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NAVIGATING THE IOT LANDSCAPE: A COMPARATIVE STUDY OF LORAWAN AND NB-IOT

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Abstract— Low-power wide-area networks (LPWANs) have become a critical enabler of Internet of Things (IoT) connectivity. Smart cities, smart agriculture, intelligent logistics, and transportation all demand communication systems with large transmission ranges and high energy efficiency. Recent and future trends make the long-range wide-area network (LoRaWAN) and narrowband-IoT (NB-IoT) the most promising drivers of the IoT industry.

In this article, after discussing the main features of the two technologies, we conduct a fair quantitative comparison of the two, investigating various performance indicators, to help designers choose the most appropriate techno logy based on application requirements.

Index Terms: Accuracy assessment, city coverage, cross-validation, deployment planning, LoRaWAN, low-power wide-area networks, Narrowband IoT, propagation models, Sigfox.

I.INTRODUCTION:

Over the course of the past years the possibilities to the Web of Things (IoT) market have been filling in amount as well as in number of utilizations [1, 2]. Because of the interest forced by this market, new remote advancements are arising to empower power effective remote correspondence over extremely significant distances [3]. Such lengthy reach remote advancements conveyed for the IoT use can be partitioned into two primary classes:

Cell and Low-Power Wide-Region Organizations (LPWAN). The cell organizations, which have been up to this point addressed predominantly by Broad Parcel Radio Help (GPRS), have right now the Narrowband (NB)- IoT as its leader innovation [4, 5]. Normalized by 3GPP (third Era Organization Venture), NB-IoT targets supporting countless lowthroughput gadgets, with minimal expense and further developed power proficiency [6]. With respect to, the long reach (LoRa) innovation is absolutely one of the vitally agent advances in this classification [7]. It utilizes an exclusive spread range balance conspire that empowers the sign to arrive at significant distances, while communicating with low information rate and low power [8], and normally depending on the LoRaWAN engineering to characterize the higher layers. An inclusion examination for NB-IoT is tended to in [9], where reproduction results show that enhancements for Most extreme Coupling Misfortune (MCL) in the request for 20 dB can be accomplished over customary Long haul Development (LTE) innovation. In [10], the creators examine issues connected with the sending of NB-IoT just in a subset of base stations (BSs), for instance the overhaul of only some BSs with NBIoT inside a district: this game plan can areas of strength for cause channel obstruction from the non NB-IoT cells. As displayed in [10], this issue can be tried not to by hop the Actual Asset Block (PRB) utilized by LTEjust BSs, i.e., BSs without NB-IoT arrangement ought to leave the PRB bound for NB-IoT unused. The inclusion of LoRa is concentrated in [11], where an exclusive programming was utilized to gauge the LoRa inclusion for two urban communities in Argentina, whose outcome is upheld by real estimations. . In [12], Hoeller et al. proposed a hypothetical model to infer inclusion likelihood which incorporates both inner impedance, because of blemished Spreading Component (SF) symmetry, and cross-innovation obstruction. A more itemized and more extensive inclusion examination is introduced in [13], where LoRa, Sigfox [14], GPRS, and NB-IoT advances are looked at in a locale of northern Denmark. The motivation behind the creators was to assess the exhibition of these innovations for open air and indoor-found gadgets, taking into account reasonable country and metropolitan conditions. Besides, to get morerealistic results, a Computerized Height Model (DEM) of the climate, alongside the data of regions with legitimate family numbers, was considered. It was shown that NB-IoT gives better inclusion among all the previously mentioned advances, for both rustic and metropolitan situations. An examination acted in [15], expanding the work done in [13], showed that in any event, while considering the likelihood of crashes and obstructing, NB-IoT beats different advancements. A comparative report including inclusion and limit with regards to provincial regions was created in [16], in which the creators look at two Client Hardware (UE) classes proposed by 3GPP: NB-IoT and LTE-M. The outcomes showed that notwithstanding NB-IoT giving better inclusion, LTE-M backings more gadgets because of its lower above and bigger transfer speed. In this paper, we look at LoRa1 and NB-IoT as far as inclusion in two different reasonable situations of southern Brazil, enveloping a general area of 8182.6 km2. Uniquely in contrast to [13], our examination envelops all the considered region while assessing a given innovation inclusion, and not just the bits of the chose locale with a family number, i.e., with legitimate addresses. Thusly, our investigation is centered around open air situations, while indoor correspondence has been considered by [13]. The point is to analyze different BS densities for the two proposed advances, as well as to assess the impacts of NB-IoT working at independent mode under two groups, specifically 850 and 1900 MHz, that are right now accessible toGPRS innovation in the locales considered [17]. In our examination, we take on the 3GPP way misfortune model [18], which can represent both rustic and metropolitan situations.

