC inactivity timer. If a DL data arrives at the eNB in between paging events, the data is temporarily buffered by the network. Upon expiration of T_{3324} without any activity, the UE can switch to PSM.

2.2 Power Saving Mode

The PSM timer for NB-IoT is up to 413.3 days and is represented as T_{3412} *extended* [1]. Although in PSM mode the UE consumes the least amount of energy, it cannot receive DL data. On expiration of T_{3412}, the UE monitors the channel for paging messages or performs a Tracking Area Update (TAU) for synchronization. Therefore, it can receive DL data only when PSM ends, which happens when the PSM timer expires or the UE switches to the Connected state (e.g., when it needs to send UL data). The procedure of switching to the Connected state from PSM is simpler than initiating a new attach procedure, as the UE context is saved upon its entrance to the PSM state.

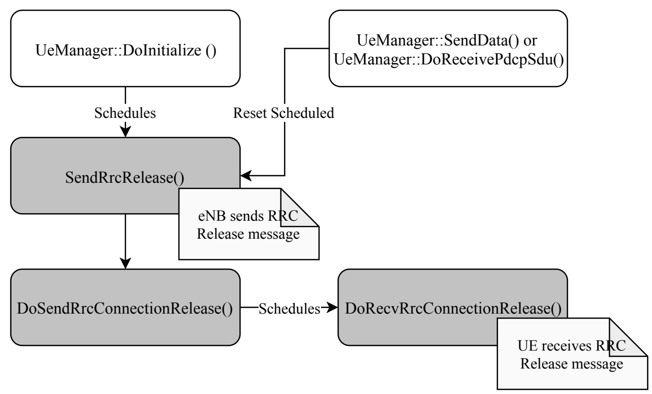


Figure 2: Implementation of Sending RRC Release Message

3 IMPLEMENTATION IN NS-3

Our contributions to the implementation for improving the available ns-3 code include sending the RRC Release message and the paging notification, the addition of new states, and the change of the UE states based on the configured state timers. The implementation modifies a few existing methods and adds some new ones. For example, an overview of the methods for sending the RRC Release message from the eNB is presented in Figure 2, where the grey background denotes the new added methods.

Our implementation focuses on the following key aspects:

- The UE can transit to the RRC Idle state.
- The flexibility provided to the user-defined simulation script for configuring the RRC inactivity timer, PSM timer, eDRX timer, eDRX cycle, and a flag to enable/disable power saving features. Ideally, these timers should be configured during the attach procedure using Master Information Block (MIB)

and the System Information Blocks (SIBs) messages. However, this is left for future work.
- An energy calculation module is developed for NB-IoT, which is adapted from the framework of Pasca *et al.* [3].
- The calculation of energy consumption, latency and states of a UE can be done automatically using post-processing scripts on the traced logs.

Some new states of UEs are added: IDLE_PSM, IDLE_SUSPEND and SUSPEND_PAGING representing PSM, eDRX and paging respectively. The method *SwitchToState()* in LTE_ENB_RRC and LTE_UE_RRC are modified to keep track of these states for each UE. A UE is eligible for switching to these states only after it completes the Random Access Channel (RACH) procedure and is in the RRC Connected state. The eNB sends the RRC Release message using the method *SendRrcRelease()* in LTE_ENB_RRC at a fixed interval configured by the user script, which enforces the UE to change its state to IDLE_SUSPEND. The method *DoSetFrameSubframe()* in LTE_UE_RRC is called at every subframe to decide the state of the UE in that subframe. This method also maintains all the state timers and switches the UE to the PSM state at the expiration of T_{3412} or to the RRC Connected state in case a DL data notification or an UL grant is received. The eNB also maintains the UE's state information which helps the network to save all the DL data while the UE is in the PSM or eDRX state. To handle this mechanism, the method *SendData()* is modified to save all the data in a variable vector called *m_packetsaved* in case the UE's state is either IDLE_PSM or IDLE_SUSPEND. These buffered DL data are sent after sending data notification to the UE during SUSPEND_PAGING state or when UL data are received on the eNB. As the timers can be configured via scripts, some modifications have also been done in the LTE_HELPER file. With all these changes, now the UE can be diverted from the RRC Connected state to the RRC Idle state for saving its energy.

As mentioned before, to calculate the energy consumption, we have developed an energy module named "energy-module-nbiot", which receives the callbacks from LTE_UE_RRC. We can also enable some logs which can be easily post-processed to know the UE's state at any specific time. These logs also provide flexibility to calculate latency and the energy consumption for different NB-IoT hardware modules using the script *parsestate.py*.

4 VALIDATION

Different experiments have been conducted using our extended NB-IoT ns-3 module to verify and validate its correctness. The timings and states of UEs have been checked for different power saving scheme timers. The module has also been validated for a large number of UEs associated with a single eNB and verified if it follows the NB-IoT specifications. In this paper, we show how the UE's state changes for a single (cf., Section 4.1) and two UEs (cf., Section 4.2) while sending UL and/or DL data. The considered simulation parameters for the shown scenarios are summarized in Table 1.

