International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 01 | Jan 2021 www.irjet.net p-ISSN: 2395-0072

LPWAN Technology to enable Interoperable Fog-Edge Computing Model for Smart Grids

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Abstract - *In this paper, a dedicated hybrid Fog - Edge computing architecture is proposed for Smart Grids with respect to their constraints such as power consumption, network structure and transmission modes. Cloud computing models have continued to rise in adoption throughout many different sectors, but with the increasing volume of data being produced, the primary concern of both commercial and industrial consumers has shifted from storage and large-scale analysis to more localized, low-bandwidth applications. IoT architectures based on the cloud have been revealed to encounter various bottlenecks such as network congestion and the lack of interoperability. The proposed framework uses a fog computing model that significantly reduces costs and friction points involved by leveraging ubiquitous computing models demonstrated by LPWAN (Low Power Wide Area Network) technology, improving latency and creating efficient lines of communication for nodes across multiple layers.*

Key Words: **Internet of Things; LoRaWAN; Fog Computing; Edge Computing; Smart Objects; LPWAN**

1.INTRODUCTION

LORAWAN is one of the most popular open standard protocols that provides access to the LoRa (Long Range) architecture and provides multiple functionalities. It is based on using multiple end nodes on a mesh network to communicate to one or more gateways, which features a variety of ways to connect such as the use of GSM modules, Wi-Fi transceiver antennas, or direct ethernet port connections. In this paper we will conceptualize a Fog-Edge computing model with considerations such environmental conditions, computing capacity, latency, optimal network structures, and power consumption. For this particular research, LPWAN technology was selected because of its performance flexibility, ability to integrate with complex structures, and protocols which prevent interference in terms of distribution density. The method selected is not intended to create a design specific to a single application, but rather to cater to a wide array of use cases by providing an architecture for a viable backbone in common Smart Objects. In the conventional cloud system, users (clients) send all data to the cloud and the cloud returns the computation result to users (clients). In the edge system, multiple servers called edges is connected directly or to close the distance between the cloud and the terminal [1].

2. LoRaWAN TECHNOLOGY

In this paper, we will delve into LoRa (Long Range), a protocol that enables wireless technology present in devices with low-power chipsets that are capable of communicating with a long transmission range directly to one or more fog computing networks using an internet connection as its backbone. In such cases, its servers and gateways are hosted by a network provider, while end-users supply the device and its complementing application server. Fog computing models based on this technology are capable of optimizing computational resource distribution which enables their gateway device with sufficient CPU cycles to decide on event-based triggers in real time, and essentially deviates from the original model of processing data from central servers in the cloud towards more individualized levels in IoT networks [2]. LoRa technology can be used in long distances and various terrains with adjustable transmission spectrums. LoRa is considered to be under the category of LPWAN (Low Power Wide Area Network) technologies that is based on a radio modulation technique called CSS (Chirp Spread Spectrum). It is most suited for industrial applications that require devices to operate with low power and send packets of data over to network gateways.

LoRa (LoRa) is a less power wide area network (LPWAN) protocol developed by Semtech. It is based on spread spectrum modulation techniques derived from the chirp spread spectrum (CSS) technology [3].

As depicted in Figure 2.1, these devices are able to operate for years on just a single battery charge. LoRa transceivers are able to operate from frequencies of 137 MHz to 1020 MHz, adjustable through SF (spreading factors). They are suitable to operate in licensed bands but are more often than not deployed in ISM bands.

