BioGecko

Vol 12 Issue 01 2023

ISSN NO: 2230-5807

Energy Performance Evaluation in Narrowband IoT Data Transmission: A Survey

1. **T. Amudha,**
Research Scholar, Department of Electrical and Electronics Engineering,
Aarupadai Veedu Institute of Technology, Vinayaka Missions Research Foundation, Chennai.
amudha.ece@avit.ac.in
2. **S. Regilan,**
Research Scholar, Department of Electronics and Communication Engineering,
Aarupadai Veedu Institute of Technology, Vinayaka Missions Research Foundation, Chennai.
regilan.research@avit.ac.in

Abstract
The Narrowband Internet of Things (NB-IoT) technology provides an improved cellular connectivity to the IoT devices. This technology offers an improved indoor network coverage, deploys massive devices, reduced delay and increased energy efficiency. However, the energy efficiency associated with the deep coverage area is found to be a greater challenge. Hence, the IoT devices present in the inaccessible regions is considered essential and the coverage should be provided to such network with a greater coverage gain. The problem arises here is the performance degradation due to increased energy consumption as the network is prone to provide a strong coverage in the unattended environment. In this paper, various methods on improving the energy efficiency in NB-IoT technology is discussed. The challenges that affect the energy efficiency is further studied and the solutions to resolve the preamble message repetition is thus provided. Further, the paper offers insights for the future researchers to improve the energy-efficiency while accommodating massive IoT devices in the network.

Keywords: NB-IoT, Energy Evaluation, Data Transmission

1. Introduction

Internet of Things (IoT) in recent times has gained a major impact that includes low cost, low power and long range over various wireless network applications (Table 1). The NarrowBand-IoT (NB-IoT)covers a wide geographical location in critical propagation areas even in the presence of massive IoT nodes [1].

Table 1: Various IoT transmission

	SigFox	LoRa	LTE-M	NB-IoT
Transmission Range (km)	3-50	2-5	11	10-15
Bandwidth	100 Hz	300-500 kHz	1.08 MHz	180 KHz
Data Rate	<100 bps	50 kbps	375 kbps	200 kbps

Lifetime (years)	10-20	10	>10	>10

The NB-IoT is one of the multiple Low-Power Wide-Area Networks (LPWAN) technology among various other technologies in the market including Long-Range (LoRa) andSigFox. It is found that NB-IoT competes with LoRa in terms of long-range communication in both licensed and unlicensed bands, respectively [2]. NB-IoT is supported via various licensed cellular operators and it is fully functional with major telecom equipment. It is high compatible with 4G, 5G and other future generation models with maximum battery lifetime.

With increasing number of IoT devices, performance of the NB-IoT poses crucial challenges and one such challenge is the energy consumption that affects the retention of the network in terms of reduced network lifetime and throughput [3].

In this paper, energy efficient NB-IoT models are discussed and various models of NB-IoT communication offers an improved performance (as in section 4) in terms of increased energy efficiency is presented. Various other consideration includes longer battery life, reduced power consumption and low data cost while data is been communicated via NB-IoT are promoted for improving the energy-efficiency of NB-IoTs.

The rest of the paper organized as: section 2 provides the related works. Section 3 discusses the NB-IoT and power consumption model. Section 4 evaluates the work. Section 5 provides the limitations and section 6 concludes the entire work with possible directions for future scope.

2. Related Works

In this section, various techniques on energy evaluation over narrowband IoTdata communication is studied. This includes evaluating the idle power, packet transmission, battery lifetime, data/channel scheduling, signal quality, modulation coding selection, deployment cost, preamble repetition, computational overhead, and coverage class. The energy efficiency is further evaluated in terms of error reduction models, machine learning model and QoS based models.

2.1. Techniques on Energy Performance Evaluation (EPE)

The power consumption and latency are studied in [4] in case of data packet transmission in NB-IoT. The idle power is neglected in the cases where the authors measure the transceiver performance without splitting it from the separating it from the microcontroller.

NB-IoT enables devices to be located in regions that are inaccessible by cellular networks because of penetration losses or their remote locations by decreasing capacity and repeating communications. Achieving the desired low range of Signal-to-Noise Ratio (SNR) requires repeats, which might significantly limit the coverage expansion depending on the performance of the channel estimator. The methodology for performing in-depth evaluations of NB-IoT efficacy is found in [5]. The study investigates the limits that are imposed by a realistic channel estimate in addition to the SNR. The test also showed that the coverage had an effect on battery life and transmission latency in case of uplinks. The redundancy across the NB-IoT system consumes more energy and takes longer to respond. The scheduling of uplink and downlink channels and their effect on the system as a whole is crucial. The control/data channels develop a functional model of NB-IoT as in [6]. The channel scheduling and the interaction of coverage classes affect the performance of IoT devices is studied by determining the anticipated latency and battery longevity. The optimal scheduling points, i.e. the scheduling of data and control channels for a given set of users and coverages are determined. These results verify the validity of the channel scheduling and coverage classes significantly affect the latency and battery life.

Using commercial IoT devices from a variety of operators, [7] provides a comprehensive set of empirical measurements for evaluating the effect of various factors on energy consumption. Our findings indicate that an incorrect arrangement can increase the energy consumption. The theoretical operational modes into existing consumption patterns of NB-IoT devices is found in [7]. The findings indicate that the paging interval is the important power consumption factor as the time interval is set by the base station. Not all service providers consistently use the advised settings. In addition, if the signal quality is really bad, packet size and signal quality have lesser or nil effect on energy consumption in this configuration.

To solve the problem of a constant data rate in real-time applications, spectral efficient frequency division multiplexing (SEFDM) technique is employs in [8] that uses higher modulation formats in NB-IoT. These strategies need substantial energy input and an adaptive selection of the modulation coding and the repetition accounts mainly for the 2D channels to increase the data rate while maintaining the cost of deployment. With massive NB-IoT nodes are added to the network, the findings show that the proposed method outperforms conventional MCS and repetition selection schemes in terms of data rate and energy efficiency.

