On the Integration of LoRaWAN with the 5G Test Network

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Abstract—**The major focus of the low power wide area networks (LPWAN) is to provide energy efficiency and large coverage to Internet of Things (IoT) applications that do not require a large bandwidth. There are several LPWAN technologies that can enable these functionalities such as SigFox, LoRa Wide Area Network (LoRaWAN), Narrowband-IoT (NB-IoT), and Weightless. The estimates of the number of wireless IoT devices in the near future are between 20 Billion to even 75 Billion. At the very same time the development and deployment of the 5th generation of mobile networks (5G) is rolling out. Among others, the new technology will deliver huge capacity which can be employed for enabling the backbone connectivity for LPWAN. Therefore, there is a need to have possibility to seamlessly integrate LPWANs with the upcoming 5G. In this work, we investigate how one can integrate the LoRaWAN with the 5G Test Network (5GTN) running in the University of Oulu, Finland. Furthermore, one of the options discussed is implemented in practice and its operation is verified. At the moment the implementation is used for wide range of other research activities beside this work, enabling a third party to bring their LoRaWAN compliant devices for testing and application development.**

Index Terms—**5GTN, LoRaWAN, MultiConnect Conduit, PPP, MQTT, ThingWorx.**

I. INTRODUCTION

The next generation mobile network (NGMN) implies that billions of sensor nodes would be connected simultaneously to the Internet in a few years [1]. Such a massive number of Internet of Things (IoT) devices will trigger the evolution of existing mobile network infrastructure. The fifth generation of mobile networks (5G) has been advertised to cope with billions new of wireless devices, to provide higher data rates and lower the communications latency.

Some of the future IoT applications will require long communication range, but can manage with low bandwidth. These applications can be implemented using low power wide area networks (LPWAN), which can serve as one of the IoT enabler network types. The topology of an LPWAN is usually star, where wireless sensor nodes transmit measured data to gateways that route data via standard IP connections to a server [2].

No doubt, the LPWANs will play a major role in the future IoT applications. Even though these devices transmit data seldom to enable for long lifetime, the range of possible applications in the areas of, e.g., infrastructure monitoring, security, smart home, health care and smart traffic, is still tremendous. Today there are several competing LPWAN technologies, such as SigFox and LoRa Wide Area Network (LoRaWAN) which are available already today, and Narrowband-IoT (NB-IoT) which is expected to come shortly. Each of them have particular specifics regarding their technical solutions, features and the business models implied.

While the development and deployment of the NB-IoT is being in process, the other LPWAN technologies have already matured enough to enable their large-scale deployment. As we show in the paper, the integration of the LPWAN systems with incoming 5G, and even the 4G of today, is a non-trivial problem, which can be addressed in various ways. Nonetheless, such integration would benefit both parties. To give just one practical example: the use of 4/5G wireless backhaul for LPWAN gateways would enable their easy "anytime-anywhere" deployment, whilst providing the new type of customers to the traditional telecom operators.

In order to enable the real-life validation of the diverse wireless communication technologies for IoT-era the University of Oulu have initiated the deployment of the 5G Test Network (5GTN) [3]. The network is already operational and provides the support for various research and development (R&D) activities in respect to numerous different radio technologies. These activities include: the evaluation of the performance of the different technologies and their comparison, testing of the new applications and devices, development of the novel applications and network management mechanisms, etc.

In this paper we address the problem of practical integration of an LPWAN, namely LoRaWAN, and the 5GTN. First, we discuss the specifics of the LoRaWAN technology and detail the structure of the 5GTN. Second, we discuss the opportunities for integration of the two. Finally, we select one of the discussed options and detail its implementation, summarizing the lessons learned.

II. LoRa Wide Area Network

The first version of the LoRaWAN specification was released 2015 [4]. The following releases have introduced minor updates, mostly related to frequency allocations for different regions. The LoRaWAN specifies the network protocol to be utilized on top of a physical layer based on LoRa or frequency shift keying based modulations. A single gateway can serve tens of thousands of low power wireless end devices [5]. Thus indoors one cell can cover a large real-estate [6] and outdoors coverage area can be tens of kilometers [5].