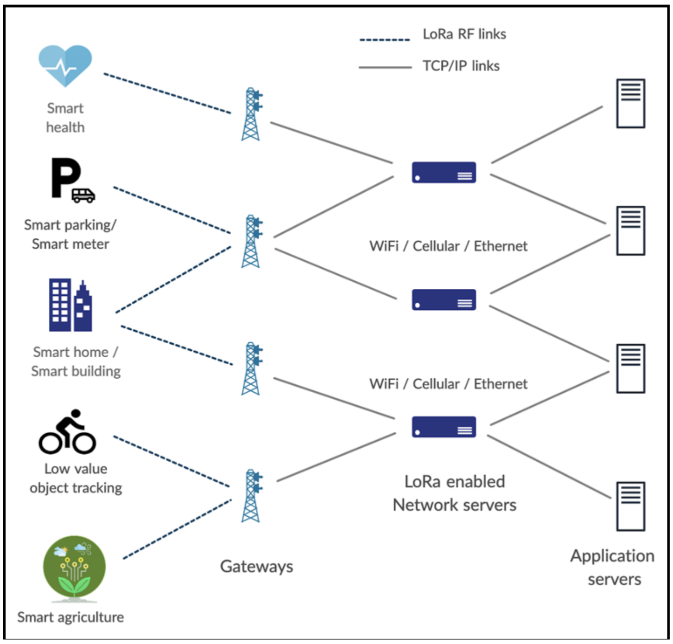
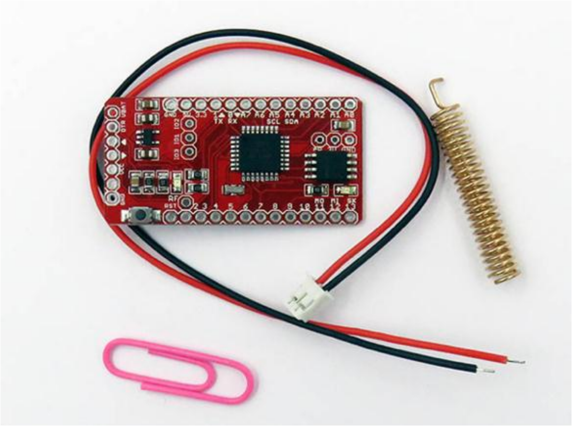


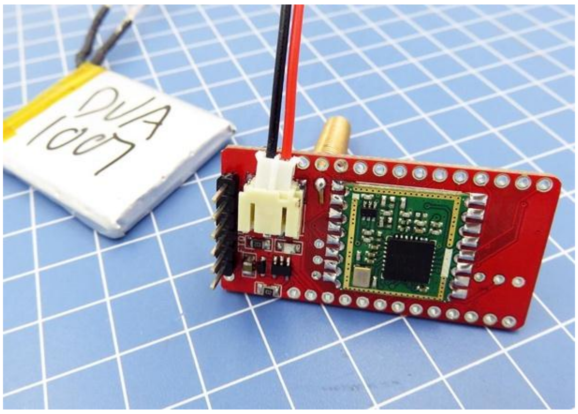
Figure 2.1 - LoRaWAN gateway servers interacting with end devices and application servers on both ends as an amplification layer

3. LoRaWAN ENABLED FOG GATEWAY TRANSMISSIONS

In an experiment conducted in a residential home, the spreading factor of LoRaWAN enabled fog gateway transmissions was measured using a sample payload of 50 bytes in order to discover the relationship between the spreading factor and multiple variables to create ideal smart city setups. The architecture takes into consideration the following aspects: power consumption, network structure and transmission modes. The figure below illustrates the experimentation functions, consisting of distinct and independent components. The first layer is made of edge nodes responsible for sending information, which can be stored temporarily or computed on a device level to perform event-based triggers. The link allows transmission to occur between the nodes and the LoRa server with dedicated fog nodes. The computing layer collects and processes data on a local database or the cloud which can be used to develop applications.

The paper's prescribed architecture is reliant on responsiveness of the devices. Spreading factor (SF) was an element which was tested as this is able to reveal how well transmission works with the LoRaWAN protocol under a fog architecture. SF can be set from SF7 - SF12 with different parameters, which can range from 128 chips/symbol to 4096 chips/symbol.





An experiment was conducted in a residential home with a basic setup using an SX1278 LoRa RF module based on the Atmega328P eight-bit processor shown in Figure 2.3. This module is connected to an Otii Arc using supplied test leads (Figure 3.3). The Arc is a device that serves as an oscilloscope to capture voltage and current readings at high resolutions.