The RACH function and the data transmission in NB-IoT usesrepetition transmission to provide reliable connections even across greater distances. This avoids the regular battery replacement for IoT devices, energy harvesting promotesthe sustainability in the NB-IoT network. The RACH success probability in [9] over a NB-IoT network considers repeated preamble transmissions and collisions as the IoTs transmits only when itis sufficient. In low-traffic, the success probability is boosted by employing the repetition scheme, whereas very inefficient channel resource consumption has only a negligible effect in high-traffic scenarios.

The cooperative relaying technique is the latest technique of the NB-IoT [10]. Power consumption in a cell is reduced as a result of the algorithm, since it selects the relay for deployment. This recommends for a greedy approach that can achieve the same results with less computational overhead. The cooperative relaying reduces the energy consumption by 30% and the energy consumptions for the greedy approach is 10% higher than the optimal strategy.

The scheduling of uplink/downlink channels and their effect on the system as a whole is crucial. To address this issue, a tractable model is created in [11] using the NB-IoT access protocol, which accounts for all message exchanges between the uplink and downlink random-access, control, and data channels. The model at channel scheduling and the interplay of coexisting coverage classes affectsthe battery life and latency for each coverage class. These results are then used to the problem of determining the possible operating points and analyzing the latency-energy tradeoff in NB-IoT channel scheduling.

The robustness of NB-IoT connection adaption against realistic channel estimation utilizing the Max-Rate, Min-Energy, and Max-Energy-approach is designed in [12]. With the exception of extremely reduced power reception, increasing the data rate in NB-IoT always improves the spectral efficiency. In addition, the report examines the impacts of data size on the efficiency of NB-IoT link adaption. Theenergy efficiency, data consumption and data rate get affected often with as the data size grows.

A precise power and protocol fusion tool for NB-IoT hardware diagnostics is developed in [13]. The study deployed 30 IoT nodes to over 1,200 locations across four regions to collect data for this extensive field measurement project. Based on comprehensive analysis of the collected 49 GB of traces, it is found that the NB-IoT nodes in the unattended environment produces variable energy consumption with ratios as high as 75:1. This may cause the battery to drain quickly and the connection to drop out frequently.

Error Reduction Models in NB-IoT Energy Analysis

Due to the severe constraints of NB-IoT, random selection is still used in the standardized preamble allocation method. This work presents a combined optimization strategy in [14] for preamble selection and to improve the energy efficiency of NB-IoT systems. The research solves this optimization problem by developing an energy estimate model that explains the results of preamble selection and energy efficiency and investigates the limitations of the random access (RA) strategy. Simulations verifies the energy efficiency performance and the applicability and convergence of the optimization approach.

NB-IoT allows a wide range of link adaptation settings, such as a variety of resource units (RU) and the number of repetitions in [15], to expand coverage and guarantee reliable transmissions. The research focus on adjusting these parameters affects NB-IoT performance using a mathematical model of link adaptation that balances energy reduction and optimization. The results of the simulations shed light on the effect of the link adaption parameters on transmission in various ways and with varying coverage ranges.

The investigations of the profile traces are is studied in [16] from the popular BG96 NB-IoT module in various states of the RRC protocol. This reveal that the model adequately captures the baseline energy consumption of an NB-IoT radio transceiver while operating at different coverage class levels and the errors for this model ranges from 0.33% to 15.38%.

ML based Models in NB-IoT Energy Analysis

Machine Learning methods can be crucial in reducing the power consumption of IoT networks by preventing the transmission of unnecessary data as in [17]. In order to transmit the data across the NB-IoT network intelligently, this architecture employs a low-power and a processing unit with a NB-IoT radio to construct a smart gateway. Before sending the data, the smart gateway compresses and improves it using supervised and unsupervised ML techniques. Reducing the number of devices using a single NB-IoT bandwidth reduces channel occupancy, saves energy, and speeds up data transfers. Our experiments in the wild reveal that it is possible to reduce the number of NB-IoT radio broadcasts by as much as 93%, to reduce the energy consumption of NB-IoT radios by as much as 90.5%, and to reduce the time it takes to transfer data by as much as 90%.

QoS based NB-IoT Energy Analysis

To increase the quality of service, several packet schedulers are evaluated in [18] that prioritize the IoT devices and assign them to separate subcarriers. The in-band, guard-band, and standalone NB-IoT deployment is selected while proposing a near-optimal radio network design. The study develops a 95% delay percentile and that lies within the acceptable limit of 20 seconds. It is reasonable to conclude that NB-IoT is an adequate technology in smart energy distribution networks.

Table 2 shows the comparisons of the above methods in terms of energy consumption, where it considers various energy models and this features comparison between these models in terms of its multi-access scheme, power consumption mode, its type, modulation coding scheme and transmission repetition.

Table 2: Comparison of state-of-art NB-IoT Energy Consumption Models

Method	Multi Access Scheme		Technology		Power consumption Mode			Power consumption Type		MCS	Transmission Repetition (TR)
	SC-FDMA	OFDMA	LTE-M	NB-IoT	Active	Sleep	Idle	Transmitter	Transceiver		
[4]	✓	×	×	✓	✓	✓	×	×	✓	✓	×
[5]	✓	✓	×	✓	×	×	×	✓	✓	×	×
[6]	✓	×	×	✓	✓	×	✓	✓	✓	×	×
[7]	✓	×	×	✓	✓	✓	×	✓	×	✓	×
[8]	✓	×	×	✓	✓	✓	×	✓	×	×	✓
[9]	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓
[10]	✓	×	×	✓	✓	×	✓	✓	×	✓	×
[11]	✓	×	×	✓	✓	×	✓	✓	✓	×	✓
[12]	✓	×	×	✓	✓	✓	✓	✓	✓	✓	×
[13]	✓	×	×	✓	✓	×	✓	✓	×	✓	✓
[14]	✓	×	×	✓	×	×	×	✓	✓	×	×
[15]	✓	×	×	✓	✓	✓	✓	✓	✓	✓	✓
[16]	✓	×	×	✓	✓	✓	×	×	✓	×	✓
[17]	✓	×	×	✓	×	✓	✓	✓	×	✓	✓
[18]	✓	×	×	✓	×	✓	✓	✓	✓	✓	✓

3. NB-IoT System Model

In this section, the NB-IoT system model involves the basic understanding of energy evaluation mechanism. The fundamental NB-IoT architecture operates behind the mechanism of LTE, where the users are communicated via eNodeB through an Uu Interface. As in Figure 1, the NB-IoT is connected with the Mobility Management Entity (MME) to communicate with the users through a S1-MME. Further, it is connected with the Service Gateway (S-GW)entity for user communication through S1-U.

