eMTC vs. NB-IoT: An Empirical Comparison of Uplink Performance

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***Abstract*—The widespread adoption of the Internet of Things (IoT) has stimulated the development of numerous networking solutions. However, selecting the best communication protocol may be challenging for developers and integrators. This work compares eMTC (LTE-CatM1) and NB-IoT (LTE-CatNB1), two cellular IoT technologies for low-power and long-range communication. The selected key performance indicators for the comparison are end-to-end latency, packet loss and energy consumption. The metrics are evaluated in different scenarios, characterized by degrading received signal strength (-73 dBm, -93 dBm, and -113 dBM), as well as at different times of the day (busy-hour or off-peak) to take into account the impact of legacy LTE traffic on such technologies. Results show that eMTC demonstrates superior latency performance, while NB-IoT exhibits admirable energy efficiency and coverage enhancement. Both technologies are affected by RSSI degradation, whereas existing LTE traffic affects only the NB-IoT standard. These findings are crucial for integrators aiming to develop Cellular IoT-based solutions, highlighting the significantly different performances and characteristics of eMTC and NB-IoT, despite their underlying similarity.**

***Index Terms*—eMTC, LTE-CatM1, NB-IoT, LTE-CatNB1, LPWAN, IoT**

I. INTRODUCTION

The Internet of Things (IoT) has evolved into an essential framework bonded with human society and deployed across multiple scenarios. IoT aims to interconnect various devices and systems, enabling them to communicate, share data, and operate seamlessly without human intervention. In most cases, ”things” are small devices of low cost and complexity with the main goal of collecting data and transmitting it to centralized platforms or other end devices. Some IoT use cases (e.g. supply chain, transportation, agriculture, and smart cities) require long-range and low data rate communication, low energy consumption, massive deployment, and cost-effectiveness. These requirements can’t be fulfilled using only short-range radio technologies (e.g. Wi-Fi, Bluetooth and IEEE 802.15.4); therefore, Low Power Wide Area Networks (LPWAN) solutions were specifically designed to satisfy the needs of applications that need to transmit small amounts of infrequent data over long distances while preserving battery life. Among LPWANs, the 3rd Generation Partnership Project (3GPP) defined the Narrowband IoT (NB-IoT) and enhanced Machine Type Communication (eMTC), two narrow-band standards based on Long-Term Evolution (LTE). They represent a sub-category of LPWAN, namely Cellular Internet of Things (CIoT). Built upon the existing framework of conventional cellular networks, such CIoT technologies are augmented by specific features, focusing on achieving ultra-low complexity and low throughput capabilities.While NB-IoT and eMTC appear similar at a first glance, a more in-depth analysis reveals that these technologies have been designed to satisfy diverse application requirements, thus offering unique advantages and adapted capabilities to meet the diverse needs of various applications and users. This work provides a detailed analysis of NB-IoT and eMTC by closely examining their technical attributes, aiming to provide insights into the strengths and weaknesses of each standard by performing a comparative assessment between the performance of the two. The assessment focuses on fundamental Key Performance Indicators (KPIs) such as latency, packet loss and energy consumption. These KPIs have been extracted by performing practical measurements based on an experimental testbed, which has been developed to reduce test setup variability to the bare minimum in order to ensure accurate and comparable results among measurements. The differences found between the two technologies are presented and compared with the theoretical background. By addressing these objectives, this research aims to provide valuable insights for IoT stakeholders, including network operators, device manufacturers, and application developers, helping them make informed decisions when selecting LPWAN technologies for their specific use cases. The remainder of this paper is structured as follows: Section II present the related works, Section III provides a theoretical background of the two CIoT standard, Section IV describes the experimental setup and environmental conditions. Section V is dedicated to presenting and interpreting the results derived from the performed measurements, and finally, in Section VI, a summary of the findings and possible future work are presented.

II. RELATED WORKS

Several researchers have conducted comparative studies evaluating NB-IoT and eMTC technologies. These studies can be categorized in two groups: those based on theory and simulations and those based on field-test measurements.