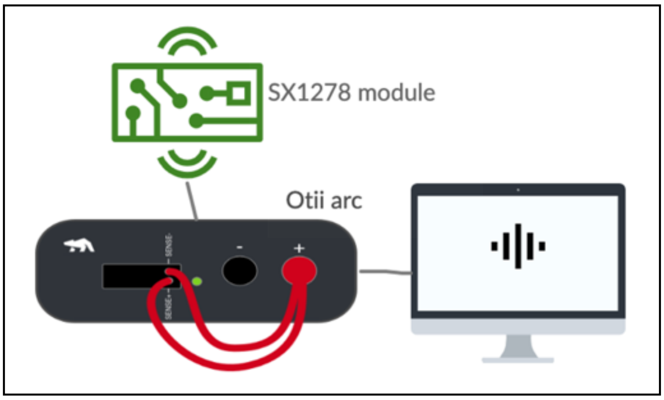


Figure 3.3 - Spread Factor test setup for power consumption measurements using SX1278 module is attached to the Otii Arc using supplied test leads.

The Otii Arc serves as a power supply for the module which is connected to a computer in order to display measurements in real time. Moreover, the software synchronizes with the Universal Asynchronous Receiver/Transmitter (UART) which logs processor operations in real-time during code execution. The following variables were evaluated:

- Relationship between SF & Power Consumption
- Relationship between SF & Transmission Time
- Correlation of SF with both Power consumption and Transmission time

4. RESULTS

Results from experimentation illustrated in Figure 4.1 reveal that increasing spreading factor also improves correction performance of the network but conversely consumes more power and increases transmission time.

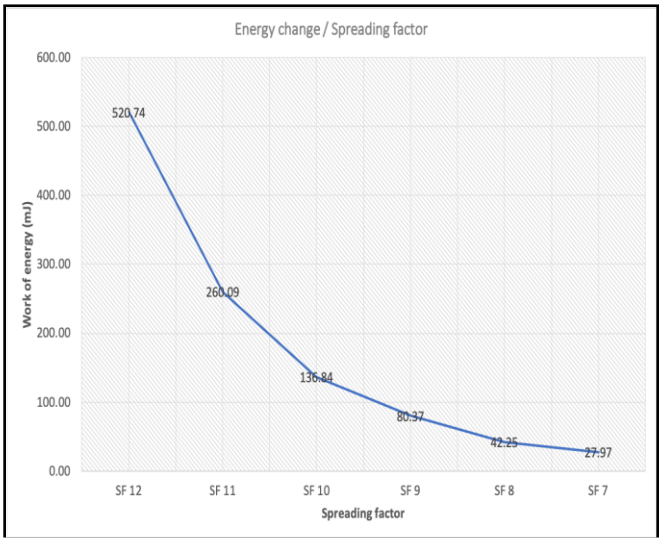


Figure 4.1 - Relationship between LoRa power consumption & spreading factor

The changes were measured thrice in order to narrow down the margin for error. As the figure depicts, there is a direct correlation between the increase of the SF and the power consumption, which also affects transmission time. The sample payload transmitted was 50 bytes, and the power consumption varies from 27.9 mJ to 520 mJ. Therefore, it can be concluded that spreading factor affects these variables.

The payload used was a constant variable. Payload ensures that device to device transmissions is able to reach their intended destination with integrity checks. It can be inferred that an increased payload also leads to increased net power consumption, as is the case with increasing the spreading factor.

Factor		Measure	
	Spreading factor	Work of energy (mJ)	Time of Transmit
1	SF 7	28.11	0.187
		27.81	0.184
		27.98	0.186
Average value		**27.97**	**0.186**
2	SF 8	42.22	0.288
		42.35	0.292
		42.17	0.283
Average value		**42.25**	**0.288**
3	SF 9	80.22	0.473
		80.5	0.466
		80.39	0.461
Average value		**80.37**	**0.467**
4	SF 10	136.82	0.791
		136.59	0.785
		137.12	0.788
Average value		**136.84**	**0.788**
5	SF 11	259.75	1.67
		259.91	1.676
		260.6	1.681
Average value		**260.09**	**1.676**
6	SF 12	519.84	2.93
		521.16	2.98
		521.22	2.87
Average value		**520.74**	**2.927**
Payload Length= 50 Bytes, Transmit Power = 10dBm, Sample frequency = 50hz			

Table 1. Table displaying the relationship of transmission time and energy consumption based on variable spreading factors.

