Design of LTE Private Network Based on Software-Defined Radio for Flooding Monitoring System

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Abstract. The rapid development of cellular communications technology has increased the need for independent and reliable networks, particularly in areas with high disaster risk. This study presents the development and deployment of a private LTE network using USRP B210 hardware and the srsRAN platform to support an IoT-based flood monitoring system. The primary objective is to ensure robust and uninterrupted communication, independent of public infrastructure, thereby enabling continuous disaster monitoring and response. Indoor testing was conducted at distances of 3, 6, and 9 meters, with a 30 Mbps Ethernet backhaul connection provided by an Internet Service Provider (ISP) to evaluate the network's performance across several key signal quality parameters, including Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), and Signal to Interference plus Noise Ratio (SINR) at varying distances. The results indicate that the private LTE network maintained satisfactory performance, although occasional degradation in signal quality was observed, which was likely attributable to environmental factors or signal attenuation. The network achieved a maximum RSRP of -90 dBm, a minimum of -105 dBm, and an average of -97.7 dBm; the best RSRQ was measured at -3 dB, and the worst at 10 dB, with an average of 7.7 dB; while SINR values ranged from a peak of 16 dB to a low of 2 dB, with the average of 9.3 dB. These findings demonstrate that the network sustains moderate to good signal quality throughout operational testing, indicating its suitability as a communication backbone for IoT-based flood monitoring in disaster-risk areas.

Keywords: 4G LTE, USRP B210, IoT, Early warning system, Flood Monitoring.

1. Introduction

Flooding is a natural disaster that often occurs throughout the world, including in tropical countries such as Indonesia. Based on a report published by the Central Bureau of Statistics (BPS) in 2024, as many as 1,091 floods occurred throughout Indonesia in 2024 [1]. Climate change, environmental degradation, land use change, and poor spatial and environmental management are the main causes of this disaster. Flood damage disrupts daily life and infrastructure and communication facilities, causing significant eco-

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nomic losses. Existing flood monitoring systems mostly rely on public telecommunication network infrastructure, such as cellular communication, Wi-Fi, or fiber optic cables. Dependence on public communication infrastructure is a major weakness, because in the event of a disaster, public communication infrastructure networks are often disrupted or even collapsed. This causes the process of sending or distributing early warning notification information to the public and government to be hampered or even fail completely [2]. The Internet of Things (IoT) system has led to a transformative change in developing a reliable and responsive flood monitoring system. This technology enables real-time connectivity between sensors and a central server through data communication so that data on water levels, rainfall, and other parameters can be directly collected and analyzed. Therefore, the IoT-based flood monitoring system has a crucial role in detecting floods early and providing warnings to the public and government authorities to mitigate flood disasters, as well as accelerating emergency response to mitigate the negative impacts [3], [4]. Implementing a private LTE network appears to be a very interesting alternative in this scenario. Private LTE permits the creation of a fully autonomous cellular communication system that runs independently of public mobile network operators and can be tailored to fit the needs of specific locations and operational conditions [5]. This study uses srsRAN as the primary technology for the private LTE system under development. The decision to use srsRAN was influenced by several factors, including its open-source nature and cost efficiency, great configurability for bespoke network topologies, ability to run on lightweight hardware, and demonstrated communication performance in various emergency conditions [6], [7]. These characteristics make srsRAN particularly well suited for the construction of isolated communication networks [8]. This research resulted in the development of a unique LTE communication system in the form of a portable manpack unit that can be carried and controlled by a single person in the field. Furthermore, after a thorough technical and operational assessment, srsRAN was chosen over Open5GS. While both open-source technologies support LTE network building, srsRAN provides a more complete and lightweight option [9]. srsRAN combines the EPC and eNodeB functions in a single system, simplifying deployment and making it perfect for portable or manpack systems. Open5GS, on the other hand, Open5GS is primarily concerned with EPC and necessitates the use of third-party software or hardware (for example, the eNodeB component), which increases complexity and hardware dependencies [10]. This system has several key advantages. For starters, its high mobility and manpack form factor make it ideal for deployment in rural or underserved areas. Second, it is powered by a battery that can operate without electricity for up to six hours, ensuring dependability in emergency scenarios. Third, its quick deployment and plug-and-play nature enable emergency response teams to activate the system in minutes. The system's resilience is based not only on its technological strength but, also on its independence from vulnerable public infrastructure. As a result, the srsRAN-based LTE communication system in a manpack model makes a significant contribution to improving early warning systems and coordinating disaster response activities, especially in flood-prone areas.