In the former group, Soussi et al. [1] compare eMTC and NB-IoT for the smart city scenario, analyzing latency, energy consumption and scalability. Their results are based on theoretical models and simulation with NS-3, showing that in average coverage conditions and when dealing with larger data packets, eMTC tends to have a longer battery life. In poor coverage scenarios and with small data rates, the battery life of NB-IoT proves to be more enduring. Hassan [2] employs theoretical analysis and link-level simulations for both NB-IoT and eMTC. The evaluation focuses on five key requirements: coverage, throughput, latency, battery life, and connection density. The findings indicate that NB-IoT excels in extremely low coverage scenarios and has a 30% higher connection density, whereas eMTC demonstrates superior uplink throughput, lower latency and better battery life.

For what concerns field-test works, Vomhoff et al. [3] evaluate the energy consumption of end devices using NB-IoT and eMTC technologies. The authors delve into understanding the suitability of each technology for different use cases, with specific attention to the application protocols Message Queuing Telemetry Transport (MQTT) and Hypertext Transfer Protocol (HTTP). Nevertheless, the analysis specifically concentrates on application layer protocols based on TCP, with no evaluation conducted on UDP-based protocols. Segura et al. [4] focused on NB-IoT only, investigating its latency and explaining the impact of the improvements that came with new 3GPP Releases, like the Early Data Transmission (EDT) in Release 15. While many works use diverse development boards to assess different technologies, [5] focuses on evaluating the performance of different technologies implemented on the same hardware. However, in their study, they do not compare CIoT technologies among themselves; instead, they compared NB-IoT with LoRaWAN and SigFox.

The presented paper differs from the existing literature by implementing a unified test setup and concentrating solely on UDP uplink-based traffic, which mirrors a typical scenario in IoT sensor nodes. TCP's susceptibility to delays and its handshake and bidirectional connectivity prerequisites make it less suitable for IoT compared to UDP [6] in CIoT technologies. The analysis includes performances at varying RSSI levels and times of the day to leverage the effects of RSSI and interference from legacy LTE traffic.

III. TECHNOLOGIES BACKGROUND

A. NB-IoT

NB-IoT also referred as LTE-CatNB1 is a radio technology standard developed by the 3GPP [7], for IoT solutions. Designed for low complexity and low throughput applications, providing network services via a physical layer optimized for minimal power consumption and cost. The key characteristics of NB-IoT include a full carrier bandwidth of 180 kHz, Frequency Division Duplex (FDD) operation, and the highest modulation scheme being Quadrature Phase Shift Keying (QPSK). The downlink of NB-IoT is based on Orthogonal Frequency-Division Multiple Access (OFDMA) and uses a single physical resource block (PRB), while the uplink is based on Single-Carrier Frequency-Division Multiple Access (SC-FDMA). The minimum duration for the resource units used in scheduling depends on the number of assigned subcarriers and the operation mode. NB-IoT optimizes performance and battery life for IoT devices by utilizing advanced features such as Power Saving Mode (PSM), extended Discontinuous Reception (eDRX), and adaptive modulation and channel coding. The advantage of this technology is its standardization and interoperability with existing cellular infrastructure, making it easy for deployment and providing secure connectivity since it entirely relies on LTE [8].

B. eMTC

The 3GPP introduced eMTC also known as (LTE-CatM1) as part of the LTE-M network in its Release 13 specification. eMTC shares resemblances with NB-IoT and serves as a complementary solution for addressing a wide array of IoT connectivity requirements. Built upon the robust foundation of LTE, eMTC leverages and seamlessly integrates with existing LTE infrastructure, spectral bands, and devices, presenting a synergy that harnesses the strengths of LTE while catering to the unique demands of IoT ecosystems. Positioned as a relatively high data rate service for data-intensive IoT applications, eMTC operates on a bandwidth of 1.08 MHz within an existing LTE deployment or 1.4 MHz in standalone mode. Notably, eMTC incorporates power-saving features such as PSM, eDRX, CIoT control plane, and user plane optimizations, enhancing efficiency in transmitting small data. eMTC also includes Voice over Long-Term Evolution (VoLTE) capabilities, allowing for voice communication over the network. The technology inherits the security and privacy features of 3GPP standards, which include user equipment User Equipment (UE) identity support, data confidentiality, entity authentication and data integrity, making it suitable for applications where higher security is needed, such as smart transportation, critical time-sensitive health services, wearable that monitor vital measurements, etc [9].