II.LITERATURE SURVEY:

The two advances were analyzed in various settings and with respect to various kinds of exhibitions: according to the perspective of bundle conveyance, [1] states that NB-IoT is more vigorous than LoRaWAN; essentially, for what concerns inclusion inside profound indoor destinations, NB-IoT actually shows a preferred way of behaving over LoRaWAN [2]. Paradoxically, in [3] LoRaWAN was picked rather than NB-IoT for either resources natural checking and modern offices interconnections. Moreover, LoRa and NB-IoT were analyzed through reenactments considering underground transmissions as testing arrangement in [4] where NB-IoT hypothetically demonstrated to accomplish improved results than the ones of LoRa. Then again, [5] does a correlation by setting up a sensor hub which is fit for communicating taking advantage of both LoRaWAN and NB-IoT, consequently understanding a model which is like the one introduced in this paper, figuring out that NB-IoT is moderately power hungrier than LoRaWAN. Nonetheless, NB-IoT enjoys different benefits as for LoRa, as [6] brings up: NB-IoT offers benefits concerning Nature of Administration (QoS), inactivity, dependability and reach; in the mean time, LoRa is better regarding battery lifetime, limit, and cost. These elements holes are likewise underlined in [7] where versatility, low dormancy, payload length and QoS are featured as NB-IoT experts, conversely, with the ones of LoRaWAN as lengthy battery lifetime, significant expense productivity and straightforwardness in arrangement. Such innovations were analyzed inside modern applications [8] as well: according to an energy utilization perspective, LoRaWAN outflanks NBIoT even in these settings; be that as it may, NBIoT offers the opportunity to send parcels having longer payload in this manner being an answer in cases in. An inclusion examination in a genuine situation has been done in [9], where NB-IoT is displayed to outflank LoRaWAN, because of directional radio wires, hence giving a superior inclusion to EDs. The proliferation models and the inclusion have been researched in [10], in light of the information of a broad observational far reaching estimation crusade. Notwithstanding a conversation on the capacity of every innovation to help connections of many kilometers, this article gives a few understanding into the qualities of business framework organizations by NB-IoT and LoRaWAN administrators. The relative field preliminaries estimating the presentation of LoRaWAN and NB-IoT in a few engendering testing situations are accounted for by Lombardo et al. [11].

III.PROPOSED METHOD:

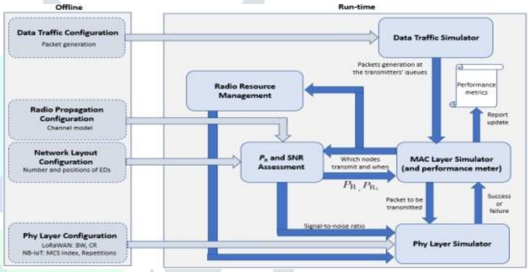


Fig1.Block scheme of each of the two (LoRaWAN and NB-IoT) simulators.

A.Network Layout and Data Traffic Configuration:

We consider a collection N of EDs with size N = |N| that are randomly and uniformly distributed in a circular area of radius R [km]. The single LoRaWAN GW and the NB-IoT eNB share the same location in the centre of the area. We suppose that EDs generate a frame with a payload of B [bytes] at regular intervals T [s]. All of these characteristics are customisable, and the identical scenario is loaded into both the LoRaWAN and NB-IoT simulators.