The MME and S-GW are interconnected through two different interfaces namely S11-C over the control plane and S11-U over the user plane.The interface namely S5-C and S5-U connects the S-GW and packet data network gateway (P-GW), respectively over the control and user planes. The data transmission occurring via the control plane is supported by the newer interface called S11-U, which is not supported in LTE communication.

Further the Cellular- IoT (CIoT) involves two different optimisation techniques adopts to improve the data transfer rate using Evolved Packet System (EPS). This includes control plane and user plane optimisation, where the former involves the data transfer between the user and control plane eNB and the latter with the user plane. NB-IoT mandates the optimisation in control plane but not in user plane. The entire operation of data communication takes place at a lower data rate and it reduces the signalling overhead to improve the energy efficiency.

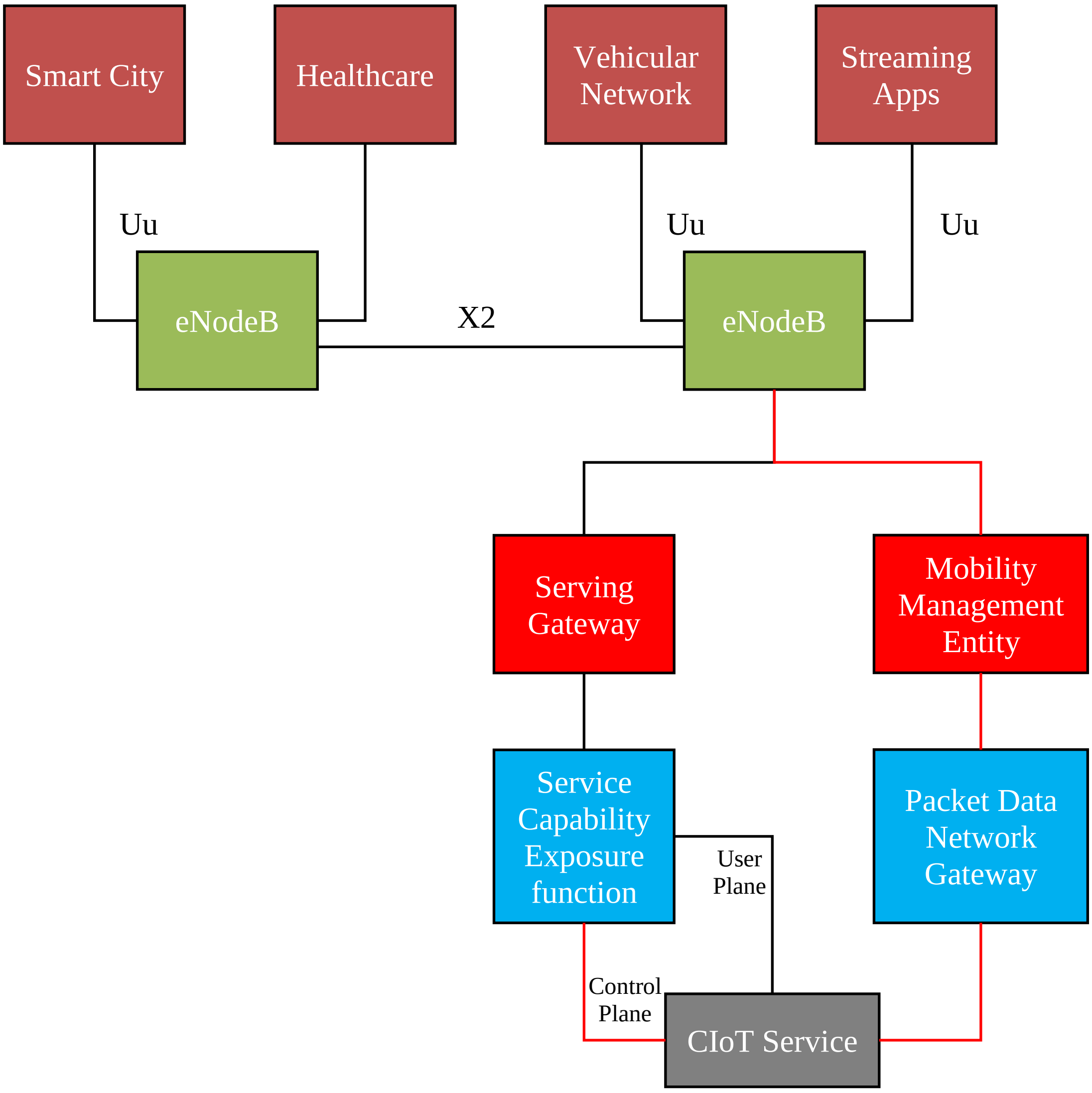

Figure 1: Architecture of NB-IoT

At the uplink/downlinks, the full carrier and channel bandwidth is 180 and 200 kHz, respectively with a 15kHz OFDMA subcarrier is used at downlinks.A tri-downlink channels in NB-IoT communication supports both TDD and FDD modes.

