Practical Deployment of a Private NB-IoT Network with Open-Source Platforms

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Abstract

Narrowband Internet of Things (NB-IoT) has emerged as a Low Power Wide Area Network (LPWAN) technology for industrial and enterprise IoT applications, offering licensed spectrum operation with guaranteed Quality of Service (QoS). This work presents a comprehensive, step-by-step guide to deploying a private NB-IoT network using open-source platforms. Existing literature on open-source NB-IoT implementations is reviewed, and candidate platforms, including OpenAirInterface (OAI) and srsRAN, are evaluated against commercial solutions. A suitable open-source NB-IoT prototyping platform is then selected based on its demonstrated compatibility with commercial off-the-shelf (COTS) user equipment and robust support for 3GPP Release 13/14 features. The complete system architecture is detailed, including the eNodeB implementation on USRP B210 software-defined radio hardware and its integration with a lightweight Evolved Packet Core (EPC) optimised for IoT applications. A comprehensive testing methodology is employed to progressively validate the system, from basic signal generation and synchronisation through broadcast channels and random access procedures to end-to-end data connectivity. Experimental results using commercial off-the-shelf equipment demonstrate successful deployment, achieving a measured uplink throughput of 11 kbps, a downlink throughput of 17 kbps, and latency ranging from 300 ms to 15 s, depending on signal conditions. This work provides researchers and practitioners with a fully reproducible framework for establishing cost-effective private NB-IoT networks suitable for industrial automation, smart agriculture, environmental monitoring, and enterprise IoT deployments.

Keywords: NB-IoT, Private Networks, LPWAN

1. Introduction

The IoT revolution has transformed industrial operations, environmental monitoring, and smart city infrastructure. As connected device deployments continue to scale exponentially, the demand for reliable, low-power, wide-area connectivity has driven the development of specialised LPWAN technologies. Among these, NB-IoT stands out as a 3GPP-standardised solution operating in a licensed spectrum, providing a guaranteed quality of service that unlicensed alternatives such as LoRa and Sigfox cannot match. (3GPP, 2016).

For enterprises and industrial operators, private NB-IoT networks provide several significant advantages, including dedicated spectrum allocation, enhanced security through network isolation, customisable coverage optimisation, and reduced dependence on public carrier infrastructure (Rastogi et al., 2020; Xu et al., 2018). These characteristics make NB-IoT particularly suitable for industrial Internet of Things (IoT) deployments that require reliable, low-power, and scalable connectivity. In contrast, traditional cellular network infrastructure is typically built on proprietary, vendor-locked equipment, resulting in limited flexibility and substantial capital expenditure requirements. The emergence of Open RAN architectures and open-source software implementations has expanded access to cellular network deployment by introducing disaggregated and interoperable network components. This shift enables organisations to implement private networks using commercial off-the-shelf hardware and freely available software platforms, thereby reducing vendor dependency while increasing deployment flexibility (Caso et al., 2021; Liu et al., 2021; Nair et al., 2019).

This paper addresses the practical challenge of deploying a private NB-IoT network using open-source platforms. The main contributions include a systematic literature review of prior work on open-source NB-IoT implementations. It also presents a comparative evaluation and selection of suitable platforms, including OpenAirInterface (OAI) and srsRAN, against commercial solutions with consideration of 3GPP Release 13 and 14 compliance. In addition, the paper provides a detailed description of the system architecture, encompassing the eNodeB implementation on USRP B210 software-defined radio hardware and its integration with a lightweight Evolved Packet Core (EPC). A comprehensive testing methodology is proposed to progressively validate the system, starting from basic signal generation and synchronisation, then advancing through broadcast channels and random access, and ultimately achieving end-to-end data connectivity. Finally, a fully reproducible testbed specification is presented, including complete hardware, software, and configuration details. This framework enables practitioners to replicate the deployment using commercial off-the-shelf equipment.