B.Radio Propagation Configuration:

The well known Okumura-Hata model [37] is adopted in the simulators of both technologies to take into account the attenuation introduced by the propagation. We address both a urban as well as a rural scenario

$$\begin{aligned}L_{\text{urban}} &= 69.55 + 26.16 \log_{10}(f) - 13.82 \log_{10}(h_b) \\ &\quad - 3.2\left(\log_{10}(11.75)\right)^2 - 4.97 \\ &\quad + \left(44.9 - 6.55 \log_{10}(h_b)\right) \cdot \log_{10}(d) + s \\ L_{\text{rural}} &= 69.55 + 26.16 \log_{10}(f) - 13.82 \log_{10}(h_b) \\ &\quad - 0.8 - \left(1.1 \log_{10}(f) - 0.7\right)h_m + 1.56 \log_{10}(f) \\ &\quad + \left(44.9 - 6.55 \log_{10}(h_b)\right) \cdot \log_{10}(d) \\ &\quad - 4.78\left(\log_{10}(f)\right)^2 + 18.33 \log_{10}(f) - 40.94 + s\end{aligned}$$

We consider a collection N of EDs with size N = |N| that are randomly and uniformly distributed in a circular area of radius R [km]. The single LoRaWAN GW and the NB-IoT eNB share the same site in the heart of the area. We suppose that EDs generate a frame with a payload of B [bytes] at regular intervals T [s]. All of these characteristics are customizable, and the identical scenario is loaded into both the LoRaWAN and NB-IoT simulators.

TABLE III :LORAWAN PARAMETERS

f	868 [MHz]	BW	125 [kHz]
H	1	L_{preamble}	8
DC	1%	CR	1

C.Physical Layer Simulations :

For a given place of an IoT hub (either ED or UE) in the considered situation, the sign tocommotion proportion (SNR) experienced in the connection is surveyed, in light of the spread model and the recipient qualities (e.g., clamor figure). Then, given the transmitter design (e.g., BW, SF, and CR for LoRa and BW, _f , and MCS for NB-IoT) the sign debased by the commotion is produced (either LoRa or NB-IoT) and passed to the relating recipient, which evaluates on the off chance that the sent edge has been accurately gotten. All the more exactly, it is as per the following.

1) LoRa: The LoRa test system recreates the tasks completed by the transmitter (channel coding, interleaving, dark coding, and adjustment), the expansion of added substance white Gaussian commotion (AWGN) in the channel and the collector conduct (demodulation, deinterleaving, and disentangling). In this manner, given the casing of information pieces to be communicated, the test system evaluates regardless of whether the at present sent outline has been accurately gotten by various boundaries, like SF, CR, and BW, and the SNR that describes a given connection. 2) NB-IoT: For NB-IoT, the achievement/disappointment of NPUSCH transmissions is surveyed through a NBIoT PHY layer test system, which depends on the LTE Tool stash [38] given by MATLAB. Specifically, for each casing to be communicated, the comparing baseband waveform of the SC-FDMA adjusted signal is produced by the test system and went through the uproarious AWGN channel. At the collector side, the test system performs SC-FDMA demodulation and deciphering lastly evaluates on the off chance that the edge has been accurately gotten or not. In the event of crash (i.e., covering of various transmissions in recurrence and time), the catch impact for the two advances is additionally considered. In particular, the collector has still an opportunity to catch the edge, gave that the signalto-impedance proportion (SIR) is over a given innovation explicit limit

$$\frac{P_R}{\sum_i P_{R_i}} \geq \gamma$$

where γ is the threshold, PRi is the power the GW/eNB is receiving from the ith interfering node, and PR is the received power of the intended signal. To be more exact, it looks like this.

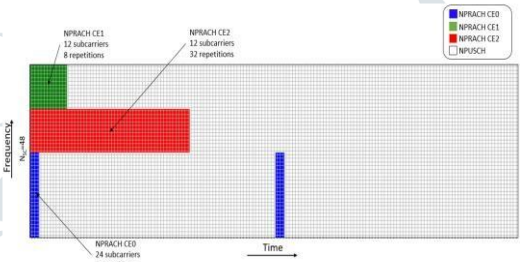


Fig.2.NB-IoT uplink resources structure.

1) **LoRa**: Because ALOHA-based channel access is used for LoRa, we take into account the possibility that two LoRa frames (delivered in uplink or downlink) may collide even when their frames do not completely overlap. Furthermore, because our simulator is built with SF quasiorthogonality in mind, collisions between EDs that use different SFs are possible, and a frame still has a possibility of being received correctly if the SIR is higher than a predetermined threshold that is dependent on the SFs taken into consideration [18].