Table 3: Abbreviations

OFDMA	Orthogonal Frequency Division Multiple Access
AWGN	Additive White Gaussian Noise
TDD	Time Division Duplex
FDD	Frequency Division Duplex

PHICH	Physical HARQ Indicator Channel
DCI	Downlink Control Information
PCFICH	Physical Control Format Indicator Channel
SC-FDMA	Single-carrier Frequency-Division Multiple Access
SNR	Signal-to-Noise Ratio
NPDCCH	Narrowband Physical Downlink Control Channel
PRB	Physical Resource Block

NB-IoT does not consider PHICH and it transmits HARQ ACK via NPDCCH with DCI and with its fixed size of the control format, the requirement of PCFICH is found unnecessary. At the uplinks, NB-IoT applies SC-FDMA as it supports both the single/multi-tone data transmission. Further, the NB-IoT supports two channels for uplink and a reference signal for improving the coverage and SNR is increased by allowing the users of NB-IoT to transmit the data at a reduced bandwidth rate. With such allocations, a 3.75 kHz band is utilised for sub-carrier spacing with a total of 48 carriers at a slot interval of 2 ms. At uplink/downlink, the operations of a physical channel are shown in Table 4.

NB-IoT allows reuse of rate matching, channel coding and interleaving under various modes of deployment that includes: standalone/guard-band/in-band. In the first deployment mode, no PRB is allocated but a new band is utilised as a carrier, in the second, a single PRB is used within the guard-band and similarly in the third mode, a PRB is found within the band of LTE.Thus, a wide coverage is offered using three modes of coverage levels, namely: 0, 1, and 2. The MCL is supported at a rate of 144 dB, 154 dB and 164 dB for 0, 1, and 2 coverage levels. Multiple repetitions of preamble increase the range/coverage at both uplinks/downlinks and this allows 128/2048 repetitions, respectively. The utilisation of smaller bandwidth at the single-tone data transmission seems to provide an enhanced coverage than the multi-tone type.

3.1. Power Consumption Model

The control signaling and multiple repetitions with 3GPP specifications improves the coverage of NB-IoT at the base stations. However, these operations increases the energy cost in an exponential manner and hence the consideration of energy consumption modelling is needed for NB-IoT to reduce the increased consumption of energy.

3.1.1. Average Energy Consumption (Transmission)

The energy consumption is defined as an average consumption of the NB-IoT networks at the time of data transmission and reception. It is defined in terms of number of repetitions allowed per data being transmitted and received as in Eq.(1).

$$E_T=(P_T+P_R)\times B\times M\times P_{sT} \tag{1}$$

where

E_T - energy consumed by the transceiver circuit on single wireless link,

P_T - transmit power,

P_R - is the receipt power,

M - packet size during uplink (in bits),

B - bit rate at transmission, and

P_s - Successful transmission probability.

3.1.2. Energy Consumption (Transceiver)

The energy consumption at the receiver is recorded as high as NB-IoT supports three different modes of operation (idle/active/synchronization mode). Higher consumption of energy is found at active state, lower at idle and medium at sync state. Thus, the total amount of energy consumed at the transceiver at the time of reception is defined as in Eq.(2):

$$E_R = P_R \times K \times t_s + \sum_{k=1}^{K} P_s t_s^k + P_I t_{Act}^k \tag{2}$$

where

P_R – Reception power

K - number of iterations for synchronization to establish an effective connection

t_s – time required for synchronization,

t_s^k - Active time for K iterations,

t_{Act}^k - Active time for K iterations, and

P_s – sleeping states and

P_I – idle states.

The consideration of state transitions further involves the transceiver operation and this involves both the state transition and operational states. Thus, the total consumption of the energy at the transceiver is defined as in Eq.(3):

$$E_{Tr}=(E_T+E_R+E_I+E_s)+E_{Tn}, \tag{3}$$

where
E_T– Total Energy consumption at the transmission,
E_R– Total Energy consumption at the reception,
E_I- Total Energy consumption at the idle state,
E_s- Total Energy consumption at the sleep state, and
E_{Tn}- Total Energy consumption while the state changes.

3.1.3.Power Consumption (Processing Unit)

The uncertain consumption of energy at the NB-IoT network involves the uncertain timing of the different operational modes and between the transitions from one to another mode. In NB-IoT, the Central Processing Unit (CPU) undergoes different modes of operation. Hence the total consumption of power at CPUs can be defined in terms of three difference states namely active (*a*), sleep (*s*) and idle (*i*) as in Eq.(4):

$$E_{CPU}= = \sum_{k=1}^{a} P_a T_a(k) + \sum_{k=1}^{s} P_s T_s(k) + \sum_{k=1}^{i} P_i T_i(k) \tag{4}$$

where

P_a – CPU power consumed during active mode,

P_s– CPU power consumed during sleep mode, and

P_i – CPU power consumed during idle mode.

$T_a(k)$ – Dynamic timing changes of CPU during active mode,

$T_s(k)$ – Dynamic timing changes of CPU during sleep mode, and

$T_i(k)$ – Dynamic timing changes of CPU during idle mode.

The energy consumption at each mode of operation at the CPU depends entirely on the battery voltage. As the CPU undergoes five different possible transitions of states and this includes $a \to i$, $i \to a$, $a \to s$,$s \to a$, $i \to s$. In addition, with E_{CPU}, the consumption of energy between the statesE_{Tn_CPU} is defined as in Eq.(5):

$$E_{Tn\_CPU} = \sum_{k=1}^{n} \frac{F_T(k)T_T(k)}{2}\left(P_i(k)+P_l(k)\right) \tag{5}$$

where
$F_T(k)$ – total number of states transition for initialization/transmission/reception/relay operation,
$T_T(k)$ - State kTransition Duration, and
$P_i(k)$–initial state power consumption and
$P_l(k)$ –final state power consumption.
Thus, the resultant power at all states is defined as an average power consumed during these state transition process. This is defined as the true power consumed during the operation of CPU and the state transitions as in Eq.(6):

$$E_{PR}=E_{DS}+E_{ST} \tag{6}$$

With such consideration, various energy consumption representations from different methods are given in Table 4.