IV. TEST SETUP

A. Testbed Setup

This work employed a systematic methodology to evaluate the performance of NB-IoT and eMTC. The evaluation process encompassed an extensive analysis covering latency, power consumption, and packet loss. These evaluations were conducted under different Received Signal Strength Indication (RSSI) levels and at distinct times. The objective was to deeply understand how the presence of low coverage and interference within the legacy LTE network impacts these communication technologies. To ensure a fair assessment, consistent measurements were carried out using a standardized hardware platform, specifically, the P-L496G-CELL02 STM32 Discovery Pack [10] integrated with the Quectel BG96 module. The Quectel BG96 module supports a wide spectrum of frequency bands for global compatibility [11]. It is designed for low power consumption and caters to battery-powered devices and industrial applications, offering resilience against challenging environmental conditions. Moreover, its widespread deployment across industrial and consumer devices makes the obtained results instrumental for integrators and developers

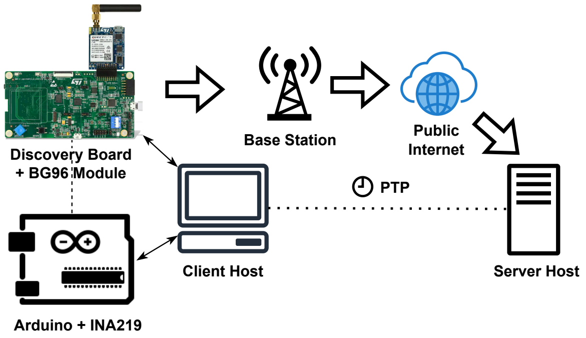

Fig. 1: Testbed Architecture Overview: i) INA219 monitoring the USB power supply of the Discovery Board. ii) Server host receiving messages from the BG96 module through CIoT Network

seeking to make informed decisions regarding the selection of the appropriate communication protocol without being influenced by specific hardware biases.The choice of a standardized hardware platform was pivotal to discern the unique impact of the underlying communication technologies on the evaluation metrics.The testbed architecture and methodology were kept constant for consistency throughout the measurement phase. The study specifically employed a physical SIM card tailored for Long-Term Evolution for Machines (LTE-M) connectivity from one of Italy's biggest internet service providers. Moreover, to induce an attenuation on the RSSI, a 20dB coaxial attenuator was used with a working frequency ranging from 0 to 12 GHz.

The system architecture, illustrated in Figure 1, delineates the interactions among the integrated components within the experimental setup. An INA219 zero-drift, bidirectional current/power monitor developed by Texas Instruments enables power consumption monitoring. It can measure high side voltage and DC current over I2C with 1% precision. It is being used to compute the power consumption of the BG96 board. The INA219 has been configured with an Arduino Uno board, and data is relayed through the serial UART interface with a sampling rate of 70 samples/second. This allowed the client to handle the received data directly during its unit test. The source power supply flows through the INA219 module before powering on the Discovery Board and the BG96 module with a voltage of 4.7 V. A central client manages the communication module and gathers the test data from the power sensor and the timestamp. This component interfaces with the BG96 Discovery board through UART serial communication and actively controls the board through the use of Attention (AT) commands. Additionally, a server with a public IP address, listening for incoming UDP packets, has been configured to allow the BG96 board to send the test packets to a controlled host. This allowed us to acquire statistics from the server side, such as the timestamp of incoming packets from the BG96 module and the packet hit rate, to compute latency and packet loss. The message structure comprises a timestamp and a dummy payload to increase the packet payload. A clock synchronization is performed to overcome the client and the server components being in two separate hosts. Since both the client and the server hosts share the same Local Area Network (LAN), it is possible to perform clock synchronization among the two entities and correct any clock drift using the Precision Time Protocol (PTP) [12]. The PTP, when performed among hosts of the same LAN, can guarantee clock accuracy in the sub-microsecond range, allowing for accurate timestamp measurements.