IoT-enabled flood monitoring systems have increased importance in disaster reduction by acquiring real-time data and propagating alerts. However, most existing solutions rely on public communication infrastructure, which is prone to outage in the event of a disaster. Several studies have used conventional cellular networks to transmit data from flood detection systems. [11] proposed an IoT solution using LoRaWan communication to transmit water level data to a mobile server. Although effective under normal conditions, the use of public cellular networks becomes a reliability issue in the event of infrastructure damage. To solve connectivity limitations in rural and disaster-prone areas, LPWAN-based systems have been explored. [12] suggested an LPWAN solution to send data on water level, flow discharge, and rainfall using LPWAN, with a delay of less than one second. However, the effective distance is only 2 km, and the packet loss is 100% at the maximum distance with a high spreading factor. Private LTE networks have been proposed as a suitable option for IoT connectivity in times of disaster. The benefits of private LTE in offering high bandwidth, local control, and low latency have been identified [13]. While these works show the possible application of LTE-based solutions, research involving standalone private LTE networks specifically for flood monitoring is limited. This research proposes an IoT-based flood monitoring system operated on a standalone private LTE network to provide low-latency communication and system reliability in disaster-prone areas.

2. System Model

2.1 Configuration of a Private Portable LTE System

Fig. 1. Overall scheme of the proposed system.

In the design of the LTE communication system, the first step was to set up a bare metal PC as the primary platform. The machine was installed with Ubuntu 22.04 LTS, 16 GB RAM, and 512 GB SSD storage, which were selected to ensure optimal stability and performance in real-time signal processing. Once the operating system had been successfully installed, preliminary configuration such as system update and installing vital dependencies, UHD USRP driver necessary for running eNodeB. Then, srsRAN software was installed to offer end-to-end LTE stack functionality, EPC components, and eNodeB. The process proceeded with SIM card configuration using a card reader and special software for writing network parameters, such as MCC, MNC, IMSI, KI, and OPC. The SIM card was then used as an authentication for user devices when attempting to connect to the LTE network. The entire LTE communication infrastructure was then combined into a ruggedized, portable tactical box (manpack) intended for field deployment. The manpack system encapsulates the eNodeB and EPC components as, well as the USRP, battery pack, and antenna interfaces. This design allows for rapid deployment in remote or disaster-prone locations and operates independently of public networks.

Fig. 2. Physical setup of the proposed private LTE system.

During the EPC configuration step, user data from the prepared SIM card are added to the user_db.csv file. The MME component is configured on the same identity parameters, such as MCC, MNC, APN, KI, and OPC. Next, the IP forwarding function is activated, and additional rules for NAT are added to the IP table to ensure that data flow can occur efficiently within the network. On the eNodeB side, the system is configured to operate in Band 8 with a frequency of 942,50 MHz (EARFCN 3625). The USRP B210 was connected to a PC via a USB 3.0 port, and the LTE antenna was installed using an SMA connector. Once hardware and software were set up entirely, system activation was performed to run the core and RAN parts in an integrated mode. As the final step, network testing was performed by inserting a customized SIM card into the modem LTE to identify and connect with the LTE network.

In measuring the performance of LTE networks, critical radio metrics include the reference signal received power (RSRP), reference signal received quality (RSRQ), and signal-to-interference plus noise ratio (SINR). These indicators reflect signal strength, quality, and link reliability, respectively [14], [15], [16].

- RSRP

The RSRP is the average strength of the signal transmitted from a cell tower as it is received by a mobile device. A high RSRP indicates a strong signal and supports better services, such as stable connections and high speeds, whereas a low RSRP indicates a weak signal that can degrade service quality.

$$RSRP = RSSI - 10\ x\ log10(12\ x\ N) \tag{1}$$

Where:

a. N is number of Resource Blocks (RB) used on the channel.

b. *RSSI* represents the total received signal strength in one subframe, including reference signal, interference, and noise.

In order to evaluate signal quality in LTE networks, standardized measures are usually applied for critical parameters. For RSRP:

Table 1. RSRP quality threshold [17].