LoRaWAN is laid on star-of-stars topology and it supports secure bidirectional communications. End device can join the network by using either over-the-air activation (OTAA) or activation-by-personalization. A gateway routes the messages between end devices and the network server. The IP connections are used at the backend to transmit messages from gateway to the network server. [4]

The LoRa modulation is based on chirp spread spectrum (CSS) [7]. This chirp signal uses wideband linear modulated pulses whose frequency varies based on encoded information. The communication can be done employing the different orthogonal spreading factors (SFs), featuring different trade-offs between the on-air time and communication range. The bit rate in LoRaWAN can be formulated as

$$R_b = {SF}/{2^{SF}} \times (Coding\ rate\ \times BW). \qquad (1)$$

Equation 1 represents coding rate is 4/5 according to [3] and BW is the bandwidth. LoRaWAN enables automatic data rate (ADR) feature to maximize both lifetime of the end devices and overall network capacity.

ALOHA type of medium access control protocol is mandatory for all the end devices. It ensures energy efficient operation, but as a tradeoff, the packets transmitted by the end devices are prone to collisions. After transmitting the uplink packet, the end device opens two receive windows for acknowledgements or, e.g., actuation commands.

III. 5G Test Network at the University of Oulu

The 5GTN deployed at the premises of University of Oulu provides a realistic environment for R&D in the area of wireless communications and application development. It provides functionalities such as network functions virtualization (NFV) and software defined network (SDN) on a cloud platform. The 5GTN provides open interfaces for integrating innovative applications that are expected to be part of the 5G. The current 5GTN is deployed in such a way that the evolved node B (eNodeB) as part of the radio access network (RAN) can establish an S1 connection with multiple core networks. This S1 connection is based on S1 application protocol (S1AP), which enables S1-mme interface for signaling. It also supports non-access stratum (NAS) signaling transport functions.

5GTN's RAN comprises of frequency division duplex (FDD) based Pico cells at 2.6 GHz and FDD and time division duplex (TDD) based Macro cells at 2.6/3.5 GHz. Also, 5G proof-of-concept (PoC) devices from Nokia has been deployed into the network. 5GTN comprises of three evolved packet cores (EPCs) as a core network, two of which are located at the Oulu Data Centre [8]. Nokia Air frame (vEPC) in the open stack and OpenEPC on VMWare's vSphere are being deployed on the same virtual local area network (vLAN) as a PoC for implementing NFV. The OpenEPC, developed by Core Network Dynamics [9], is a prototype implementation of 3GPP EPC, is offered for researchers to test different functionalities of the core network. Nokia developed shared reference network (SRN) core is an alternate option (resides in Tampere, Finland), which uses LAN-to-LAN virtual private network (VPN) connection over the Internet. The SRN has a capacity bottleneck at the VPN switch due to bandwidth limitations resulting in performance degradation but on the other hand offers network functions not deployed in Oulu EPCs. [10] [11].

IV. LoRaWAN Integration with the 5G Test Network

There are multiple ways to integrate LoRaWAN with the 5GTN that enable new possibilities to develop the future IoT applications. There are some ongoing research projects on integrating LPWAN with cellular network in both industry and academia [2] [12]. In this section, four different options, summarized in Fig. 1, are discussed. One option is then selected and implemented in practice, its operation is verified that are introduced in Section V.

The four options considered to seamlessly integrate LoRaWAN with the 5GTN are:

- via 3GPP access network,
- via non-3GPP untrusted access network,
- as a part of eNodeB, and
- virtually as a part of core network.

As part of 3GPP access network, LoRaWAN could be connected with the 5GTN by using the S1 interface. As discussed earlier, 5GTN has multiple EPC options, LoRaWAN could establish the S1 connection with any of the EPCs in the 5GTN. It would further generate general packet radio service tunneling for a user based on subscriber's profile. For authentication and authorization, the information about LoRaWAN needs to be defined in the home subscriber service (HSS) data base, which is

