LoRaWAN-5G Integrated Network with Collaborative RAN and Converged Core Network

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***Abstract*—Heterogeneity is a key feature of 5G and beyond networks for Internet of things applications in various fields. Regarded as the leading low power wide area network, long range wide area network (LoRaWAN) is expected to accomplish 5G's massive machine-type communications target by integrating it into 5G network. In this paper, we design and implement a LoRaWAN-5G integrated network with a collaborative Radio Access Network and a converged core network. We built a 5G-based LoRaWAN gateway that communicates with 5G new radio. To the best of our knowledge, this is the first LoRaWAN gateway that uses 5G network as its backhaul. Moreover, the LoRaWAN servers are deployed within the core network of the 5G testbed, enhancing the security and privacy of LoRaWAN data. This hybrid network has been deployed to monitor the heating system of rooms in James Watt South Building at the University of Glasgow, demonstrating the stability, high flexibility and low deployment cost of the network.**

***Index Terms*—LoRaWAN, 5G, Internet of Things, ChirpStack**

I. Introduction

The 2021 United Nations climate change conference concluded with nearly 200 countries agreeing on the Glasgow climate pact [1] to keep the critical 1.5°C global warming goal alive. Internet of things (IoT) technologies and their application to smart buildings, smart factories, smart transportation, etc., will contribute massively to achieving this goal. Due to various requirements, a single IoT technology can not provide ubiquitous coverage or address all the vertical IoT use cases. It is important to design an efficient hybrid network that many IoT technologies can be integrated into. The fifth generation of mobile networks (5G) has been designed from the ground up to support a number of cellular IoT technologies.

Characterized by low cost, low data rate, low power consumption, and wide-area coverage, cellular low power wide area networks (LPWANs), such as narrowband Internet of things (NB-IoT), enhanced machine type communication (eMTC) and extended coverage global system for mobile communication IoT (EC-GSM-IoT), are an important class of cellular IoT technologies for massive IoT applications. Standardized by 3GPP, cellular LPWANs operate in licensed bands and are designed to co-exist with cellular networks. Unlike cellular LPWANs, non-cellular LPWANs, such as long-range wide area network (LoRaWAN) [2] and Sigfox, are designed independently of cellular networks, requiring end-to-end deployment of a dedicated access and core infrastructure. However, non-cellular LPWANs are also the main players capturing the LPWAN market mainly because of their advantages over cellular LPWANs in terms of battery lifetime, capacity, cost, and unlicensed frequency band [3].

LoRaWAN is the leading non-cellular LPWAN technology. ABI Research forecasts that LoRaWAN will account for over a one-fourth share of all LPWAN connections by 2026 [4]. To ease the deployment and management of LoRaWAN, some work has been done to integrate LoRaWAN into 4G/5G networks. The authors in [5] propose four integration options, i.e., 1) via 3GPP access network, 2) via non-3GPP untrusted access network, 3) as a part of eNodeB, and 4) virtually as a part of the core network. The authors in [6] propose to implement the virtual base station function of eNodeB protocol stacks into LoRaWAN gateways. Focusing on roaming scenarios, a core-level integration is proposed in [7] for end devices of dual connectivity of 5G and LoRaWAN. Adopting the 3GPP access network based integration option in [5], the authors in [8] evaluate two use cases of a long-term evolution (LTE)-LoRaWAN integrated network. The authors in [9] propose a traffic management method for LTE-LoRaWAN integration. Adopting the integrated architecture proposed in [6], the authors in [10] propose a routing and packet scheduling mechanism for the integrated network. In addition to the efforts in academia, the industry also takes action to facilitate LoRaWAN-5G integration. Kerlink [11] produced commercial LoRaWAN gateways with 4G backhaul, such as the indoor Wirnet iFemtoCell-evolution gateway and the outdoor Wirnet iStation gateway. Actility [12] and Simfony [13] announced in April 2021 that they will cooperate on developing a multi-technology IoT platform that can provide mobile network operators (MNOs) and mobile virtual network operators an integrated solution for LoRaWAN and cellular IoT networks management.