Table 4: Comprehensive Analysis of Power Consumption at Uplink/downlink in NB-IoT

Ref	Objective	Ideology	Limitation
[19]	To study the energy consumption in NB-IoT	Energy consumption and signal quality is not correlated	Discontinuous Reception (DRX) and Paging intervals increases delay
[20]	To guarantee the QoS	Resource scheduling model to reduce the energy	Reduced transmission reliability in NB-IoT

		consumption	
[21]	To evaluate the energy efficiency using massive IoT devices	Group based DRX is obtained via semi-Markov model	Wake-up latency increased
[22]	To find the power usage	NB-IoT integrated with Markov Chain for energy consumption evaluation	Increase in latency while sending the uplink periodic reports
[23]	To find the energy consumption over different coverage areas	Consideration of deep sleep mode while considering IoT devices	Marginal improvement is reported in comparison with LTE networks
[24]	To find energy consumption during data scheduling in uplinks/downlinks	Queuing theory model for data scheduling	Improves network lifetime but at a smaller rate than conventional methods.
[25]	To minimize the energy consumption with reduced delay	Semi-Markov to find the uplink periodic traffic	Trade-off between the energy and delay poses a serious threat

4. Performance Analysis

Various configuration to set up the simulation settings for the energy consumption analysis includes standby-, inactive-, reception-, and maximum power consumption during the process of transmission. Various other transmitter settings include battery capacity and power amplifier efficiency, transmit power of the user equipment's (UEs), discontinuous reception cycle and its timer, preamble detection probability and active timer. The parameters considered for evaluating various NB-IoT models are given in Table 5.

Table 5: Simulation Parameters

Parameters	**Value**
Carrier frequency (MHz)	900
System bandwidth (kHz)	200
Spacing between subcarriers (kHz)	15
NPDCCH	Sequential

Transmit antennas	2
Receiver Antennas	4
Time offset period	2.5 µs
Network deployment	Mesh
Channel Model	Slow Fading AWGN
Multi Access Scheme	SC-FDMA/OFDMA
Power consumption Mode	Active/Sleep/Idle

4.1. Experimental Setup

In this section, the battery pack of the NB-IoT nodes run at 4.5V and it is made of a Li-Ion type of 3 Nos, where each cell runs at 1.5V. At the sleep mode, the NB-IoT node runs the microcontroller and at the idle state, it allows handling of the data reception. The simulation is conducted in MATLAB, where the NB-IoT node is allowed to transmit a single packet using a uniform random process in a predefined interval.

4.2. Network/Simulation Parameters

The physical layer settings involve setting the required values for the carrier frequency offset, noise figure, power class and propagation condition. The protocol overhead settings involve overheads of PDCP/MAC/RLC, higher layer procedure and PDCP packet size.

NB-IoT simulation settings includes design of NPDCCH using Aggregation level, its format and periodicity. NPUSCH after NPDCCH transmission, thresholds at coverage level, Random Access configuration level, repetitions of NPRACH/NPDCCH, Random Access, Synchronization time and acquisition time are some of the other critical parameters related to the NB-IoT design.

4.3. Metric Evaluation

Various other network parameters include System bandwidth, Carrier frequency, Subcarrier spacing, Chanel estimation, Interference Rejection Combiner, transmit and receive antennas, Frequency offset, Time offset period, Network deployment Model, Channel Model, and LTE Modulation Scheme. The comparison is conducted by clustering various methods based on its MCS rate [4,7,12], TR rate [8,9,11,13,15-17] and DRX [19-25] rate.

The important metrics relating to the present energy consumption analysis include energy consumption (J), bandwidth utilisation (%),CPU memory utilisation (%) and network latency (ms) is hence considered. The present analysis considers various payload capacity like 12 bytes from 1 sensor sample (12B/1 Sensor), 24 bytes from 2 sensor sample (24B/2 Sensor) and 36 bytes from 3 sensor sample(36B/3 Sensor) [26].

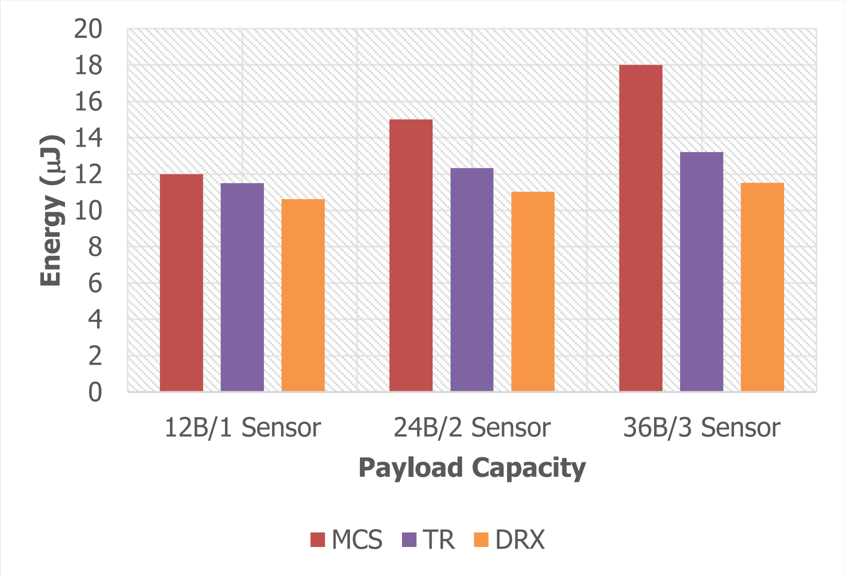

Figure 2: Energy consumption

Figure 2 shows the results of energy consumption between the MCS [4,7,12], TR [8,9,11,13,15-17] and DRX [19-25] models. From the results, it is found that the DRX models various payload capacity like 12B/1 Sensor, 24B/2 Sensor and 36B/3 Sensor shows a reduced consumption of energy. The DRX achieves 0.0008% reduced energy consumption than TR and 0.0013% than MCS for 12B/1 Sensor. For 24B/2 Sensor, the DRX achieves 0.0016% reduced energy consumption than TR and 0.00412% than MCS. Finally, for 36B/3 Sensor, the DRX achieves 0.00246% reduced energy consumption than TR and 0.00695% than MCS.