2) **NB-IoT**: Since each UE has its own NPUSCH resources for uplink data, collisions for NB-IoT may only occur during the RA procedure. When sending Msg3, two or more UEs selecting the same NPRACH preamble will clash, as explained in. But if a UE's SIR is high enough during MSG3 transmission—which the simulator has adjusted to be—it can still finish its process and receive MSG4. $\gamma = -4.6$ dB.

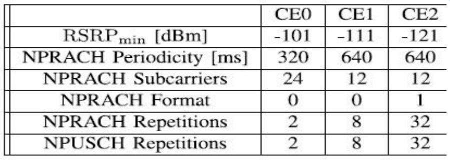
D. Protocol-Specific Parameters and Operations:

1) ***LoRaWAN:*** We consider EDs already joined to the network using one of the two activation procedures supported by LoRaWAN. Therefore, each ED generates a data frame to be sent in uplink periodically every *T* seconds. The DC limitations are implemented according to LoRaWAN specification version 1.0.1, which imposes that a device (i.e., ED or GW),, must not use the same.

for the upcoming ToA([1/DC]−1) seconds in that frequency band. An ED may choose to utilize a particular SF or the one that comes from the ADR algorithm (if not specified differently, we assume EDs utilizing ADR in the results reported). Following the selection of an SF, we determine the associated performance metrics and verify that a transmitted frame was appropriately received in accordance with the process outlined in Section IV-C. Table III provides a summary of the important LoRaWAN parameters we used in our simulations.

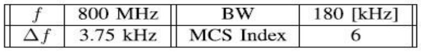
2) NB-IoT: In our test system, we consider UEs previously synchronized to the organization, so every UE begins by deciding a CE level as per the deliberate RSRP and its arrangement of tasks starts from the RA methodology. Every ED is arranged by the CE level to which it has a place (the configurationsused in the test system are accounted for in Table IV and Fig. 3) by contrasting its RSRP and the RSRPmin in Table IV. We likewise expect convenient criticism from the eNB to the UEs during the RACH methodology, in the event of Msg2 and Msg4 transmissions, as uplink transmissions can be more difficult than the downlink ones [39]. Thusly, in the test system, we expect that the time spans between the finish of such messages, as the need might have arisen to send them (see Segment V-A)are fixed, as thought to be in [40] and [41]. When the CE level is chosen, the UE sends the irregular NPRACH preface at the primary NPRACH event and theRA methodology is done , by checking assuming each and every message is accurately gotten. On the off chance that not, the strategy falls flat and the UE should begin all along. Each time the RRC association is arrangement accurately, an ED.

TABLE IV
NB-IoT COVERAGE PARAMETERS [32]



	CE0	CE1	CE2
RSRP_{min} [dBm]	-101	-111	-121
NPRACH Periodicity [ms]	320	640	640
NPRACH Subcarriers	24	12	12
NPRACH Format	0	0	1
NPRACH Repetitions	2	8	32
NPUSCH Repetitions	2	8	32

TABLE V
NB-IoT PARAMETERS



f	800 MHz	BW	180 [kHz]
Δf	3.75 kHz	MCS Index	6

transmits uplink data following resource assignment during the planned NPUSCH. A UE requests a total resource use equal to NRU · Nrep · τRU (10) for the Transport Block Duration. where Nrep is the number of transmission repetitions determined by the CE level, NRU is the number of RUs required to deliver a frame, which is dependent on the MCS used, and τRU is the length of one RU. In order to allow the network connection to be relinquished and the UE to be unplugged from the eNB, we assume that the UE enters power saving mode (PSM) after providing uplink data and stays there until a new frame is generated.

TABLE VI: SCENARIO PARAMETERS

IV.RESULTS:

The results obtained via simulation are based on the configurations reported in Table VII. Each simulation run covers 5 min of simulated time and 10000 iterations of simulation are carried out for each run. The results are presented assuming a urban scenario, if not otherwise specified.