In typical LoRa setups, depending on transmission frequency, reception requirements are increased where transmission power from devices is limited. This is based on the radio engineer formula, derived and simplified from the friis transmission equation where d = distance and λ = wavelength [4]:

$$L_{FS} = 20 \cdot log_{10}\left(\frac{4\pi d}{\lambda}\right)$$

Spreading factor, packet length and transmission power consumption are the three variables that can vary to take into consideration when performing further experimentation [8]:

$$w(t) = \int_0^t p(x)dx$$

SF and Packet length directly affect the transmission time, while transmission power is only affected by device power [8].

$$w(t) = P \cdot t$$

This equation can be rewritten as follows, where I = payload length, **α** is the SF, **PTx** represents transmission power, and **β** remains a constant variable [8].

$$w_{(l)\,frame\_send} = (P_{Tx} \cdot \beta) \cdot (\alpha \cdot l_{payload})$$

In a similar research conducted in [4] by Shanhe Yi et al, an experimental environment was created using a dynamic software simulation platform called iFogSim. The comparative study revealed important information about the performance of localized fog computing networks against a typical cloud-based architecture reliant on a cloud service with regard to latency, power consumption and bandwidth usage taken into consideration. The setup consists of heterogeneous devices connected to each other with edge computing capabilities, as well as the fog network which receives incoming traffic from the devices which effectively decreases the potential for latency issues. All devices had individual access points which enabled incoming connections from devices to the fog and the application side cloud capabilities.

Results of the experiment in [5] reveal that connecting to the cloud produced a much higher bandwidth consumption rate. Moreover, the evaluated power consumption differences under various parameters and revealed that fog networks use significantly less power, making it ideal for Smart City setups that involve the fog-to-fog communication networks that are responsible for communicating with multiple edge nodes and end devices.

5. LPWAN ARCHITECTURE FOR LIMITED CONNECTIVITY AREAS

A primary setback for deploying IoT solutions in low adoption areas is the absence of viable modes of communication for machine-to-machine, machine-to-man and machine-to-environment interactions. A LoRaWAN-based infrastructure is proposed as an appealing alternative to high bandwidth consuming devices in different settings. In locations with limited connectivity or lack thereof, it is still possible to transmit data using a local architecture which can produce and publish the information from sensors even for areas where connections are slow or inconsistent [6].

This can be accomplished by utilizing devices with edge computing capabilities. Such setups would entail harnessing edge gateways to process information from nodes to filter relevant data with a connectivity backhaul (Figure 5.1). It then utilizes the LoRa gateways as the fog layer that batch processes across a mesh topology within a local network before sending it out to cloud servers for storage and large-scale computing (if needed). Additionally, edge gateways have the capability to send packets back to the nodes in case there is a need for real-time event triggers. For this setup, LoRa Gateways act as an access point or more commonly known as a base station in which mobile devices and computers alike may connect to in order to gain access to the information collected by the nodes [5].

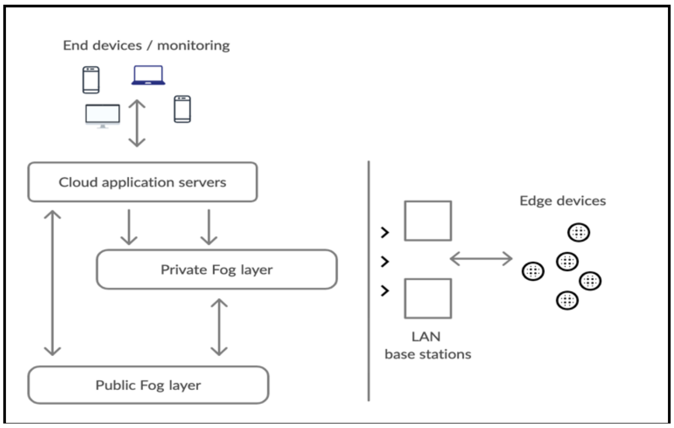


Figure 5.1. An illustration of a communication architecture for Edge nodes with LAN access points.