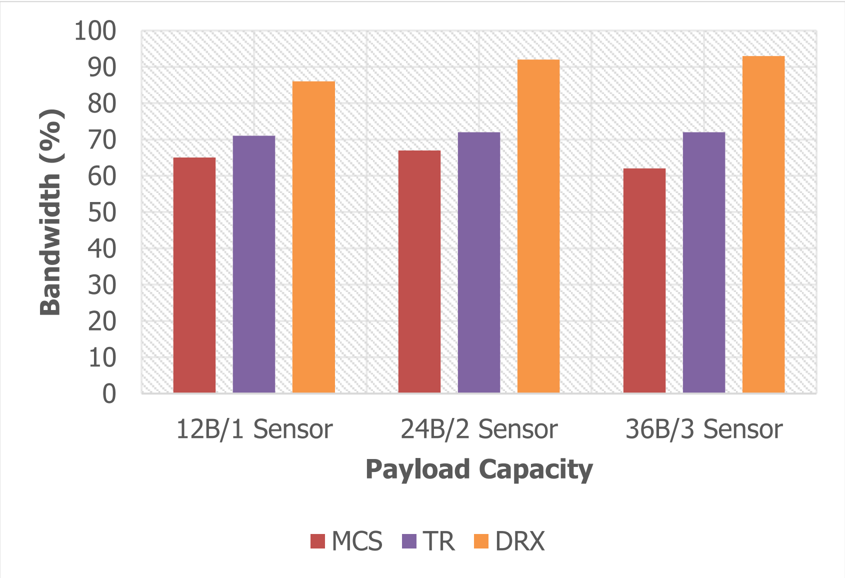

Figure 3: Bandwidth utilization

Figure 3 shows the results of bandwidth utilisation between the MCS [4,7,12], TR [8,9,11,13,15-17] and DRX [19-25] models. From the results, it is found that the DRX models various payload capacity like 12B/1 Sensor, 24B/2 Sensor and 36B/3 Sensor shows anincreased utilisation of bandwidth. The DRX has 0.17% increased utilisation than TR and 0.24% than MCS for 12B/1 Sensor. For 24B/2 Sensor, the DRX has 0.16% increased utilisation than TR and 0.22% than MCS. Finally, for 36B/3 Sensor, the DRX achieves 0.16% increased utilisation than TR and 0.28% than MCS.

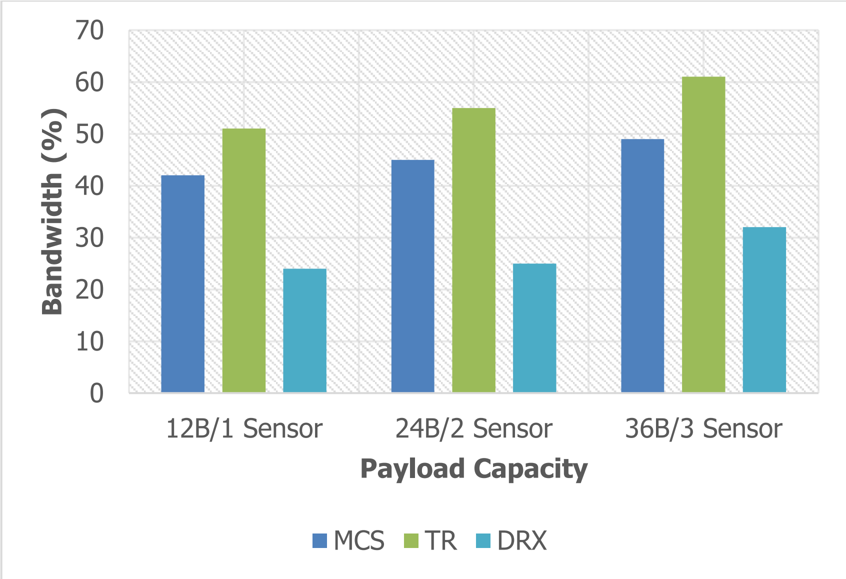

Figure 4: Memory utility

Figure 4 shows the results of CPU memory utilisation between the MCS [4,7,12], TR [8,9,11,13,15-17] and DRX [19-25] models. From the results, it is found that the DRX models various payload capacity like 12B/1 Sensor, 24B/2 Sensor and 36B/3 Sensor shows an increased utilisation of memory. The DRX has 1.125% reduced utilisation than TR and 0.75% than MCS for 12B/1 Sensor. For 24B/2 Sensor, the DRX has 1.3% reduced utilisation than TR and 0.9% than MCS. Finally, for 36B/3 Sensor, the DRX achieves 1.54% reduced utilisation than TR and 1.04% than MCS.