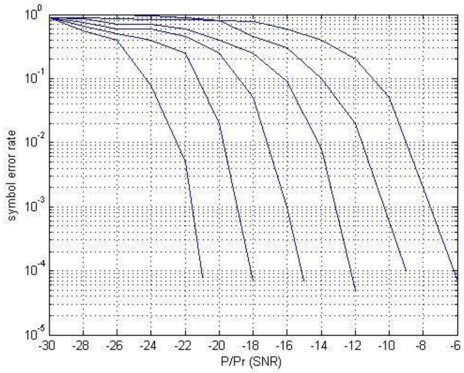


Fig. 3:LoRa symbol error rate. BW = 125KHz

Initially, we verified the LoRa physical layer simulator by contrasting its output with the findings recorded in an AWGN channel, where P stands for signal power and Pn for noise power. Figure 43plots these reference curves using a dashed line style. Using our simulator, the same figures of merit for LoRa signals with BW = 125 kHz have been produced. The resultsant symbol error rates, which are plotted in a solid line style in Figure 4, are evidently coincident with the reference ones for every SF, indicating that the simulator is accurate (more information about the simulation setup and the LoRa performance at the physical layer can be found in [18] and [19]).

N	1,50,100,250,500,750,1000
GW/eNB	1
R	1,3,5,7,9 km
T	10,20,30,40,50,60 s
10,20,25,50,100 bytes B	
h_b	30 m
h_m	1 m
ϵ	3 dB
f	868 MHz for LoRaWAN 800 MHz for NB-IoT

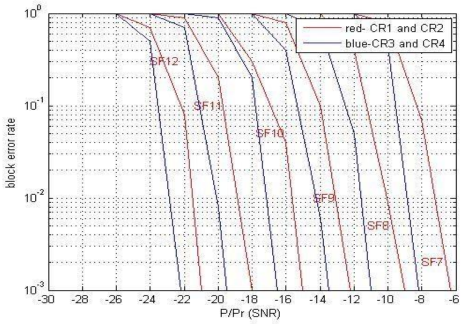


Fig. 4: LoRa BLER. BW = 125 kHz.

Using a block size of B = 20 bytes, the LoRa BLER is depicted in Fig. 4 as a function of the SNR for all SFs and CRs. It is possible to see that switching from CR1 (CR2) to CR3 (CR4) provides for an approximate 1.5 dB increase in SNR for a given SF. It is also noted that, as would be expected, there is no gain by moving from CR1 to CR2 or from CR3 to CR4. In actuality, only one bit in a codeword can be corrected using CR3 and CR4, while CR1 and CR2,donot offer any bit correction capabilities.

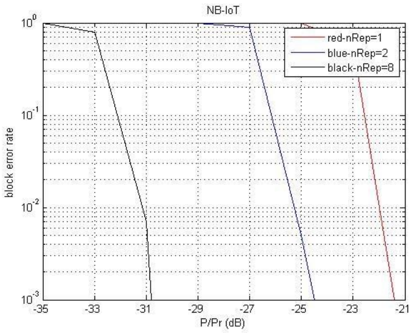


Fig. 5:NB-IoT BLER,MCS=6

Figure 5 displays the NB-IoT NPUSCH BLER for various repeat counts, once more assuming a block size of B = 20 bytes. It is evident that a gain in SNR is obtained by increasing the number of repeats. We may conclude from a comparison of the two technologies that NB-IoT is more noiseresistant. For example, if an application requires a maximum BLER of 10−2, the minimum SNR for LoRaWAN is between −23 and −7 dB (depending on SF and CR) and for NB-IoT is between −31 and −22 dB (depending on the number of repetitions).

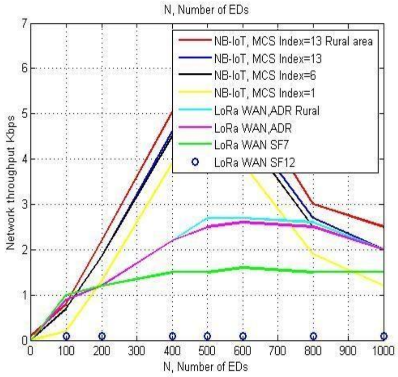


Fig. 6: Network throughput *S* [kbit/s] as a function of the number of EDs in the network *N*, with *R* = 3 km, *B* = 20 bytes, and *T* = 10 s

The network throughput is plotted against the number of EDs in the network in Figure 6. Specifically, for LoRaWAN, we take into account all EDs using SF = 7, SF = 12, or the SF obtained using the ADR method for each of them; in contrast, for NB-IoT, we take into account all EDs using MCS Index = 1, 6 or 13. It is to be expected that for medium traffic, NB-IoT usually always offers superior throughput compared to LoRaWAN, but for very heavy traffic, the two become equal.