2. Literature Review

2.1. NB-IoT as a 3GPP Standard for mMTC

Narrowband Internet of Things (NB-IoT) is a cellular low-power wide-area (LPWA) technology standardised by the 3rd Generation Partnership Project (3GPP) in Release 13 and enhanced in Release 14 to support massive machine-type communications (mMTC). It was specifically designed to address the requirements of large-scale IoT deployments, including high device density, extended coverage, low device complexity, and long battery lifetime (Ratasuk et al., 2016; Wang et al., 2017). Operating within a narrow bandwidth of 180 kHz per carrier, NB-IoT achieves improved link budget and spectral efficiency, enabling reliable communication in challenging environments such as deep indoor and rural scenarios. NB-IoT supports three deployment modes to facilitate integration with existing cellular infrastructure. In standalone mode, it operates in re-farmed GSM spectrum. In in-band mode, it utilises resource blocks within an LTE carrier. In guard-band mode, it exploits unused spectrum at the edges of LTE carriers (Malik et al., 2018; Ratasuk et al., 2016). These flexible deployment options allow operators to deploy NB-IoT with minimal modifications to existing networks. To meet mMTC requirements, NB-IoT incorporates several key features, including coverage enhancement techniques based on signal repetition, support for massive device connectivity, and energy-saving mechanisms such as Power Saving Mode (PSM) and extended Discontinuous Reception (eDRX). These capabilities enable long device lifetimes and scalable connectivity, making NB-IoT well suited to applications such as smart metering, environmental monitoring, and industrial sensing (Malik et al., 2018; Ratasuk et al., 2016; Wang et al., 2017).

2.2. Open-Source NB-IoT Implementations

Open-source platforms have become essential for the development and evaluation of NB-IoT systems. OpenAirInterface (OAI) is one of the most widely used open-source implementations of 3GPP cellular protocols, supporting both LTE and 5G New Radio. It provides a full-stack implementation that enables real-time experimentation and prototyping on general-purpose hardware (Nikaein et al., 2014). Its flexibility and adherence to 3GPP specifications make it particularly suitable for academic and industrial research. OAI has been extended to support NB-IoT functionality through collaborative research efforts. Early work by Ruei-Gang Cheng, Chia-Chen Chen, Yu-Ling Hsiao, and Chih-Hung Lin demonstrated the design and implementation of an open-source NB-IoT eNB, validating the feasibility of software-defined NB-IoT systems (Cheng et al., 2018). Subsequent work further demonstrated end-to-end NB-IoT prototyping using OAI integrated with commercial core networks, confirming interoperability with commercial NB-IoT devices (Chen et al., 2020).

The srsRAN platform, formerly known as srsLTE, represents another widely adopted open-source cellular stack. It is designed with a focus on modularity, computational efficiency, and ease of deployment, making it suitable for rapid prototyping and resource-constrained environments (Gomez-Miguelez et al., 2016). Research by Andreas Puschmann, Paul Sutton, and Ismael Gomez explored early NB-IoT implementations using the srsLTE library, including integration with existing LTE deployments (Puschmann et al., 2017).

Comparative studies have highlighted trade-offs between OAI and srsRAN. Experimental evaluations indicate that OAI offers broader protocol coverage and closer alignment with 3GPP standards, while srsRAN provides a more lightweight and performance-optimised implementation (Alves et al., 2023; Amini et al., 2024). These complementary characteristics make both platforms valuable for NB-IoT research, depending on system requirements.

2.3. Transition to OpenRAN Architectures

The OpenRAN paradigm represents a significant shift in cellular network design, emphasising disaggregation, open interfaces, and vendor interoperability. Unlike traditional RAN architectures, which rely on vertically integrated and proprietary solutions, O-RAN decomposes network functions into modular components connected through standardised interfaces (Polese et al., 2021; Sallent et al., 2017). This approach enables multi-vendor deployments and promotes innovation through software-defined networking and network function virtualisation principles. A key architectural feature of O-RAN is the introduction of the RAN Intelligent Controller (RIC), which is divided into near-real-time and non-real-time components. This enables closed-loop optimisation through programmable applications, commonly referred to as xApps and rApps, facilitating intelligent and adaptive network control (Bonati et al., 2021; Polese et al., 2023).

For private network deployments, O-RAN offers advantages such as increased flexibility, vendor diversity, and cost efficiency. Studies have demonstrated the feasibility of implementing private 5G networks using O-RAN principles, highlighting both performance benefits and practical deployment considerations (Aijaz, 2020; Rost et al., 2017). However, challenges remain, including system integration complexity, reliability requirements, and support for uplink-heavy IoT traffic patterns. Recent work has also explored the integration of open-source platforms such as OAI within O-RAN-based testbeds, demonstrating multi-vendor interoperability and programmability in experimental environments (Nikaein et al., 2014). In parallel, cloud-native architectures and containerised network functions have emerged as key enablers for scalable and flexible deployment of private cellular networks (ETSI, 2013; Mao et al., 2016).