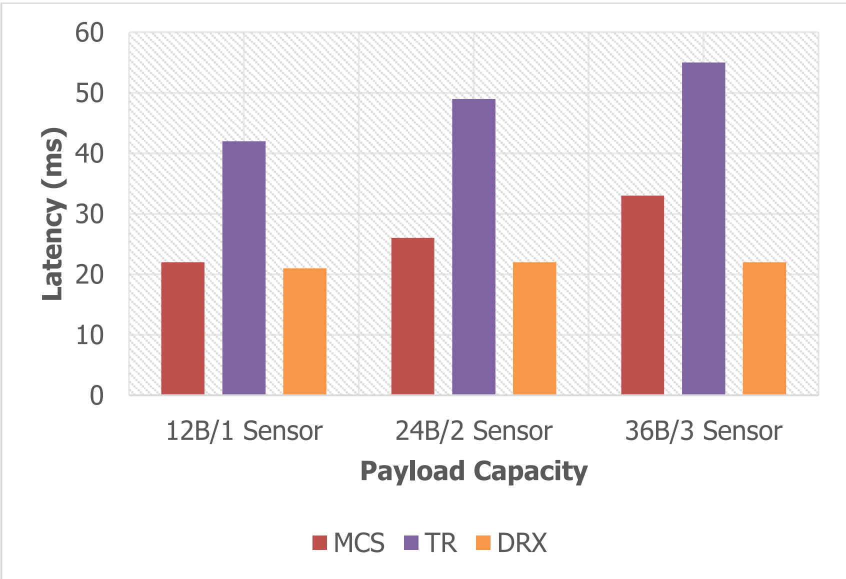

Figure 5: Latency

Figure 5 shows the results of latency between the MCS [4,7,12], TR [8,9,11,13,15-17] and DRX [19-25] models. From the results, it is found that the DRX models various payload capacity like 12B/1 Sensor, 24B/2 Sensor and 36B/3 Sensor shows a reducedlatency of memory. The DRX has 1% reduced latency than TR and 0.04% than MCS for 12B/1 Sensor. For 24B/2 Sensor, the DRX has 1.3% reduced latency than TR and 0.24% than MCS. Finally, for 36B/3 Sensor, the DRX achieves 1.6% reduced latency than TR and 0.57% than MCS.

5. Research Challenges

Various research challenges that affect the energy efficiency of the NB-IoT communication includes the following:

Transmission Challenges:

NB-IoT aims to handle the IoT equipment's lying-in deep coverage areas, where coverage extension is required to maintain the communication. The NB-IoT offers an extended coverage via repeated transmission of packets that offers solution in terms of reduced complexity and higher energy efficiency. However, there exist a threshold limit in transmitting the packets in repeated manner and with insufficient radio resources, it may prone to serious degradation to the communication. In such cases, multi-carrier formulation is handled and it may have negative impacts on the carrier services as that uses additional carriers in LTE system.

Conventional IoT devices tends to transmit only a smaller number of data packets. With transmission schemes, it is easy to handle the radio resources as the data packets are small in number. With increasing number of devices, the control plane offers a better allocation of resources but at the cost of increased signalling overhead while setting up the radio resource control. The increased devices and message repetitions further affects the signalling overhead and this causes high level interruption in uplink radio resources in NB-IoT.

Further, it is found challenging for the IoT devices to stay in idle mode as it affects the data transmission after the reception of response message. Such challenge arises due to the failure in reporting the size of data and an identity prior setting up the NB-IoT connection. A preamble without the data size is unsure of the number of radio resources to be allocated post the reception of data packets. Since there is no unique identifier for devices in an idle state, congestion is found impossible when massive number of IoT devices broadcast a packet to the same radio resources.

Deployment Complexity:

The devices present in NB-IoT technology is easily deployable in LTEs and it also allows the operates to choose the network based on the availability. However, the physical resource blocks lie only within the spectral range of LTE rather than operating at its own frequency and this causes an interference between the resource blocks.

Coverage Issues:

NB-IoT communication offers improved coverage in deeper areas than the existing LTE communication.The physical configuration of NB-IoT and deployment offers reduced coverage and other issues includes operating in poor topographical regions, device interoperability and network design, which poses serious coverage problem.

Network Capability:

There exists a massive increment in the number of devices during deployment and this causes poor management of resources, thereby leading to increased energy consumption and reduced network life. Thus, the technology fails to endure an exponential growth of devices and that may increase the cost of deployment.

Lifetime:

This technology offers a higher lifespan of the battery utilized in the devices. However, with varying topographical condition, this may vary and cases deterioration of power. This is due to higher consumption of energy by the transmitting devices in low connectivity areas, as message repetition causes a major part.

6. Conclusions

In this paper, various energy efficient models and their applicability on NB-IoT is discussed. Most of the conventional techniques fails in deployment with existing technologies as the spectral range gets limited. The manufacturers hence should take proper concern on easier deployment of the NB-IoT devices with conventional communication devices. The other concerns relating to the energy-efficiency involves optimising of the field performance in poor network coverage area. Solutions are required in case of improving the increased data size when accustoming the preamble for uplink data transmission.

7. Future work

In future, the operators should ensure that the modules and devices should be deployable and energy efficient as it should overcome various challenges like 1) poor network coverage, 2) poor battery life in un authorized environment or noisy paths, 3) poor compatibility, 4) multi-mode deployment and 5) various use case applications. Also, the future networks should concern more on massive data traffic caused by IoT devices and increased range of coverage in such a manner that the network should be energy-efficient one. Finally, an on-chip energy efficient model should be incorporated on various other applications and that should be validated theoretically in terms of highly an energy-efficient one.

References

[1] Lombardo, A., Parrino, S., Peruzzi, G., &Pozzebon, A. (2021). LoRaWAN Versus NB-IoT: Transmission Performance Analysis Within Critical Environments. *IEEE Internet of Things Journal*, *9*(2), 1068-1081.

[2] Mekki, K., Bajic, E., Chaxel, F., & Meyer, F. (2019). A comparative study of LPWAN technologies for large-scale IoT deployment. *ICT express*, *5*(1), 1-7.

[3] Ikpehai, A., Adebisi, B., Rabie, K. M., Anoh, K., Ande, R. E., Hammoudeh, M., ... &Mbanaso, U. M. (2018). Low-power wide area network technologies for Internet-of-Things: A comparative review. *IEEE Internet of Things Journal*, *6*(2), 2225-2240.

[4] Mutescu, P. M., Petrariu, A. I., &Lavric, A. (2021, March). Wireless communications for IoT: Energy efficiency survey. In *2021 12th International Symposium on Advanced Topics in Electrical Engineering (ATEE)* (pp. 1-4). IEEE.