The benefit of using the additional LoRa fog layer is in its long-range transmission capabilities. Though a connectivity backhaul is still required, LoRa gateways are able to extend the range of communication to as far as 5 kilometers in urban areas and 15 or more kilometers in rural areas with a clear line of sight using transceiver modules [7]. Without this layer, edge computing nodes will require a stable connection nearby, which makes the fog an essential component of this architecture (Figure 5.2).

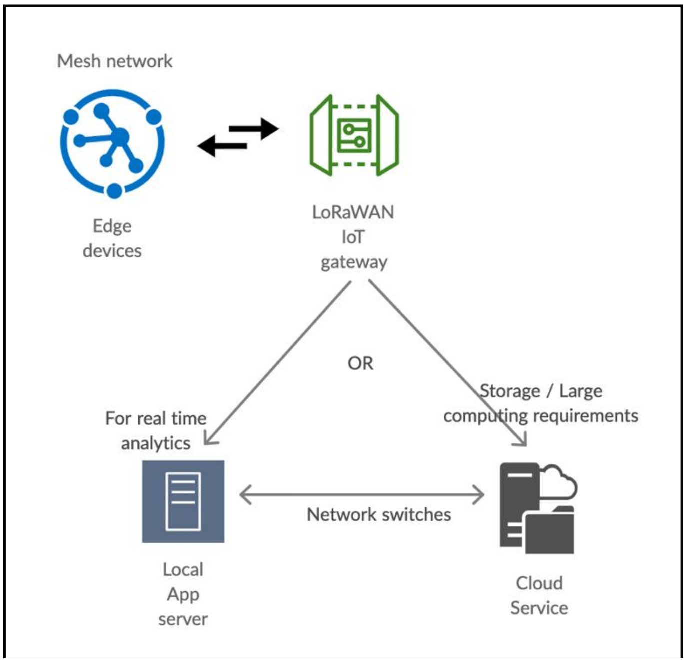


Figure 5.2. A hybrid fog/edge architecture with network switching capabilities for online and offline functionality.

Detailed below are several practical advantages to such a setup:

1. Fog nodes enable IoT devices to become truly ubiquitous. In situations where applications are reliant on cloud, there are unforeseen circumstances such as the loss of connectivity or

server downtime. In such cases, LoRa fog nodes then act as backup servers. This holds a significant advantage over direct-to-cloud setups, as the fog nodes are able to deliver services to application or device endpoints in the event that there is limited connectivity [7].

2. Heterogeneous IoT networks can take full advantage of edge computing nodes and sensors [8]. While dumb devices that function offline generally rely on sensor readings and pre-programmed reactions, adding a layer of edge computing creates a more dynamic range of critical to these changes without the need for firmware adjustments or human intervention. Mesh networks allow for these devices to communicate with each other and make adjustments, and LoRa acts as the endpoint which transmits data to and from the cloud.

3. This model effectively deviates from centralized networks, allowing more flexibility on the enterprise level. In smaller setups, such as a smart agriculture system, cloud computing only functions as a storage mechanism while load processing is more attuned to the fog layer comprising multiple edge nodes. As mentioned previously, LoRaWAN devices are able to exploit unlicensed frequency bands over long range links which ensures that they are able to operate in even low-connectivity environments [7].

6. DECENTRALIZED FOG ARCHITECTURE FOR SETUPS WITH POOR IT INFRASTRUCTURES

Service providers such as Amazon (AWS), Google (Cloud) and Microsoft (Azure) are at the forefront of providing large virtual data centers to host enterprise resources using a flexible cost model known as the cloud. This technology paved the way for application providers to use their diverse set of services to suit their needs and requirements, and ultimately save on costs involved with physical data centers while enabling smaller businesses to create value by using the cloud for hosting, processing and networking purposes [9]. Convenient and widely used, most Smart City implementers have thus designed their data infrastructures around the cloud computing paradigm. However, there are particular disadvantages that were brought to light, among the most prominent ones being the inability of less capable organizations to handle large amounts of traffic, privacy concerns over invasive devices, and larger costs for lower-bandwidth usage which has become an obstacle for adoption for smaller scale use [9]. Fog Computing was developed as both an extension and a lightweight version of the cloud and serves as an endpoint mediator to communicate with higher load remote servers.