2.4. Specialized Prototyping Platforms

In addition to general-purpose platforms such as OAI and srsRAN, specialised prototyping platforms have emerged to address specific research requirements in NB-IoT and cellular IoT systems. These platforms are typically designed to optimise particular aspects of experimentation, including simplified configuration, enhanced debugging capabilities, and tighter integration with specific hardware environments.

Sonica is one such example, representing a purpose-built platform tailored for NB-IoT research and prototyping. Unlike general-purpose cellular stacks that prioritise broad protocol coverage and multi-standard support, Sonica focuses on streamlined NB-IoT experimentation, enabling researchers to more easily configure, deploy, and analyse NB-IoT systems in controlled environments. Such platforms are particularly useful for rapid prototyping, educational use, and targeted experimentation where full 3GPP stack implementation may not be required.

The choice of platform for NB-IoT research depends on several factors, including protocol coverage and standards compliance, compatibility with software-defined radio hardware, development ecosystem and community support, performance characteristics, and deployment flexibility (Cheng et al., 2018; Nikaein et al., 2014; Polese et al., 2023). General-purpose platforms such as OpenAirInterface and srsRAN provide extensive functionality and flexibility, making them suitable for end-to-end system development and integration with core networks. In contrast, specialised platforms such as Sonica may offer advantages in usability, reduced system complexity, and faster experimentation cycles.

As open and disaggregated network architectures continue to evolve, the availability of both general-purpose and specialised platforms enables researchers to explore different dimensions of NB-IoT system design and optimisation. Consequently, platform selection should be guided by the specific objectives of the research, the required level of protocol fidelity, and the available hardware and software resources.

3. RAN Selection: Evaluation and Verdict

3.1. Introduction to RAN Selection

The selection of an appropriate open-source Radio Access Network (RAN) implementation is critical to the success of a private NB-IoT deployment. The chosen platform must satisfy several key requirements: (1) compliance with 3GPP Release 13/14 NB-IoT specifications, (2) demonstrated interoperability with commercial off-the-shelf (COTS) NB-IoT user equipment, (3) support for software-defined radio (SDR) hardware platforms, (4) active development community and documentation, and (5) licensing terms compatible with private network deployment.

Three primary candidate approaches were evaluated: OAI, srsRAN (formerly srsLTE), and commercial turnkey solutions. OAI provides experimental NB-IoT support within its broader LTE framework and has demonstrated successful connectivity with commercial modules; however, its NB-IoT documentation is less mature than that of its core LTE features. srsRAN offers a modular, software-based implementation of the NB-IoT PHY and MAC layers and performs well in research testbeds, with strong hardware support for USRP platforms. However, explicit examples of end-to-end integration with commercial off-the-shelf (COTS) user equipment are less prominent. Commercial solutions deliver carrier-grade reliability and excellent interoperability but are associated with high capital costs, vendor lock-in, and limited customisation options, making them less suitable for experimental or cost-sensitive private deployments.

3.2. Verdict: Selection of the Open-Source Prototyping Platform

Following evaluation against the defined criteria and insights from the literature review, a purpose-built open-source NB-IoT prototyping platform, Sonica, was selected. Sonica is designed specifically for NB-IoT experimentation, offering a streamlined implementation optimised for this technology rather than treating NB-IoT as a secondary feature within a broader LTE codebase. The platform demonstrates strong compatibility with commercial off-the-shelf (COTS) devices, provides optimised configuration for USRP B210 hardware, and is supported by targeted documentation, contributing to its overall cost-effectiveness.

Importantly, Sonica is built upon established open-source cellular frameworks, leveraging OAI for the radio access network components and srsEPC for the core network functionality. This architectural foundation combines the maturity and flexibility of widely adopted platforms with a more focused and simplified environment tailored to NB-IoT use cases.

While OAI and srsRAN remain valuable for comprehensive LTE and 5G experimentation, Sonica more effectively satisfies the requirements for developing a practical, reproducible, and dedicated private NB-IoT network, particularly in research contexts that prioritise ease of deployment, reduced system complexity, and rapid prototyping.

4. Development and System Architecture

4.1. Platform Overview

The selected open-source NB-IoT prototyping platform implements both the eNodeB and a lightweight EPC optimized for IoT. It fully supports 3GPP Release 13/14 NB-IoT specifications and operates effectively with USRP B210 software-defined radio hardware while maintaining compatibility with commercial NB-IoT devices.