[5] Andres-Maldonado, P., Ameigeiras, P., Prados-Garzon, J., Navarro-Ortiz, J., & Lopez-Soler, J. M. (2019). An analytical performance evaluation framework for nb-iot. *IEEE Internet of Things Journal*, *6*(4), 7232-7240.

[6] Azari, A., Stefanović, Č., Popovski, P., &Cavdar, C. (2019). On the latency-energy performance of NB-IoT systems in providing wide-area IoT connectivity. *IEEE Transactions on Green Communications and Networking*, *4*(1), 57-68.

[7] Michelinakis, F., Al-Selwi, A. S., Capuzzo, M., Zanella, A., Mahmood, K., &Elmokashfi, A. (2020). Dissecting energy consumption of nb-iot devices empirically. *IEEE Internet of Things Journal*, *8*(2), 1224-1242.

[8] Migabo, E., Djouani, K., &Kurien, A. (2021, September). Energy Efficient Data Rate Enhancement Channel Coding Technique for Narrowband Internet of Things (NB-IoT). In *2021 IEEE AFRICON* (pp. 1-6). IEEE.

[9] Liu, Y., Deng, Y., Elkashlan, M., Nallanathan, A., Yuan, J., & Mallik, R. K. (2020). RACH in self-powered NB-IoT networks: Energy availability and performance evaluation. *IEEE Transactions on Communications*, *69*(3), 1750-1764.

[10] Di Lecce, D., Grassi, A., Piro, G., &Boggia, G. (2018, September). Boosting energy efficiency of NB-IoT cellular networks through cooperative relaying. In *2018 IEEE 29th annual international symposium on personal, indoor and mobile radio communications (PIMRC)* (pp. 1-5). IEEE.

[11] Azari, A., Miao, G., Stefanovic, C., &Popovski, P. (2018, December). Latency-energy tradeoff based on channel scheduling and repetitions in NB-IoT systems. In *2018 IEEE Global Communications Conference (GLOBECOM)* (pp. 1-7). IEEE.

[12] Yassine, F., El Helou, M., Lahoud, S., &Bazzi, O. (2021, December). Performance of Narrowband IoT Link Adaptation with Rate and Energy Objectives. In *2021 IEEE 3rd International Multidisciplinary Conference on Engineering Technology (IMCET)* (pp. 6-10). IEEE.
[13] Yang, D., Huang, X., Huang, J., Chang, X., Xing, G., & Yang, Y. (2021). A first look at energy consumption of NB-IoT in the wild: Tools and large-scale measurement. *IEEE/ACM Transactions on Networking*, *29*(6), 2616-2631.
[14] Guo, Y., & Xiang, M. (2019, December). Multi-agent reinforcement learning based energy efficiency optimization in NB-IoT networks. In *2019 IEEE Globecom Workshops (GC Wkshps)* (pp. 1-6). IEEE.
[15] Yassine, F., El Helou, M., Bazzi, O., &Lahoud, S. (2021, June). Investigation on Narrowband IoT Link Adaptation with Rate and Energy Objectives. In *2021 International Wireless Communications and Mobile Computing (IWCMC)* (pp. 412-417). IEEE.
[16] Khan, S. M. Z., Alam, M. M., Le Moullec, Y., Kuusik, A., Pärand, S., &Verikoukis, C. (2021). An Empirical Modeling for the Baseline Energy Consumption of an NB-IoT Radio Transceiver. *IEEE Internet of Things Journal*, *8*(19), 14756-14772.
[17] Khan, S. Z., Le Moullec, Y., &Alam, M. M. (2021). An NB-IoT-Based Edge-of-Things Framework for Energy-Efficient Image Transfer. *Sensors*, *21*(17), 5929.
[18] Nair, V., Litjens, R., & Zhang, H. (2019). Optimisation of NB-IoT deployment for smart energy distribution networks. *Eurasip journal on wireless communications and networking*, *2019*(1), 1-15.
[19] Michelinakis, F., Al-Selwi, A. S., Capuzzo, M., Zanella, A., Mahmood, K., &Elmokashfi, A. (2020). Dissecting energy consumption of nb-iot devices empirically. *IEEE Internet of Things Journal*, *8*(2), 1224-1242.
[20] Liang, J. M., Wu, K. R., Chen, J. J., Liu, P. Y., & Tseng, Y. C. (2018). Energy-efficient uplink resource units scheduling for ultra-reliable communications in NB-IoT networks. *Wireless communications and mobile computing*, *2018*.
[21] Xu, S., Liu, Y., & Zhang, W. (2018). Grouping-based discontinuous reception for massive narrowband Internet of Things systems. *IEEE Internet of Things Journal*, *5*(3), 1561-1571.
[22] Andres-Maldonado, P., Lauridsen, M., Ameigeiras, P., & Lopez-Soler, J. M. (2019). Analytical modeling and experimental validation of NB-IoT device energy consumption. *IEEE Internet of Things Journal*, *6*(3), 5691-5701.
[23] Andres-Maldonado, P., Ameigeiras, P., Prados-Garzon, J., Navarro-Ortiz, J., & Lopez-Soler, J. M. (2017). Narrowband IoT data transmission procedures for massive machine-type communications. *Ieee Network*, *31*(6), 8-15.
[24] Azari, A., Miao, G., Stefanovic, C., &Popovski, P. (2018, December). Latency-energy tradeoff based on channel scheduling and repetitions in NB-IoT systems. In *2018 IEEE Global Communications Conference (GLOBECOM)* (pp. 1-7). IEEE.
[25] Bello, H., Jian, X., Wei, Y., & Chen, M. (2018). Energy-delay evaluation and optimization for NB-IoT PSM with periodic uplink reporting. *IEEE Access*, *7*, 3074-3081.
[26] Ballerini, M., Polonelli, T., Brunelli, D., Magno, M., &Benini, L. (2019, July). Experimental evaluation on NB-IoT and LoRaWAN for industrial and IoT applications. In *2019 IEEE 17th International Conference on Industrial Informatics (INDIN)* (Vol. 1, pp. 1729-1732). IEEE.