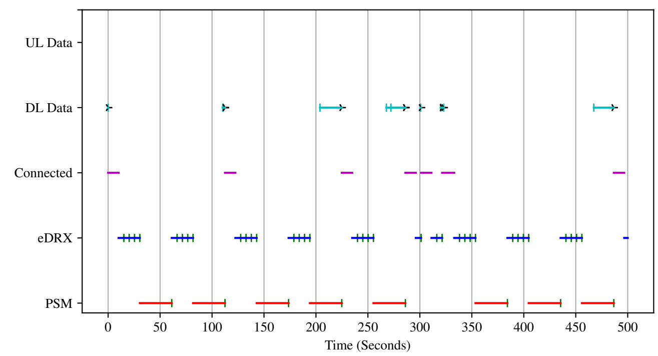
4.1 Case I: Single UE

In this case, we are considering a single UE and a single eNB in the simulation, and two scenarios are evaluated. In the first scenario, the UE only receives Poisson distributed DL data at an interval of 50 s from the remote host. It can be observed from Figure 3a that the UE behaves correctly according to the 3GPP specification. At the time around 0.05s and 110s, the UE is in Connected state and so the DL data is sent immediately. However, at 203 s, 267 s, 272 s, and 467 s, the UE waits until the expiration of the PSM timer, causing DL delay as shown in the "DL Data" line of the graph. Also, when the UE enters in the eDRX state at 296 s, it needs to switch to the RRC Connected state during paging as the eNB tries to send a data at 301 s. The average latency to receive the DL data in this scenario is 7.89 s.

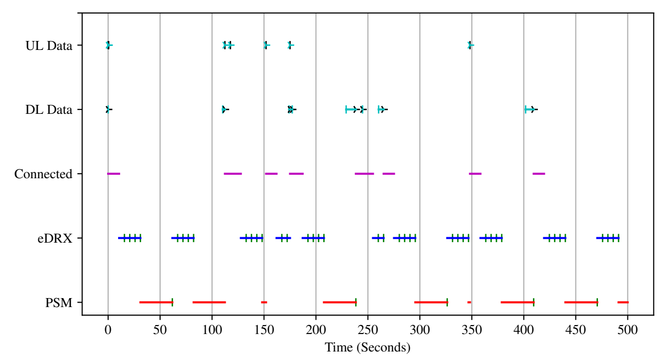
The DL latency is reduced to 3.19 s in the second scenario, as shown in Figure 3b. The second scenario considers that the UE is

Table 1: Simulation Parameters

Parameters	Symbol	Value
RRC Inactivity Timer	*rrc_release_timer*	10 *s*
PSM Timer	T_{3412}	51.2 *s*
eDRX Timer	T_{3324}	20.48 *s*
eDRX Cycle	*edrx_cycle*	5.12 *s*
Downlink Data Interval	*dli*	50 *s*
Uplink Data Interval	*uli*	60 *s*
Data Size		32 *bytes*
Simulation Time		500 *s*

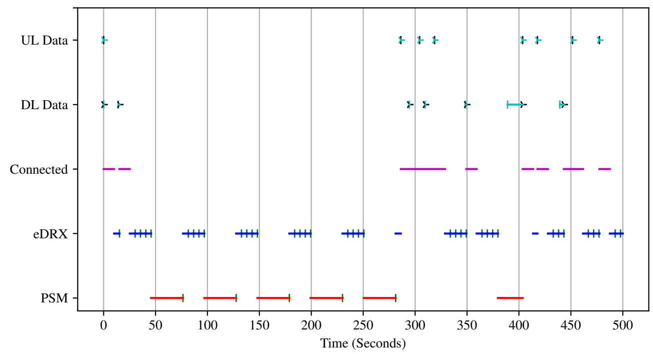


(a) Downlink Data Enabled Only

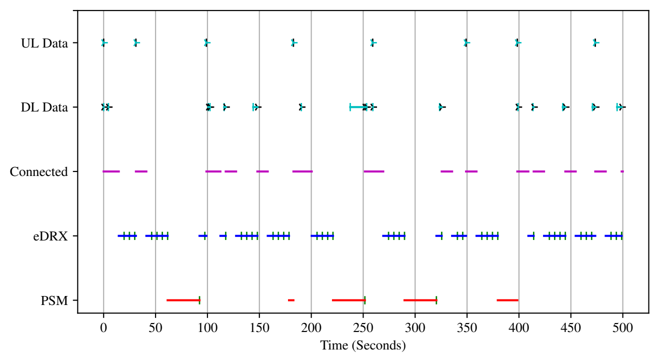


(b) Uplink and Downlink Data Enabled

Figure 3: State Shange for Single UE



(a) Uplink and Downlink Data Enabled UE_1



(b) Uplink and Downlink Data Enabled UE_2

Figure 4: State Change for two UEs

also sending UL data as well as DL data and so the UE can exit from the PSM or eDRX state whenever it receives the UL sending grant. This can be observed at time 112 s, 152 s and 348 s of Figure 3b. Upon exiting the PSM or eDRX state to the Connected state, buffered DL data is queued and sent to the UE. This reduces the overall DL latency, while increasing the energy consumption. If we consider the reference power values from the u-blox SARA-N2 NB-IoT module specification, the energy consumption increases in the second scenario by around 20% from 0.0124 W to 0.0149 W.

4.2 Case II: Multiple UEs

In this case, two UEs are associated with a single eNB in the simulation test case. We can observe that the pattern of the UEs behaviour is similar to Case I. Interestingly, an observation at time 300s of Figure 4a also shows that the frequent UL data keeps the UE in the Connected state longer and DL data in this period also achieves low latency during that period. The implementation provides support for multiple UEs to behave independently according to their data arrivals and timers.

5 CONCLUSIONS

In this paper, we presented an extension of the ns-3 NB-IoT simulator, with support for power saving features such as PSM and eDRX. The validation of our implementation has been shown using the state transitions obtained from simulation results. The observed changes in the UE states allow us to conclude that our implementation of the new power saving features of NB-IoT is correct. The current version of the module does not yet include all the procedures defined in the 3GPP standard to configure the PSM and eDRX timers and parameters through MIB and SIB messages. Instead, it provides a script-based configurable module. The implementation of message-based configuration is left for future work.

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