4.2. System Architecture

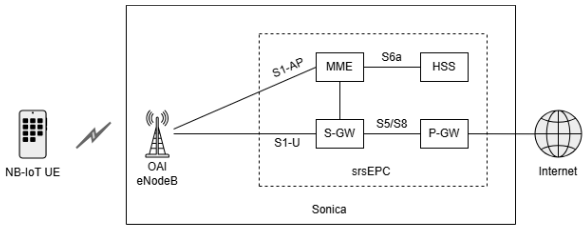

Figure 1. High-level system architecture of the private NB-IoT network

The eNodeB implements full NB-IoT physical layer processing, MAC scheduling with HARQ, RRC connection management, and S1 interface connectivity to the EPC. The EPC comprises the MME for mobility and session management, the HSS for subscriber data, the S-GW for user-plane routing, and the P-GW for IP address allocation and external connectivity. Key parameters include standalone operation mode, a 180 kHz bandwidth (single PRB), a configurable carrier frequency (e.g., Band 20 at 806 MHz), and a transmission power of 0 dBm for indoor testing.

Software dependencies include Ubuntu 26.04 LTS, the UHD driver for the USRP B210, Boost libraries, FFTW, and libconfig. The development workflow consists of environment setup, hardware verification, software compilation, EPC configuration with test subscribers (IMSI, K, OPc), parameter tuning, and incremental testing.

5. Testing Procedure

A comprehensive incremental testing methodology was used to systematically validate each layer of the stack.

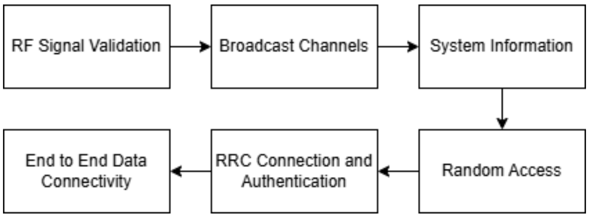

Figure 2. Overview of the incremental testing methodology

The testing covers:

- Basic RF signal transmission and synchronization signal detection using spectrum analyser.
- NPBCH and MIB-NB decoding validation.
- NPDCCH/NPDSCH system information broadcast and SIB decoding.
- NPRACH random access procedure with EPC integration.
- RRC connection establishment, authentication, and security mode command.
- End-to-end IP connectivity and bidirectional data transfer using AT commands on commercial off-the-shelf NB-IoT equipment.

Success criteria, common issues, and troubleshooting steps for each phase are documented to ensure reproducibility.

6. Results and Discussion

The deployed private NB-IoT network achieved successful end-to-end operation with commercial off-the-shelf equipment. Measured performance metrics are summarised below:

Table 1. Measured Performance Metrics

Metric	**Value**	**Notes**
Uplink Throughput	11 kbps	Single-tone NPUSCH
Downlink Throughput	17 kbps	NPDSCH under good signal conditions
Latency (RTT)	300 ms – 15 s	Depends on coverage class and repetitions
Packet Delivery Ratio	>95%	1-hour test under indoor line-of-sight

The results confirm reliable connectivity suitable for low-data-rate IoT applications. Uplink and downlink throughputs align with typical NB-IoT expectations given the narrow 180 kHz bandwidth and single-tone/multi-tone configurations. Latency varies significantly with signal conditions and repetition levels, which is characteristic of NB-IoT's coverage enhancement mechanisms. High packet delivery ratio under controlled indoor conditions demonstrates system stability.

The chosen open-source platform proved effective for private network deployment, offering a good balance between standards compliance and practical usability. Compared to commercial solutions, the SDR-based approach significantly reduces cost while maintaining sufficient performance for industrial and enterprise IoT use cases. Limitations include lower peak throughput than LTE/5G and sensitivity to RF environment, which can be mitigated through proper antenna placement and power optimization.

6. Conclusion

This paper presented a practical and reproducible guide for deploying a private NB-IoT network with open-source platforms. Through systematic literature review, platform evaluation, detailed architecture documentation, rigorous testing, and a complete testbed specification, we demonstrated a functional private NB-IoT system using USRP B210 hardware and commercial off-the-shelf equipment.

Experimental results validate reliable operation with measured throughput of 11 kbps uplink and 17 kbps downlink, acceptable latency, and high packet delivery reliability. The framework significantly lowers the barrier for researchers and practitioners to establish dedicated NB-IoT networks at a fraction of the cost of commercial solutions.

Future directions include exploration of multi-carrier operation, enhanced coverage modes in real-world environments, integration with edge computing, and further interoperability testing with diverse COTS NB-IoT modules. This work contributes to the democratization of private cellular networks for Industrial IoT and smart infrastructure applications.

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