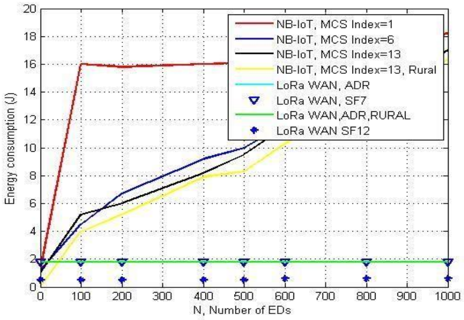
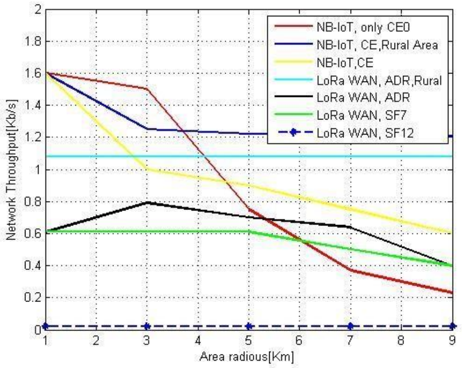


Fig. 7: Energy consumption *E* [J] as a function of the number of EDs in the network *N*, implying *R* = 3 km, *B* = 20 bytes, and *T* = 10 s.

Fig. 7 displays the energy consumption as a function of ED count. It is evident that NB-IoT devices have higher energy consumption, which rises as the number of EDs that are actively connected to the network increases. This occurs as a result of increased competition among EDs for resources, and EDs that are unsuccessful attempt again during subsequent NPRACH events.On the other hand, because LoRaWAN is based on ALOHA and a LoRaWAN ED transmits when necessary, its energy consumption is constant regardless of the number of EDs in the network



Experiment

Fig.8: Network throughput *S* [kbit/s] as a function of the area radius *R* [km], with *N* = 100, *B* = 20 bytes, and *T* = 10 s

Figure 8 shows the network throughput as a function of the circular area's radius R, which is where the EDs are dispersed. As previously mentioned, we take into account all EDs for LoRaWAN using SF = 7, SF = 12, or the SF obtained by the ADR algorithm, while we address the option of having only CE0 or all three coverage classes for NB-IoT.It is evident that when NB-IoT is compared to LoRaWAN, it offers better throughput. Availability of several CEs significantly enhances performance, especially as the region grows.

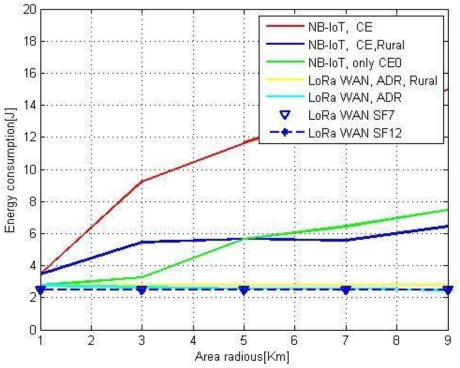


Fig. 9: Energy consumption E [J] as a function of the area radius, R [km], with N = 100, B = 20 bytes, and T = 10 s.

Fig. 9 displays the energy usage as a function of area radius R. LoRaWAN devices use a lot less energy than NB-IoT devices, whose consumption is heavily dependent on the number of transmission repetitions UEs are configured to utilize while delivering their data if they run in CE 1 or 2, especially over wide areas and when employing all three CE classes.

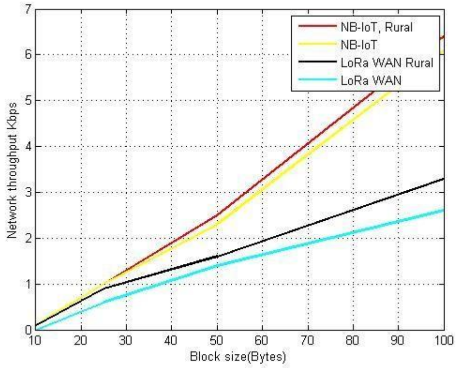


Fig. 10: Network throughput S [kbit/s] as a function of the block size B [bytes], with N = 100, R = 3 km, and T = 10 s.