B. *Test Description*

The performance assessment of eMTC and NB-IoT technologies comprise the following key metrics tailored for IoT use-cases: energy efficiency (where lower consumption equates to reduced costs and carbon footprint), message loss percentage, and message latency (striving for the shortest time in delivering a message to its ultimate destination). The evaluation of the network technology performance entails transmitting raw UDP messages from the device to the server host, carrying a timestamp and some dummy data to control the payload length. The employed test pipeline synthesized in I comprise:

1) **Latency Measurement:** Latency was computed as the difference between the timestamp of packet reception at the server side minus the timestamp of when the packet has been sent from the client side, which, to simplify the computation process, was embedded into the packet payload, allowing for latency computation directly at the server side. Latency measurement tests have been executed according to the following methodology: (i) clock synchronization performed between client and server through PTP, (ii) transmission of packets with different payload lengths (ranging from 10 up to 1000 Bytes) to the server at a constant speed of 1 packet every 5 seconds for 500 seconds, (iii) latency computation at server side. Latency measurements have been performed multiple times on different days to remove possible measurement errors related to interference with legacy LTE traffic and peaks.
2) **Packet Loss:** packet loss has been quantified as the number of messages lost during packet transmission. Packet loss has been computed by comparing the predetermined number of messages sent by the client against the actual number of received packets. Packet loss measurements were performed at a fixed packet transmission rate of 1 packet every 5 seconds and different payload lengths (10,100 and 1000 Bytes). Each test involves sending 100 packets with fixed sizes and constant rates.
3) **Power Consumption:** The power consumption measurements have been performed using the INA219 power monitor sensor and an Arduino Uno. The power consumption tests have been performed by saving the instantaneous power level transmitted by the Arduino board over the UART interface. The power acquisitions throughout the entire operational cycle have been documented,

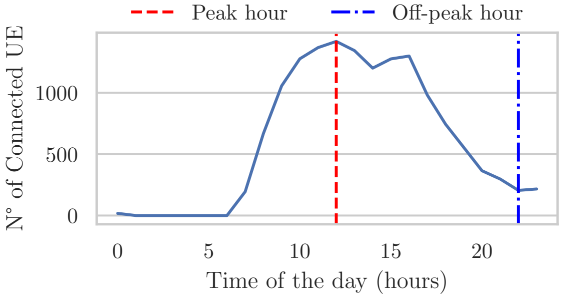

Fig. 2: Average numbers of connected UEs distribution in a working day

encompassing various states, including not connected mode, connection mode, transmission mode, and idle mode. The transmission mode involved sending 20 consecutive packets with a 5 second delay and 100 Bytes payload.

To assess the influence of channel quality on the performance of the two communication protocols, tests have also been performed with attenuation levels of 20 dB and 40 dB. This was achieved by introducing 20 dB coaxial attenuators in series with the antenna and by detaching the antenna from the board. The attenuation was additionally determined empirically by examining the Signal Quality Report provided by the board, which indicates the received Signal Strength level. A preliminary analysis of the base station to which the BG96 board is linked was conducted to characterize the cell occupancy. This analysis identified two distinct periods characterized by varying levels of LTE network traffic and the number of UE connected: peak and off-peak hours. Subsequently, we investigated how interference from the legacy LTE network impacted the two CIoT technologies. Figure 2 illustrates the average distribution of UE connected to the base station over a typical working day. Notably, peak hours span from 11 AM to 4 PM, peaking at 12 PM, while off-peak hours range from 10 PM to 5 AM. This preliminary assessment facilitated examining and characterizing both eMTC and NB-IoT technologies under varying cell occupancy conditions. Therefore, all tests were conducted during both peak and off-peak hours.