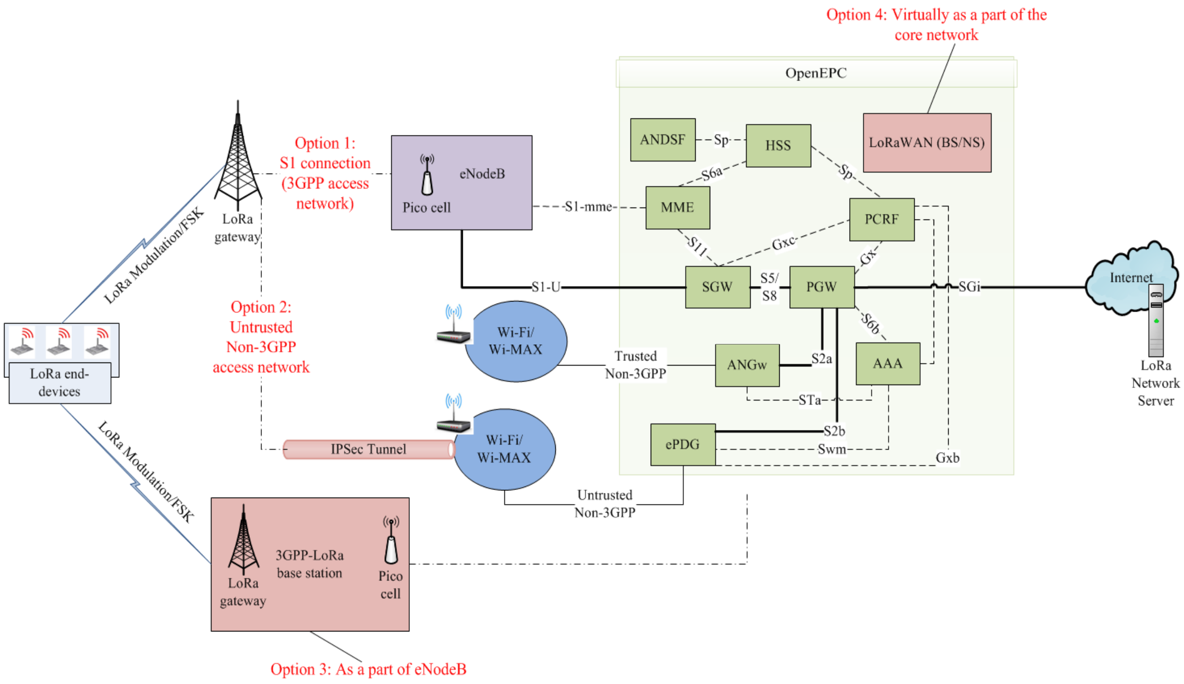


Fig. 1. Possibilities of Integration LoRaWAN with the 5GTN.

connected to mobility management entity (MME). According to current status of the user, the MME updates location of the subscriber in HSS by sending update location request that includes public land mobile network (PLMN) identifier i.e., mobile network code (MNC) and mobile country code (MCC). The integration could also be feasible as part of non-3GPP access network as shown in Fig. 1. In this option, the LoRaWAN would be merged with the OpenEPC (5GTN's core). OpenEPC has an evolved packet data gateway (ePDG), which can be configured to create internet protocol security (IPSec) tunnel for untrusted non-3GPP access network [9]. This IPSec tunnel provides a secure communication mechanism for each user, i.e., LoRaWAN gateway in this case. The authentications for users/devices that are connected via non-3GPP access network, is possible by using authentication, authorization and accounting (AAA) module. This module is further connected to policy and charging rules function (PCRF), which is responsible for enforcing the charging the usage, forcing the policy rules, and for allocating resources to each established bearer based on the subscriber's profile. For non-3GPP users/devices, ePDG establishes a connection with the packet data network (PDN) gateway to route the packets to the Internet. This could be utilized for transmitting LoRaWAN packets to the network server.

Integration is also possible at the RAN level by merging LoRaWAN with the eNodeB. So the eNodeB would be able to receive LoRa packets as well as has to be capable of handling 3GPP connections. This approach would ease the deployment of future networks if the eNodeB would support multiple LPWAN technologies.