The network throughput is displayed in Fig. 10 as a function of block size B. While for NB-IoT we address EDs using MCS Index = 6 for both the urban and rural situations, for LoRaWAN we consider all EDs using the ADR algorithm. Generally speaking, throughput increases as block size does. It is also evident that NB-IoT may offer greater throughput in comparison to LoRaWAN in any situation. We draw attention to the fact that different areas' maximum payloads for each SF are defined by the LoRaWAN specifications [21]. To ensure a fair comparison, we address the same dimensions for both LoRaWAN and NB-IoT in this instance.

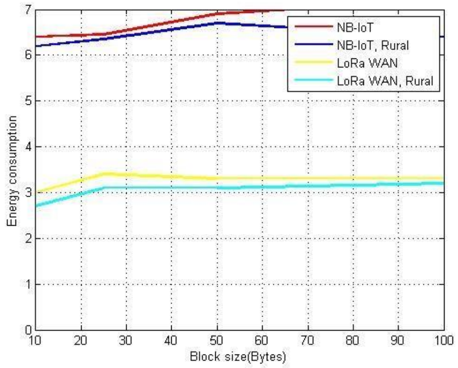


Fig. 11: Energy consumption E [J] as a function of the block size B [bytes], with N = 100, R = 3 km, and T = 10 s.

Figure 11 reports the associated energy usage as a function of block size B. As anticipated, NB-IoT uses more energy than LoRaWAN, but performs somewhat better in rural areas because of improved link quality and fewer packet losses. In any event,

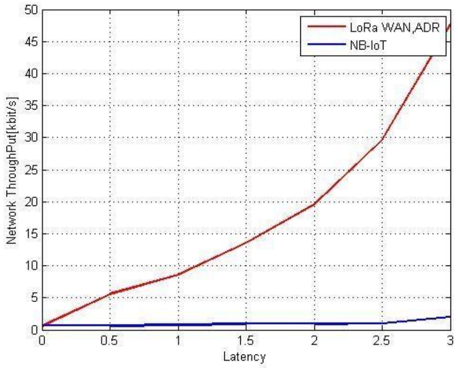


Fig. 12: Latency L [s] as a function of the network throughput S [kbit/s], with R = 3 km, B = 20 bytes, and T = 10 s.

Lastly, the latency as a function of the network throughput S is displayed in Fig. 12. The high number of collisions caused by the number of EDs sending results in LoRaWAN's enormous delay for increased throughput; as a result, when a frame is lost, the network should wait for the subsequent transmission attempt, which occurs T seconds later. NB-IoT, on the other hand, allows for a retry at the subsequent NPRACH instance in the event that the RA procedure is unsuccessful owing to collisions, without having to wait for the subsequent frame generation.

V.CONCLUSION:

accounting for technical aspects, both at PHY and Link layers, and regulatory issues. In conclusion, the two technologies differ in many aspects and both have strengths and weaknesses. Depending on the specific application, the best solution can be identified based on the above reported discussion and numerical results. To summarize, NB-IoT implements a more robust modulation and coding scheme, together with a highly reliable link layer, at the cost of a larger energy consumption. Therefore, NB-IoT is more suitable for applications that are demanding in terms of reliability and network throughput. In addition, it is not limited by any regulation in terms of DC, thus devices can transmit more frequently or bigger data volumes. On the other hand, LoRaWAN is convenient for applications having strict requirements in terms of lifetime (i.e., for battery-constrained use cases) and where the reliability requirements can be relaxed. At the very same time, our results show that the network configurations (e.g., ADR support for LoRaWAN, or the CE level support and RACH configurations for NB-IoT) affect the performance of the considered technologies quite significantly. Notably, as we have shown in this study, subject to some configurations and scenarios, either of the considered technology may outperform its counterpart. It is important to keep this in mind when considering the communication technology to be used for the particular use case scenario. Also, this motivates the further more in-depth study of the effects the different network parameters have on the technology performance as well as the development of relevant optimizations mechanisms. Unfortunately, this aspect (especially for NB-IoT technology) has got somewhat limited attention so far.

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