V. EXPERIMENTAL RESULTS

A. *End-to-End Latency*

The first experiment analysed the end-to-end latency observed when sending UDP packets with a 100 Bytes payload. In Figure 3, the Euristic Cumulative Distribution Function (ECDF) is presented by comparing both eMTC and NB-IoT in peak and off-peak traffic conditions. The Figure shows that the eMTC protocol, which caters to delay-sensitive use cases, obtained an average latency of 160 ms and is unaffected by the interference with legacy LTE traffic. NB-IoT, which has relaxed latency requirements, exhibits an average latency of 810 ms in off-peak conditions and highly depends on the network cell's usage state. This behaviour is mainly due to eMTC characteristics, which include a larger bandwidth and higher modulations. These results can also be seen in Figure 4, where the latency is presented as the length of the transmitted payload varies from 10 up to 1000 Bytes. It can be seen that packet size has a small impact on eMTC latency while introduces extra delays and uncertainty within NB-IoT. It can also be observed that in NB-IoT the cell occupancy has a big impact on latency as the packet size increases. The LTE interference manifests as a power leakage from LTE Physical Resource Block (PRB)s onto NB-IoT PRBs. This effect is more pronounced in the uplink, where the carrier spacing is 3.75 kHz compared to the 15 kHz downlink carrier spacing [13] [14].

TABLE I: Performance Metrics Analyzed

KPI	**Methodology**	**Free Variables**
End-to-End Latency	Difference between arrival timestamp at server host and sending timestamp encoded inside the UDP packet. PTP clock synchronization performed between client and server	- Packet Size - RSSI - Time of Day - Throughput
Packet Loss	Difference between number of sent and received UDP packets	
Power Consumption	Power measured through INA219 to characterize connection stage, idle state and packet sending power consumption of the BG96 board	

To estimate the impact that different RSSI values have on latency, tests were conducted by sending 100 Bytes packet at different RSSI levels. Figure 5 shows a correlation between RSSI values and latency, attributed to packet retransmissions in deteriorating signal-strength environments. In scenarios where the RSSI reached -113 dBm, eMTC faced challenges in the connection establishment. In contrast, NB-IoT demonstrated resilience by successfully configuring connections, transmitting packets, and receiving them but with notably prolonged latency. The results emphasize the robustness of NB-IoT in adverse signal strength conditions, positioning it as a more reliable communication solution under such challenging circumstances.

B. *Packet Loss*

Table II represents packet loss measurements conducted across different payload sizes (10, 100, and 1000 Bytes) and at various propagation channel conditions (-73 dBm, -93 dBm, and -113 dBm). The analysis reveals that under good propagation channel conditions eMTC demonstrates higher reliability. Notably, when RSSI value is -73 dBm, every packet dispatched through eMTC has been successfully received, unlike the NB-IoT scenario. Furthermore, the impact between peak and off-peak traffic hours can also be noticed in NB-IoT case. Contrary to conventional expectations, a noteworthy finding is the improvement in the number of received packets with larger payload sizes. Downlink Control Information (DCI) influences Narrowband Physical Uplink Shared Channel

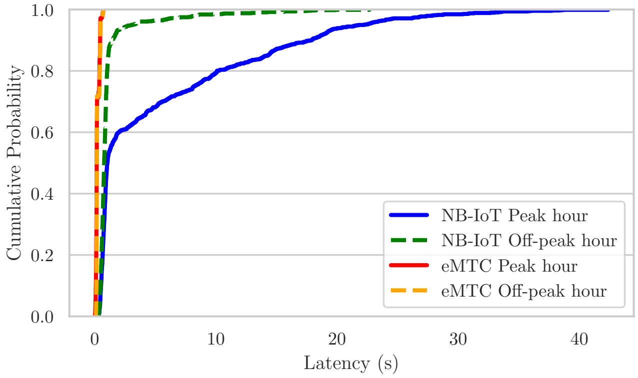

Fig. 3: ECDF of end-to-end latency for NB-IoT and eMTC protocol when sending packets with a payload length of 100 Bytes