Currently, the 5GTN infrastructure is arranged to be compatible with cloud platforms by virtualizing the network components. To integrate LoRaWAN with the 5GTN as a part of the core network, LoRa network server could be installed in the cloud along with the core network components. The OpenStack cloud platform could be utilized to implement LoRa components as a virtual instance. The OpenStack cloud platform supports dashboard to generate virtual instance on top of Linux operating system installed in physical machine. LoRaWAN functionalities could be defined into either a single virtual instance or multiple virtual instances. In the OpenStack, these virtual instances are deployed and modified based on requirement by using application programmable interfaces (API). This section concludes the discussion regarding the comparison between four integration possibilities in Table 1.

V. IMPLEMENTATION

As becomes clear from the previous section, the LoRaWAN can be integrated with the 5GTN in various ways, each of which enables for particular benefits and has specific drawbacks. Based on the analysis of these and of the requests and of the needs of the current industrial and academic projects around 5GTN, as well as taking into account the current state of the technology and the available on the market solutions, we decided to proceed with the implementation of the first option. The current implementation is intended to prove the feasibility of integration the two networks and provide the

TABLE I. COMPARISON BETWEEN DIFFERENT INTEGRATION METHODS

Features	**Integration method**			
	3GPP access	***non-3GPP access***	***eNodeB integration***	***virtual in core***
communication interface and traffic effects	S1 connection: LPWAN packets added to LTE traffic	WiFi/Wi-MAX: LPWAN packets added to WiFi/Wi-MAX traffic	3GPP backbone: LPWAN packets added to users' traffic	external: LPWAN traffic does not affect core network
security mechanisms[1]	S1 connection	IPSec	S1 connection	implementation specific
resource management instance	PCRF	ePDG based on PCRF	PCRF	implementation specific
hardware & software requirements	gateway must support: LTE connectivity and have an IP stack	gateway must support: WiFi/Wi-MAX connectivity, IP stack, IPSec, 'strongswan'	integration of LoRa gateway with eNodeB is required	OpenStack cloud platform on top of hypervisor
support in today's commercial products	already available	not available	not available	not available
implementation complexity[2]	medium	high	very high	high
deployment complexity[3]	medium	medium	low	high
scalability	good	good	good	poor
quality of service	medium	medium	good	implementation specific

[1]-from LPWAN gateway

[2]-efforts needed for instrumenting the required solution (i.e., hardware and software) from the todays state of the art

[3]- efforts needed to deploy and configure the system once the respective solutions are designed and implemented

"baseline" references solution, with which the other options can be compared. In future the other options are planned to be implemented also.

A. Hardware and software components

For the implementation, four components are being utilized: the LoRaWAN compatible end devices, a LoRaWAN gateway, the 5GTN infrastructure, and an IoT cloud platform for storing, analyzing and visualizing the received data.

The Modular R&D IoT platform [13] designed at the Centre for Wireless Communications, University of Oulu is used as the LoRaWAN end device. It enables extensive control over, e.g., the physical and MAC layers that ensures connection with the gateway.

The gateway utilized is Multitech's commercial-of-the-shelf MultiConnect Conduit [14]. The parameters of the gateway (i.e., band, addresses, channel configurations, EUIs of devices, applications, etc.) were adjusted to enable its use within the test network.

Even though, as discussed in Section III, the 5GTN has quite reach functionalities already, for the sake of this work it has been extended by adding an IoT cloud platforms. There are plenty of alternatives of such platforms available now, including, e.g., Microsoft's Azure, Nokia's IMPACT, PTC's ThingWorx and Amazon's AWS. In this work, the ThingWorx development platform is utilized.

B. Connectivity

The communication between the end devices and the gateway occurs on the industrial, scientific, and medical 868 MHz band. The end device is authenticated with the gateway using OTAA. For that the following information is required: an application identifier, an AES-128 key, and a globally unique end device identifier [4]. The AES-128 key is used to encrypt application data and network communication. The received LoRaWAN data packets are handled and displayed on Node-RED [15], which is a programming tool for combining hardware devices, APIs and online services. The Node-RED enables the connections between the gateway and the ThingWorx.