RSRP	Signal Strength
> -90 dBm	Excellent
- 90 to -105 dBm	Good
- 106 to -120 dBm	Fair
< -120 dBm	Poor

- RSRQ

The RSRQ is a measure of signal quality that considers interference and noise, reflecting how clean the received signal is. The RSRQ is represented in decibels (dB). High RSRQ values, reflect good network quality, and low RSRQ values reflect poor network quality, reflecting interference that could degrade service performance. The RSRQ is calculated from the ratio of RSRP and RSSI.

$$RSRQ = \frac{N\ x\ RSRP}{RSSI} \tag{2}$$

Where:

a. *N* represents the number of resource blocks used.
b. *RSRP* for the average of the received reference signal power.
c. *RSSI* for total received power, including signal, interference, and noise.

To evaluate signal quality in LTE networks, standardized measures are usually applied for critical parameters. For RSRQ:

Table 2. RSRQ quality threshold [17].

RSRQ	Signal Strength
> -9 dB	Excellent
- 9 to -12 dB	Good
< -13 dB	Fair to Poor

- SINR

SINR indicates the desired signal-to-noise ratio in the network, which reflects the ability of the received signal to be processed by the device. SINR is in decibels (dB), and high SINR implies good signal quality, whereas low SINR implies interference that can reduce the quality of the connection.

$$SINR = \frac{P_{signal}}{P_{interference} + P_{noise}} \tag{3}$$

Where:

a. P_{signal} is the average received signal power.
b. $P_{interference}$ is the average power of interference from other cells or sources.
c. P_{noise} is the power of random noise in the network.

To evaluate signal quality in LTE networks, standardized measures are usually applied for critical parameters. For SINR:

Table 3. SINR quality threshold [17].

SINR	Throughput
> 10 dB	Excellent
6 to 10 dB	Good
0 to 5 dB	Fair
< 0 dB	Poor

Universal Software Radio Peripheral (USRP). SDR is a radio communication technology that embeds most of the functions in traditional radios, such as modulation, demodulation, filtering, and signal detection. Because, protocols can be configured and updated without changing the hardware, SDR enables the development and operation of high-flexibility communication systems [18], [19], [20].

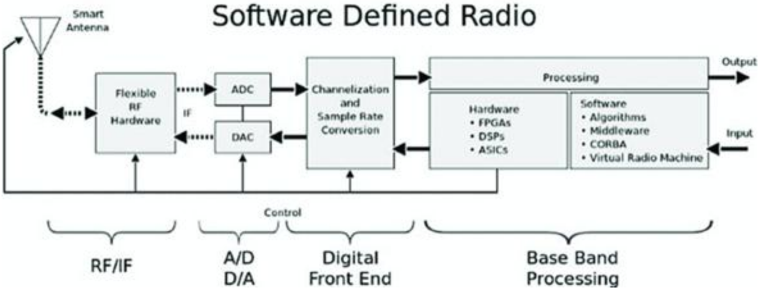

Fig. 3. Overall of the Software-Defined Radio Architecture [21].

As shown in Fig. 3, the software-defined radio (SDR) architecture is separated into two main parts. The first, which includes the antenna, radio frequency (RF) front end, analog-to-digital converter (ADC), and digital-to-analog converter (DAC), and the second is the software part, which manages the digital signal processing (DSP) performed by the processor or field programming gate array (FPGA) [22], [23].

The Universal Software Radio Peripheral (USRP) is a software-defined radio (SDR)-based hardware developed by Ettus Research. USRP is designed to provide flexibility because it can be configured according to user needs, has frequency coverage from 70 MHz - 6 GHz with a bandwidth of up to 56 MHz for the B210 type, which is used in this research. The main advantage of USRP is its ability to perform real-time digital signal processing with high speed and precision, and it can function as a transmitter and receiver in radio and cellular communication systems. USRP radio hardware has been widely used in the fields of research, mobile network protocol testing, education, and the development of wireless communication technologies such as long-term evolution (LTE) and 5G [24], [22], [25].

srsRAN. srsRAN is an open-source software platform (formerly known as srsLTE) developed by Software Radio Systems. Now transformed into a more complete solution, srsRAN was developed to build end-to-end 4G and 5G LTE cellular communication networks for network architectures, including EPC, eNB, and UE [25], [27]. srsRAN allows anyone to build an independent mobile network that is technically functional and in compliance with the 3rd Generation Partnership Project (3GPP) standards. srsRAN is supported by 3GPP standards release 10 to release 15 for LTE networks and release 17 for 5G networks [28], [29], [30].