Cellular and LoRaWAN will co-exist in the form of hybrid networks in the 5G and beyond era. However, equipped with flexible, agile, and powerful core networks, 5G can serve as more than a backhaul network for LoRaWAN. The LoRaWAN-5G integration is expected to evolve from access networks to core networks like cellular LPWANs and fixed-mobile convergence that can communicate with the converged 5G core network efficiently. There are three motivations behind LoRaWAN-5G integration with a converged core network: 1) From the perspective of MNOs, to maximize the

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returns of infrastructure deployments by going beyond serving as only backhaul providers in the big market of non-cellular LPWANs. Instead, they will evolve their cellular networks to expand their business [14]. With a converged core network, MNOs will have the capability of taking over the operation of LoRaWAN. 2) From the perspective of customers, the integration of LoRaWAN and 5G with a converged core is cost-effective as it avoids the dual deployment and management of LoRaWAN and 5G. 3) From a technical perspective, a converged core can enhance the capabilities of LoRaWAN, such as security, capacity and roaming ability. For an more detailed review and analysis on LPWAN-5G integration, please refer to the comprehensive survey in [15].

In this paper, we implement a LoRaWAN-5G integrated network with a collaborative radio access network (RAN) and a converged core network by utilising the Glasgow 5G testbed. The LoRaWAN gateway that we built using Raspberry Pi and a 5G modem can access the 5G new radio network over the air as a 5G user equipment (UE). To the best of our knowledge, our gateway is the first LoRaWAN gateway that uses 5G as its backhaul technology, proving the feasibility of LoRaWAN-5G integration. Moreover, the LoRaWAN servers deployed on an edge server of the Glasgow 5G testbed is also the first set of LoRaWAN servers running within the core network of a 5G network. Furthermore, we demonstrate the viability of this hybrid network in a smart building heating management system to save energy.

II. 5G Network and LoRaWAN

Prior to discussing the LoRaWAN-5G integrated network, 5G network and LoRaWAN are introduced briefly in this section.

A. 5G network

Standardized by 3GPP from Release 15 in 2018 [16], 5G has three main use cases for IoT including enhanced mobile broadband (eMBB), ultra-reliable and low-latency communications (URLLC), and massive machine type communication (mMTC). The mMTC is expected to enable ultra-dense connection of up to 1 million per km^2, where the end devices are characterized by low cost and low power consumption. LPWANs are perfectly suitable for addressing these requirements. 5G already has some integrated cellular LPWAN technologies including NB-IoT, eMTC, and EC-GSM-IoT. Moreover, by virtue of NFV, SDN, and network slicing, 5G is a flexible, scalable, agile, and programmable network platform that other non-cellular LPWAN technologies can be integrated into. The deployment of 5G started from non-standalone architecture (NSA) mode to achieve the smooth evolution from 4G to 5G. Although 3GPP proposes eight options of combining 5G with 4G in [17], MNOs select option 3 in which the core network is still evolved packet core (EPC) and the access network is LTE and 5G new radio. The Glasgow 5G testbed is an NSA 5G network composed of an EPC+, gNB, and eNB for the anchor. An edge server sits next to the EPC, which can be used to host applications.

B. LoRaWAN

LoRaWAN is one of the most popular LPWAN technologies. It is a medium access control (MAC) layer standard based on long range (LoRa) physical layer standard proposed by Semtech and promoted by the LoRa Alliance [15]. LoRa is characteristic of chirp spread spectrum modulation that modulates each single bit of data to a chirp signal, achieving anti-noise and long-distance communication. Moreover, LoRa operates in unlicensed industrial, scientific and medical (ISM) bands with a bandwidth of 125 kHz, which decreases the costs. In the MAC layer, LoRaWAN has a star topology with a set of centralized LoRaWAN servers and multiple gateways. LoRaWAN servers are usually deployed in the cloud and use the Internet as the backhaul between the servers and the gateways. The gateways forward any packets that they receive from end devices to the servers. The servers deduplicate the packets and manage the whole network.

III. Implementation

In this section, we will introduce our implementation of the LoRaWAN-5G integrated network that is characterized by a collaborative RAN and a converged core network.