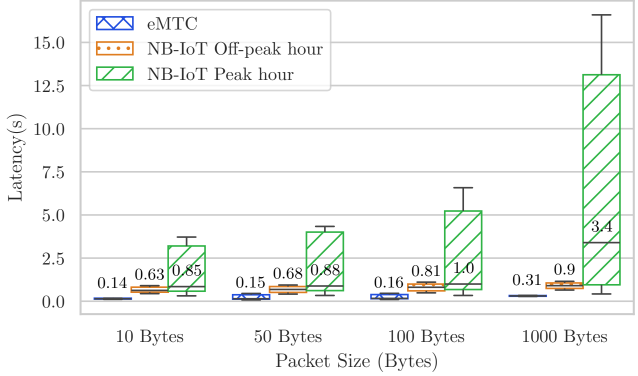

Fig. 4: Boxplot of end-to-end latency varying packet size for NB-IoT and eMTC technologies

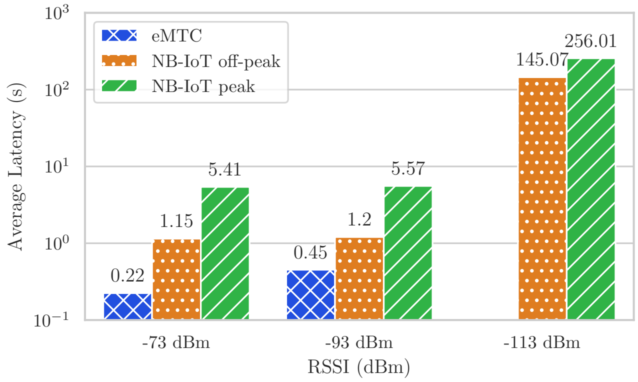

Fig. 5: Average latency of 100 Bytes payload packet transmission at different RSSI levels

TABLE II: Packet Loss Rate (%) for NB-IoT and eMTC under different RSSI values

Packet Size	10 Bytes			100 Bytes			1000 Bytes		
RSSI (dBm)	-73	-93	-113	-73	-93	-113	-73	-93	-113
NB-IoT peak	5.4%	37.3%	40%	2.2%	45.3%	52,3%	1.2%	0%	48%
NB-IoT off-peak	2.3%	39%	40%	0.7%	48%	52%	0.6%	0%	40%
eMTC	0%	40%	-	0%	48.7%	-	0%	0%	-

(NPUSCH) scheduling in NB-IoT and the MTC Physical Downlink Control Channel (MPDCCH) in eMTC, crucial for optimizing uplink communication by determining transmission parameters like modulation and repetition number based on message length and channel conditions. These parameters are dynamically adjusted to ensure efficient and reliable data transfer. Favourable conditions prompt higher modulations to optimize communication, while challenging channels call for lower modulations. Likewise, severe channel conditions necessitate increased repetitions, whereas fewer repetitions suffice in more favourable environments. DCI predefined these parameters, ensuring efficient data transfer. This explains the observed trend of higher packet reception with larger payload sizes. In signal strength conditions of -93 dBm, NB-IoT demonstrates superior effectiveness compared to eMTC, resulting in slightly higher packet reception. This highlights NB-IoT's reliability in demanding scenarios, while eMTC performs better in situations with optimal signal quality but experiences a complete inability to transmit packets at -113 dBm.

C. Power and Energy Consumption

Energy measurements were conducted across different states of the board. These distinct states encompass the not-connected state, connection establishment state, packet-sending state, and idle connected state. In the connection establishment state, the connection to the base station and the opening of a UDP socket is performed, while in the packet-sending state, 20 packets of 100 Bytes with a sending rate of 5 seconds are sent to the server. Figure 6 compares all the transmission states of NB-IoT and eMTC with the board initiate in a non-connected state. Notably, eMTC exhibits a higher overall power consumption across almost all states compared to NB-IoT despite employing the same test-bed hardware. These results attribute inherent features of the technologies, such as eMTC's utilization of higher modulations compared to NB-IoT. In the packet-sending phase eMTC protocol requires, on average, 200mW more than NB-IoT to perform the same transmission task. While when a packet is transmitted, instantaneous power consumption peaks at 1750 mW for both eMTC and NB-IoT, in power gaps (used for network resynchronization) existing among packet transmission, eMTC requires an additional 25 % of power compared to NB-IoT.