Configuration for IoT. The first design phase of this IoT setup is the preparation of the main hardware components that constitute the core of sensor data communication and processing. The Raspberry Pi computer was used as the main processor because of its ability to run Python-based programs, ease of communication with various sensors, and efficiency in managing real-time systems. The Raspberry Pi is also connected to an LTE modem, which serves as a data exchange channel between the system and server. Jumper wires are used as an interface between Raspberry Pi GPIO pins and sensors to connect all components.

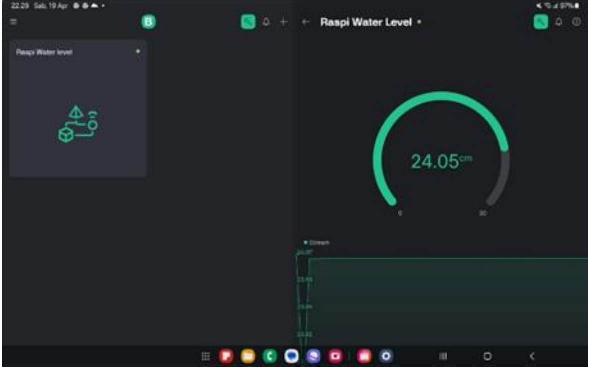

Fig. 4. Blynk IoT dashboard.

The HC-SR04 ultrasonic sensor is the key device used in measurement in this system, and it is used to measure the distance of water level from a reservoir or a container. The sensor sends ultrasonic waves toward the water surface and measures the reflection time of the waves to compute the distance of the water surface from the sensor. By incorporating this information, the system can accurately calculate the water level. A buzzer is also offered as a sound warning device, which will trigger when the water level reaches a specified level, for example when the water level reaches the minimum or maximum. The Blynk platform is used as a dashboard monitor for the IoT system. The users can monitor the water level in real time using the indicators and charts displayed in Fig. 4.

3. Results

After conducting several LTE system tests using a 30 Mbps Ethernet backhaul from an Internet Service Provider (ISP) at distances of 3, 6, and 9 m, measurements were collected with both a mobile phone and an Internet of Things (IoT) modem. For the mobile phone, data were gathered using the NetMonitor app. The analysis indicates that the mobile phone measured based on RSRP, RSRQ, and SINR as the main observed parameters. Higher RSRP and SINR values correlated with stronger and more reliable connections, whereas lower RSRQ values indicated higher interference and reduced signal quality. In contrast, IoT modem device testing followed RSRP only due to the modem's limitation. These results emphasize the functions of RSRP, RSRQ, and SINR as overall signal strength indicators. To describe these results, we obtained the following findings:

Table 4. LTE Network test results on mobile phone

Attempts	Distance (m)	RSRP	RSRQ	SINR
1	3	-90 dBm	-3 dB	16 dB
2	6	-99 dBm	-10 dB	10 dB
3	9	-100 dBm	-10 dB	2 dB

Table 5. LTE Network test results on IoT modem

Attempts	Distance (m)	RSRP
1	3	-92 dBm
2	6	-100 dBm
3	9	- 105 dBm

4. Discussion

The results indicate that the private LTE network developed through USRP B210 and srsRAN can ensure quality signal with an average value of RSRP at -97.7 dBm, RSRQ at -7.7 dB, and SINR at 9.3 dB. This indicates that reliable connectivity is required to support real-time IoT-based flood surveillance systems. Compared with earlier studies, such as LoRaWAN or LPWAN, which are distance restricted and have more data loss, this system is more reliable in disaster cases. Despite the fact that this system has been functioning well and delivering results in line with expectations, the RF transmission power of the USRP B210 is limited. which has implications for the limited range of the LTE signal. Further research is required to develop solutions capable of expanding signal coverage.

5. Conclusion

This study demonstrates the viability of a standalone private LTE network as a resilient communication backbone for IoT-based flood monitoring systems in disaster-prone areas, which can be deployed within minutes and powered for up to six hours without requiring external electricity. By leveraging SDR and open-source platforms, it offers a flexible and independent alternative to public infrastructure, enhancing the reliability of early warning systems. The proposed architecture contributes a practical model for real-time environmental monitoring and indicates that the LTE system can support cellular communication during mission-critical disaster response and, as well as post-disaster communication.

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