A. Integration solution

As shown in Figure 1, we integrate a private LoRaWAN to an NSA 5G network which is composed of gNB, eNB, and EPC+. The LoRaWAN gateway can communicate with gNB as a 5G UE by virtue of a 5G modem. The LoRaWAN servers are deployed on an edge server of EPC+. The hybrid network can support both 5G UE and LoRaWAN end devices at the same time. In terms of standard 5G UEs, the integration has no impact on their usage as there is no modification of the gNB or any entity of EPC+. In terms of LoRaWAN end devices, they can communicate with the LoRaWAN servers through the LoRaWAN gateway, gNB, and EPC+ in sequence. However, for LoRaWAN end devices, they can regard the network as a standard LoRaWAN network. The integration has two parts including the collaborative RAN and the converged core network.

At RAN level, there are a number of potential solutions to the integration of LoRaWAN and cellular networks [15]. However, only two solutions have been implemented so far due to the state of the technology and the availability of commercial products. The first solution, which inserts a universal subscriber identity module card and an LTE UE module to the LoRaWAN gateway, was implemented in [5], [8] and [9]. By doing so, the gateway can access the cellular network to communicate with LoRaWAN servers in the cloud. The second solution incorporates the eNB stack in the LoRaWAN gateway and was implemented in [6] and [10]. By doing so, the gateway can access the EPC directly via the S1 interface. Given that the first solution has advantages over the second solution in terms of flexibility, the cost of deployment, and the complexity of the gateway, we adopt the first solution, i.e., building a LoRaWAN gateway with a 5G UE module. However, there is a significant difference between our implementation and the

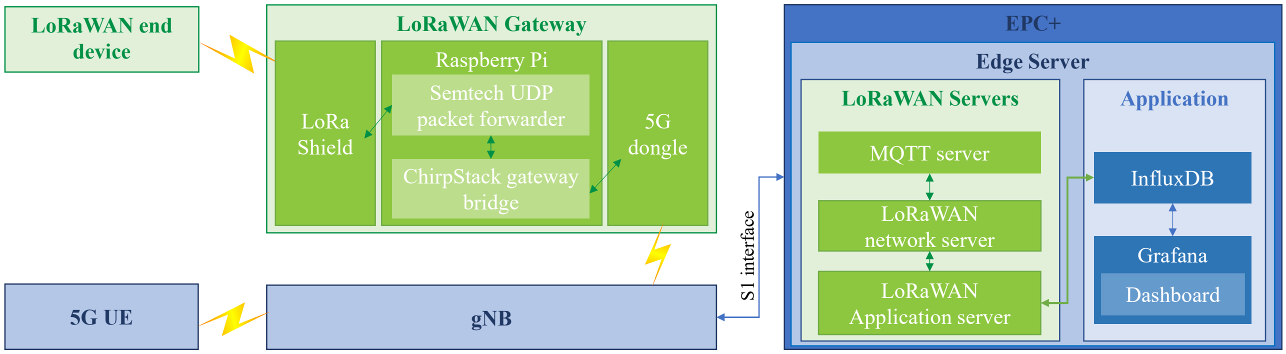

Fig. 1. System Diagram of the LoRaWAN-5G integrated network

related works [5], [6], [8]–[10], which are all based on the 4G cellular networks. Although the cellular network in [5] is a 5G test network, it uses eNodeB as RAN and EPC as core network. In this paper, the cellular network that the LoRaWAN is integrated into is a telco-grade NSA 5G network composed of gNB, eNB, and EPC+. With the ability to communicate with gNB over the air, the gateway can collaborate with gNB and access EPC+. Through the collaborative RAN, both 5G UE and LoRaWAN end devices can access the EPC+ at the same time.

At core network level, all the LoRaWAN servers, including a message queuing telemetry transport (MQTT) server, a LoRaWAN network server, and a LoRaWAN application server, are deployed in a virtual machine (VM) on the edge server of the EPC+. The data generated in the LoRaWAN end devices goes through the LoRaWAN gateway and gNB to EPC+. In the EPC+, the serving gateway receives the LoRaWAN data and routes it to the edge server that resides within the operator's IP network. In the whole process, the LoRaWAN data does not leave the EPC+, ensuring its security and privacy. Moreover, the converged core network with the integration of EPC+ and LoRaWAN servers can reduce the cost of deployment for those who need a 5G network and LoRaWAN at the same time as they only need to deploy one hybrid network. Furthermore, deploying LoRaWAN servers within EPC+ provides the possibility of interoperation between the 5G core network and LoRaWAN servers. The interoperation is expected to improve the efficiency, security, mobility, and compatibility of the hybrid network [15].