By fixing the packet length, an analysis of the Energy required to send one packet of 100 Bytes at different RSSI levels is presented in Figure 7. It can be observed that the

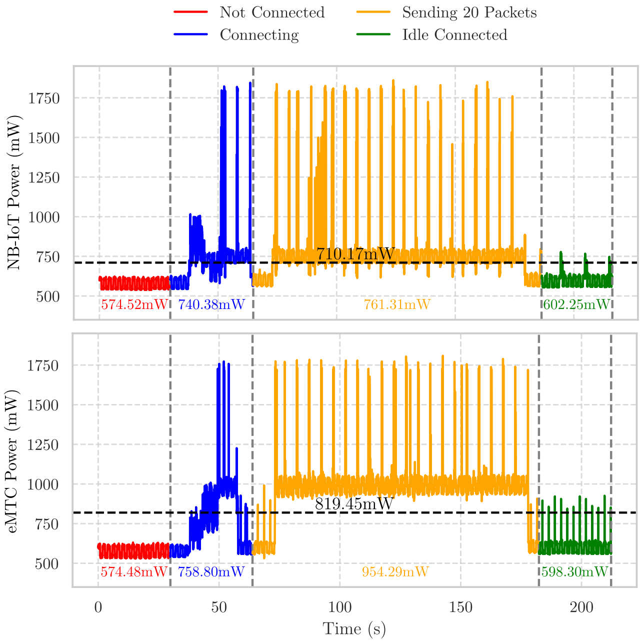

Fig. 6: BG96 Power Consumption of different connection state to send 20 packets of 100 Bytes with NB-IoT in off-peak conditions and eMTC technologies

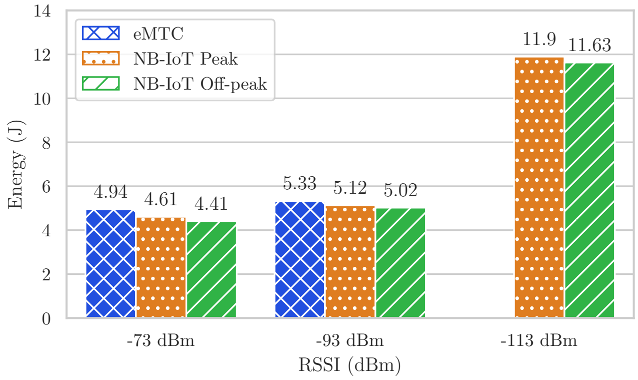

Fig. 7: Energy spent by NB-IoT (peak and off-peak conditions) and eMTC in the sending phase to send one packet of 100 Bytes at different RSSI levels

energy consumption increases with the degradation of the received signal strength. This is mainly due to re-transmissions, which increase the average sending time. Moreover, the eMTC exhibits higher energy utilization compared to NB-IoT during packet transmission in both measured RSSI scenarios. At RSSI level of -113 dBm, the energy expended on transmission doubles the one required in nominal conditions. This significantly highlights the dependency of NB-IoT energy consumption on RSSI conditions, suggesting to perform an on-field assessment of RSSI to avoid doubling the battery drain over time.

VI. CONCLUSIONS

This work provides a general overview of eMTC and NB-IoT technologies by comparing end-to-end latency, packet loss, power and energy consumption when sending uplink UDP-based traffic. eMTC demonstrates superior performance in terms of lower latency, while NB-IoT exhibits admirable energy efficiency. eMTC proves to be more stable, accommodating larger data volumes and supporting mobility, whereas NB-IoT excels in challenging conditions, offering extended coverage. Conversely, eMTC stands out with its support for larger data transfers, lower latency, mobility capabilities, and overall stability. This study also unveils the influence of LTE and other device communications on these technologies, highlighting eMTC's minimal impact, while NB-IoT is noticeably affected by interference.

The scope of this study can be expanded by exploring downlink assessments and integrating mobility adjustments to study the effect of the analyzed technologies on devices that are in motion. While tests in this work primarily utilized UDP, further investigations can incorporate TCP and application layer protocols. Additionally, future research could delve deeper into power-saving features such as PSM and eDRX, enhancing the comparison of power consumption of CIoT technologies.

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