The 5GTN's subscriber identification module (SIM) card is installed to the MultiConnect Conduit in order to establish a connection with the 5GTN's core network based on point-to-point protocol (PPP). In general, the PPP is an encapsulation protocol by which a point to point connection can be established between two nodes over the Internet [16]. After installing the SIM card, the access point name (APN) and PLMN needs to be configured according to the cellular network requirements. After proper configurations, the MultiConnect Conduit transmits 'combined attachment request' [14] to the 5GTN. Then the gateway exchanges proper signaling messages (encapsulated into NAS) with the MME via eNodeB. If the connection is established successfully, the Conduit gets the local IP address along with the respective DNS IP address. The connection between LoRaWAN gateway and 5GTN is shown in Fig. 2. The LoRaWAN packet is going through the network provided by the 5GTN.

The communication between the LoRaWAN gateway and the ThingWorx via 5GTN is handled with message queuing telemetry transport (MQTT) protocol. MQTT is a lightweight publish subscribe based messaging protocol suitable for IoT. The MQTT provides remote

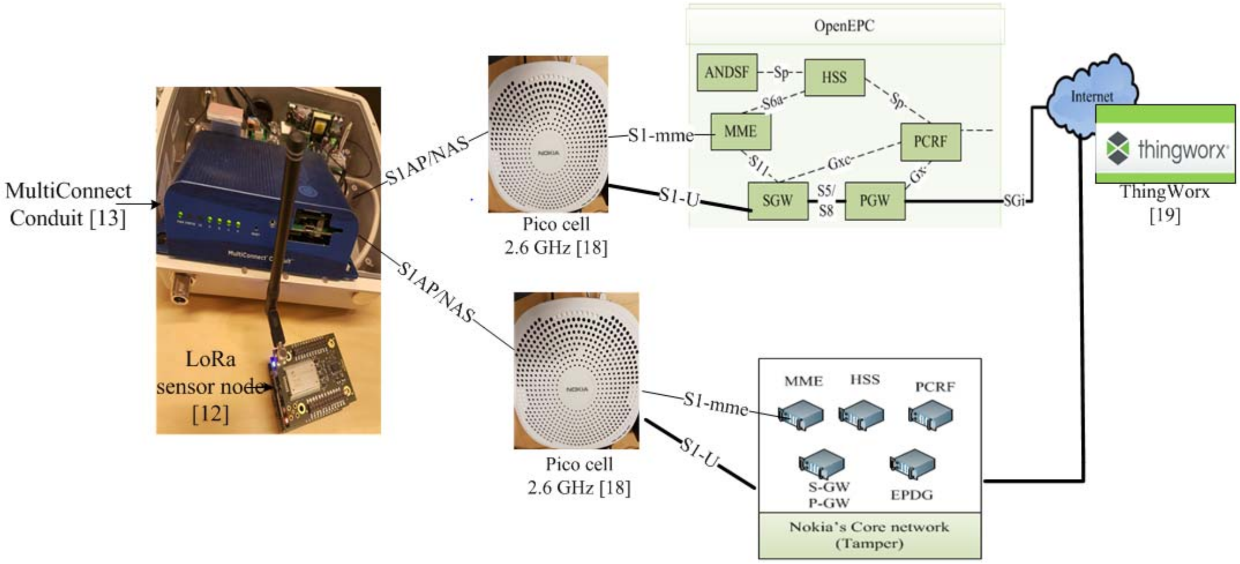


Fig. 2. Cellular connection established with the 5GTN.

connection between the broker and the client for secure transmission even if the network is unreliable [17]. Multiple clients can publish or subscribe messages to the broker. The broker can handle thousands of concurrently connected MQTT clients. It is used on top of TCP/IP and it enables bidirectional communication.