The details of the implementation of the LoRaWAN gateway and the LoRaWAN servers will be discussed in the next two subsections.

B. LoRaWAN gateway with 5G UE module

As shown in Figure 2, the hardware of the gateway includes a Raspberry Pi, a LoRa shield, and a 5G dongle. The Raspberry Pi is Pi 4 model B with 4GB RAM powered by a 5.0V 3A adaptor. The LoRa shield is LoRaGO PORT [18] which is designed specifically for multi-channel LoRaWAN gateways. The 5G dongle is assembled at the University of Glasgow and can access the Glasgow 5G testbed. The 5G dongle and the LoRa shield are powered by the Raspberry Pi. The test demonstrates that the 5.0V 3A power adaptor can support the Raspberry Pi, the LoRa shield, and the 5G dongle at the same time. It makes the deployment of the gateway very straightforward, flexible, and cost-effective, as we only need to simply put the gateway anywhere under the coverage of the 5G network and provide it with the power supply. Except a cable for the power supply, the gateway does not need any other cables.

In terms of the software, as shown in Figure 1, the Semtech user datagram protocol (UDP) packet forwarder [19] and the ChirpStack gateway bridge [20] are deployed in the Raspberry Pi with the Raspberry Pi OS. The Semtech UDP packet forwarder forwards the radio frequency packets received by the LoRa shield to the ChirpStack gateway bridge in the format of UDP packets. The ChirpStack gateway bridge converts the UDP packets to JSON and Protobuf which are the required data formats of ChirpStack LoRaWAN servers. Then, through the 5G dongle, gNB and EPC+, the bridge transmits the JSON and Protobuf packets to the specified MQTT server which is deployed on the edge server of EPC+. The 5G dongle and the LoRa shield have their own firmware and drivers, and there is no need to deploy extra software on them. The logs of the packet forwarder, the bridge, and the 5G dongle are displayed in Figure 2. The log of the packet forwarder shows its status. The log of the bridge shows the uplink and downlink communications between the bridge and the MQTT server. The log of the 5G dongle shows the PDN session established in the EPC+ for the gateway.

C. LoRaWAN servers in 5G edge server

In the 5G edge server, a VM is created by Proxmox for the LoRaWAN network and its applications. Ubuntu 18.04 is selected as the operating system of the VM. ChirpStack LoRaWAN server solution [21] is chosen for the network. As shown in Figure 1, the LoRaWAN servers include an MQTT server, a LoRaWAN network server, and a LoRaWAN application server. All the three servers are deployed in the VM. The MQTT server forwards the packets received from the ChirpStack gateway bridge to the ChirpStack LoRaWAN network server. The network server plays the vital roles in authentication of end devices, de-duplication of the LoRaWAN frames received by the LoRaWAN gateway, and processing of the downlink and uplink LoRaWAN MAC-layer message. Moreover, the network server sends the processed messages to