The proposed architecture deviates from common fog computing node setups which are usually configured for use only for specified parties and devices on a single network [11]. This particular model reduces initial costs that accompany first-time integration to mesh network IoT structures. Moreover, applications that are envisioned to use this model fall under the category of only needing to transmit minimal bytes of data within certain time frequencies, which is in line with LoRaWAN specifications [12]. Outlined below are particular challenges that are taken into consideration for the design:

1. Compatibility. LoRa gateway manufacturers essentially act as network server providers. The proposed system ensures that the architecture allows nodes to communicate seamlessly regardless of providers by utilizing open-source servers for each sensor.
2. Computing Mode Flexibility. A robust model that allows devices on the edge to switch between interfacing locally with a LoRaWAN fog layer for lower-bandwidth computations and also being able to transmit larger amounts of data to the cloud for heavier processing requirements.
3. Privacy and Security. This approach allows for distributed computing while taking into account privacy consideration since the data is encrypted.

Increasing the efficiency of localized systems in this form of IoT architecture entails the use of multiple network servers that are able to communicate with each other. Moreover, it is also acknowledged that although it reduces latency, introducing multiple dedicated network servers may cause problems in terms of group configuration. As seen in Figure 6.1, Contrary to traditional setups which rely on a single centralized processing unit, this architecture enables several dedicated network servers within an area to feed information to each other using a distributed computing model, which in turn creates a data deduplication mechanism.

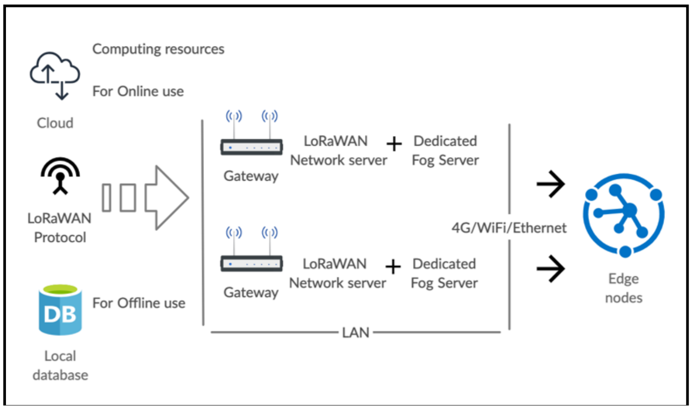


Figure 6.1. Edge nodes interacting with multiple LoRaWAN network servers with individual dedicated Fog servers to reduce latency.

7. CONCLUSION

Based on the results produced, it can be concluded the fog/edge hybrid architecture would work best with LoRa devices with optimized spreading factors for longevity and lower latency in order to function efficiently. Thus, the architecture would benefit from the use of edge devices that can perform computing functions on a local level on lower frequencies, which is then further filtered through the fog layer in order to optimize application timings. Another important factor to discuss would be the transmission time and transmission interval. From the results, it can be observed that shorter transmission intervals consume more power, which directly affects the lifetime of devices as they consume more power in the transmission state than the idle or sleep states where the devices await a potential downlink. Extending device lifetime is critical for larger scale IoT applications in a Smart City setup, as costs begin to increase if devices are not maintained properly.

How is LoRaWAN better than an alternative approach?
1. It is cheaper than 5G infra and can be deployed on an individual/much smaller scale.
2. Compared to other LPWAN tech, it has longer transmission ranges than BLE, it consumes less power than NB-IoT.

Drawbacks — smaller data packet rates, requires gateways to operate (see: The Things Network), slower transmission speeds.

In this particular architecture, the cloud computing paradigm takes a backseat to local level fog layer data processing and filtering. Accessing the LoRa network for sampling, processing and sending is a cost-effective and efficient solution for suboptimal conditions in environments with limited access to connectivity.

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BIOGRAPHIES

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