C. Testing

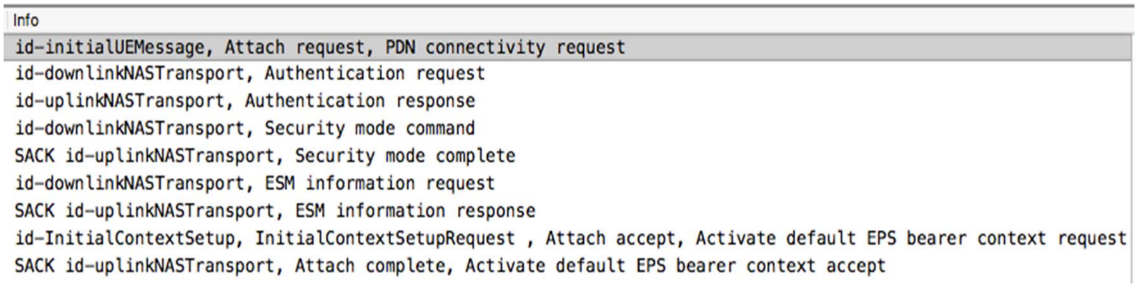
In order to ensure that the connection between the LoRa gateway and the 5GTN is established, a Wireshark trace is taken at the Pico cell (eNodeB) while Conduit triggers attachment request for establishing S1 connection. The Wireshark trace of the connection establishment first messages are shown in Fig. 3. After ensuring that the connectivity works, the 5GTN can start acting as the backhaul for transferring the LoRaWAN packets from the LoRa gateway to a predefined 'property' in ThingWorx. In this work, the ThingWorx is the MQTT client, which connects to the MQTT broker that enables message delivery between LoRaWAN and the ThingWorx. Once messages are received by the ThingWorx, data can processed and visualized, e.g., with a gauge as shown in Fig. 4. The LED buttons below the gauge were used to test the downlink communications. By pressing the LED button, the corresponding LED in the sensor node will change state. The downlink communications can be traced with the Wireshark in a similar way as with uplink messages. Different 'property' are created on the ThingWorx platform in order to publish and subscribe the messages to the MQTT clients according to 'topic'.

VI. CONCLUSION

LPWANs are vastly becoming one of the key technological IoT enablers for the future, enabling cost and energy efficient communication solution for myriads of low-end transducers. Smart home automation, smart healthcare and wellbeing monitoring, and environment monitoring are just a few potential fields where these technologies can found wide utilization. In most of these applications the data need to be delivered to the IoT cloud, where they are collectively stored and made available to the interested parties using proper interfaces and authentication mechanisms. One of the efficient mechanisms to support for this is to use the 3GPP cellular network interfaces and infrastructure already deployed, which calls for integration of the LPWANs and the cellular systems.

In the current paper we have identified and discussed the four possibilities of integrating the LoRaWAN LPWAN with a cellular network. The first two options are based on use of either 3GPP access network or an untrusted non-3GPP access network for the LoRaWAN gateway. The latter two options imply merging LPWAN gateway with either the eNodeB or integrating it with the core network. The pros and cons of these solutions have been highlighted and discussed in this paper.

As a part of the activities for instrumenting the 5GTN deployed by the University of Oulu, Finland, the practical integration of the LoRaWAN and a 3GPP-based network has been accomplished. The 5GTN features support for versatile wireless communication interfaces and is widely used for the R&D activities carried by the University of Oulu and local companies. Based on the analysis of the needs of the current industrial



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Info
id-initialUEMessage, Attach request, PDN connectivity request
id-downlinkNASTransport, Authentication request
id-uplinkNASTransport, Authentication response
id-downlinkNASTransport, Security mode command
SACK id-uplinkNASTransport, Security mode complete
id-downlinkNASTransport, ESM information request
SACK id-uplinkNASTransport, ESM information response
id-InitialContextSetup, InitialContextSetupRequest , Attach accept, Activate default EPS bearer context request
SACK id-uplinkNASTransport, Attach complete, Activate default EPS bearer context accept
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Fig. 3. Messages for establishing S1 connection with the 5GTN (Wireshark trace).

Fig. 4. Temperature measurement visualized (from ThingWorx).

and academic projects around 5GTN, as well as taking into account the current state of the technology and the available on the market solutions, the practical integration was done by using the 3GPP access network.

The practical integration was conducted by using MultiConnect Conduit as an IoT gateway integrated with the 5GTN. This gateway supports LoRaWAN technology as well as cellular network to transmit data from sensor nodes to an IoT cloud. To store and monitor data coming from sensor nodes, the ThingWorx cloud platform was used in this study. After successful integration, the network is now running and can be used by researchers and third parties to test the future IoT devices and enable the novel applications. In the future we plan to evaluate the other identified options for integrating the networks, as well as address the other potential LPWAN technologies. Also we plan to conduct the more extensive experimental evaluations of the performance metrics of the already deployed solution for the different use cases and subject to various traffic patterns.

ACKNOWLEDGMENT

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