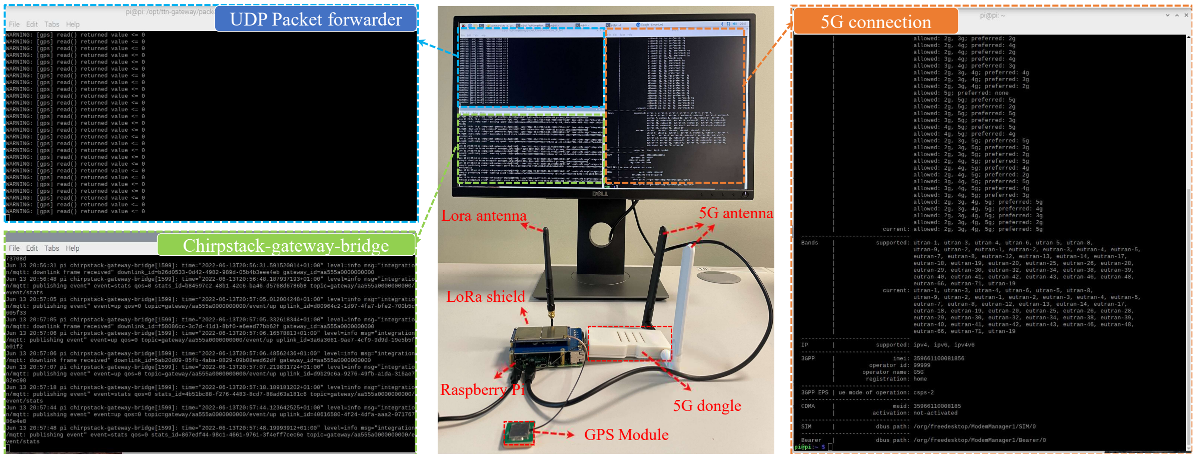

Fig. 2. The LoRaWAN gateway with 5G dongle

the ChirpStack LoRaWAN application sever. Figure 3 shows the interface of the VM and the dashboard of the application server. The dashboard illustrates that all the end devices and the gateway are active and working well. The "Device data-rate usage" indicates "DR5" which means that the sampling factor is 7 and the bandwidth is 125 kHz according to the LoRaWAN regional parameters [22]. As the LoRa shield has a global positioning system (GPS) module, the dashboard of the application server also illustrates the location of the gateway, which is at the James Watt South (JWS) Building at the University of Glasgow.

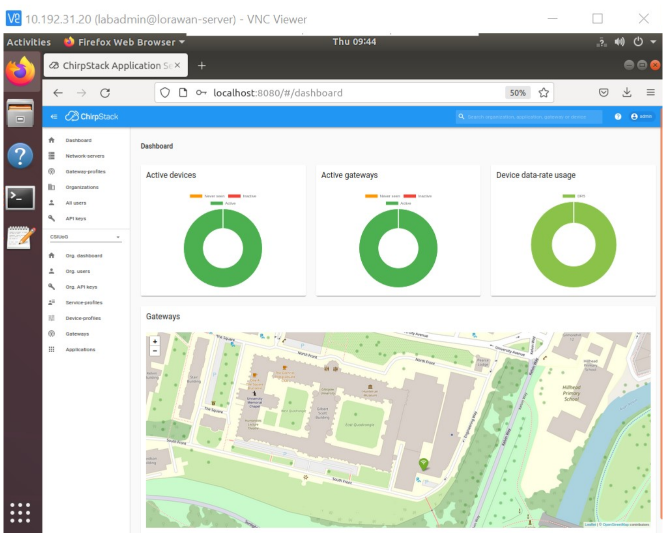

Fig. 3. The LoRaWAN servers deployed in the 5G edge server

IV. Use cases

Compared with standard LoRaWAN, the LoRaWAN-5G integrated network has many advantages in terms of flexibility, deployment cost, security, and privacy. With these advantages, the integrated network is expected to have many use cases, e.g., smart factories, smart transportation, and smart buildings. In this section, we introduce the smart heating project that we developed to digitize and upgrade the heating system of the JWS building at the University of Glasgow.

The energy shortage and the climate changes are two severe problems that all human beings are facing. According to the heating report of IEA [23], heating is the world's largest energy end use, accounting for almost half of global final energy consumption in 2021. However, the heating system of the JWS building is traditional and old-fashioned. The management team of the building knows little about the temperature, people activity, or the status of heating (on or off) in each room. Moreover, there is the possibility that the heating radiators keep on for a long time with nobody in the room, resulting in energy wastage. The LoRaWAN-5G network proposed in this paper can be used to upgrade the heating system and solve the problem at a very low cost. We deploy our LoRaWAN-5G gateway in Room 468 of the JWS building and three sensors with built-in LoRaWAN modules in Room 468 (a), Room 468 (b), and Room 534 of the JWS building. The reason why we deploy two sensors in Room 468 is that the room is too large to be measured precisely by one sensor. The sensors we select are TEKTELIC PIR (passive infrared sensor) smart room sensors that can capture the temperature, humidity, and human activity, etc. Furthermore, the sensors support LoRaWAN specification 1.0.2 and can send data to the LoRaWAN servers deployed in the edge server of 5G via the LoRaWAN gateway and gNB.

As shown in Figure 1, in addition to LoRaWAN servers, we also deployed some applications in the VM including InfluxDB and Grafana. InfluxDB is a time series database that can store the data directly from the ChirpStack application server via the application programming interface designed by ChirpStack. Grafana is a dashboard platform that can read data from InfluxDB and do some simple data processing. The Grafana dashboard of the smart heating system is shown in Figure 4. In the first row, the current temperature, humidity, and the sensor battery voltage are displayed. The second row illustrates the human activity in each room, which is perceived by the PIR detector integrated into the smart room sensor. The last row illustrates the historical data on temperature and humidity in each room. The time range of the historical data can be adjusted as needed. By the dashboard, the building management team can remotely monitor the temperature and

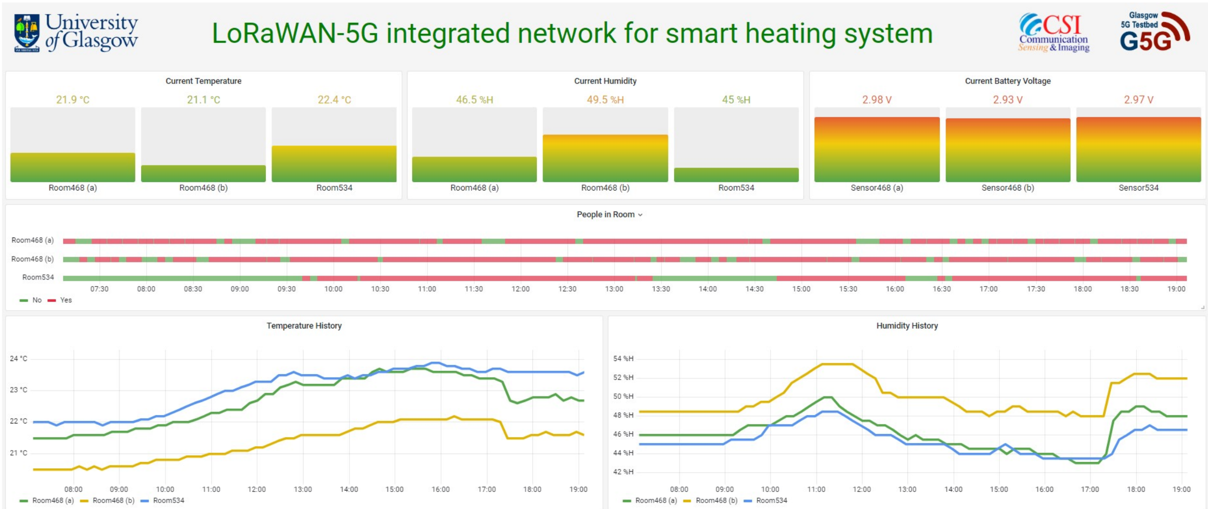

Fig. 4. Dashboard of the smart heating system

human activity level of each room, and then determine when to switch on or off the radiator.

V. Conclusion

In this paper, we design a LoRaWAN-5G integrated network with a collaborative RAN and a converged core network. With the 5G UE module, the LoRaWAN gateway can collaborate with gNB to communicate with the LoRaWAN servers deployed in the edge server of EPC+. We implement the integrated network on the Glasgow 5G testbed and use it to upgrade the heating system of the JWS building at the University of Glasgow. The use case demonstrates that the integrated network can work efficiently and stably. Building a 5G modem in LoRaWAN gateway makes the deployment very straightforward, flexible, and cost-efficient. Deploying the LoRaWAN servers in the core network of 5G enhances the security and privacy of LoRaWAN data. Because of these benefits, the proposed solution of LoRaWAN-5G integration is expected to be widely adopted in the 5G and beyond era.

In our future work, we will deploy sensors in more rooms at the JWS building and develop a machine learning-based algorithm to detect the status (on or off) of heating radiators according to the changes of temperature and humidity. Then, combined with the data on human activity, a timely alert will be sent to the building management team when heating radiators are left on for a long time in an empty room.

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