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Evaluation Of LoRaWAN In A Highly Dense Environment With Design Of Common Automated Metering Platform (CAMP) Based On LoRaWAN Protocol

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Abstract

Latest technological innovation in the development of compact lower power radios has led to the explosion of Internet of Things. With Wi-Fi, Zigbee and other physical layer protocols offering short coverage area there was a need for a RF protocol that had a larger coverage area with low power consumption. LoRa offers Long Range with lower power consumption. LoRa offers point to point and point to multipoint connections. with Single hop communication in place the need for routing protocols are eliminated. LoRa Wide Area Network stack can accommodate thousands of nodes under a single LoRa gateway with a single hop communication between the end nodes and LoRaWAN gateway. This paper takes an experimental approach to analyze the basic physical layer parameters of LoRa and the practical coverage offered by a LoRaWAN under highly dense urban conditions with variable topography. The insights gained from the practical deployment of the LoRaWAN network, and the subsequent performance analysis is used to design a novel public utility monitoring platform. The second half of the papers is designing a robust platform to integrate both existing wired sensor water meters, current and future generation wireless water meters. The Common Automated Metering Platform is designed to integrate both wired sensors and wireless (LoRaWAN and Wi-Fi) supported water meters. This integrated platform reduces the number of nodes under each LoRaWAN gateway and thus improves the scalability of the network. This architecture is currently designed to accommodate one utility application but can be modified to integrate multi-utility applications.

Keywords: LoRaWAN, Real Time Performance Analysis, Internet of Things, Water Metering, Common Automated Metering Platform

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1. Introduction

THERE is an increasing number of enabling radio technologies that are ultra-low in power consumption and can communicate over long distances. Some of the ultra-low power radio protocols are Sigfox, Weightless-N and LoRa (Long Range). These protocols allow communication range of up to tens of kilometers. These protocols allow the creation of Low Power WAN(LPWAN) that does not requires complex multi-hop topologies [1]. A distinctive of LPWAN feature is that it can make a tradeoff between throughput and distance. The ability to trade throughput and distance has found favor in the eyes of the Internet of Things market, academic as well as industrial researchers. Though this type of LPWAN feature is appealing and flexible for various IoT applications, it requires a thorough understanding of the protocol and its behavior in environment in which it is deployed [2]. A LPWAN offers radio coverage over a (very) large area by way of base stations and adapting transmission rates, transmission power, modulation, duty cycles, so that the remote nodes draw low energy. This paper analyses the performance of LoRaWAN protocol. LoRa is destined for utilizations where the remote sensor nodes (further down this paper the remote sensor node will be referred to as end node or remote node) have limited source of energy, where end nodes need to transmit not more than a few bytes at a time [3] and data traffic can be originated either by the remote node or by a peripheral that demands to communicate with the remote node. With long range wireless communication protocols providing seamless connectivity along with data security smart utility metering in urban areas are what government and private agencies are looking forward too. With lot of old manual utility metering system in place the transition time for a complete digital metering system has a long way to go. The transformation from old manual metering to digital metering poses risk and challenges like cyber security and data privacy. The issue of cyber security in public utility infrastructure is identified in [4] where incidents like the dragon fly group that attacked the U.S and European energy utilities firms using spear phishing attacks and watering hole attacks to gain access to the ICS (Industrial and Control Systems). In the year 2004 a SCADA system of water and wastewater management firm's security audit revealed the presence of mail based trojan backdoor in the Human Machine Interface (HMI). And there are other issues like the number of sensors deployed in each house by the public utilities. [5],[6] In India the government has planned to implement smart water meters that can automatically transmit the water usage to a remote server. Soon to follow are smart energy meters and gas meters. With all the essential utility services going smart and wireless there arises problem with each essential public utility wanting to have their own infrastructure. In this paper a Unified Infrastructure is proposed which provides flexibility to deploy the architecture as a single utility or a multi utility platform. The paper further is broadly divided into two section the first section deals with the performance analysis of LoRaWAN to see if it lives up to its name for performing well under highly noisy environment and the second section deals with the implementation of a Common Automated Metering Platform (CAMP) for water grid utility using LoRaWAN.

2. Related Study

2.1 LoRaWAN

The protocol here of interest is LoRaWAN, its performance and applications. [7] has made a comprehensive performance analysis on LoRaWAN with a mobile LoRa node and a static gateway. It has been observed that LoRa offers good SNR. With Chirp spread spectrum modulation LoRa provides better resistance against noise, it also provides better coverage area because of high receiver sensitivity that is on offer. LoRa performs better than other wireless protocols in terms of range, with a trade off in data capacity but well suited to be considered for IoT application. The drawback of LoRa crops up with increase in the network load. This characteristic is exhibited in ALOHA networks where, with increase in network load the network performance decreases. Based on a study conducted by [8] over a wide range of wireless protocols which includes protocols like LoRa, Sigfox and NB-IoT. The Quality of Service (QoS) of LoRa cannot match the QoS provided by NB-IoT, but in terms of message integrity over noisy channels LoRa outperforms NB-IoT. When network Latency is an integral part in a network to be deployed then LoRaWAN takes the back seat. With low latency and good QoS when compared with other radio protocols NB-IoT is good for high value applications. A study conducted in [9] on the Adaptive Date Rate feature built inside LoRa stack concluded the efficiency of ADR is dependent on the channel variance. When the channel variance is low or reaches zero it has been found to be effective. The ADR performance in denser network can be further improved by the inclusion of collision probability and parameter distribution information. Spreading Factor is the key physical parameter setting that influences other characteristics of a LoRaWAN Network. [10] has made an in-depth study on the effects of physical layer settings of a LoRaWAN Network. A study of environmental impact on a LoRaWAN network has also been done. The study concluded that when a node irrespective of the location from the gateway performs better than when the physical layer settings are the fastest (fast settings refer to the physical layer parameters that has got very low airtime) and slow physical layer settings are very resilient to noise and fading and has got greater airtime. With retransmission techniques coupled with fast physical layer settings nodes at the fringe of the network has got a better packet reception probability than the slow physical layer parameters. [11] LoRaWAN scalability is an important factor when it comes to large scale deployment. In a commercial IoT network there may be hundreds or thousands of nodes which leads to insufficient bandwidth and collision of packets. It has been observed that due to robust physical layer, LoRaWAN network is better than a pure Aloha network. The chirp spread spectrum modulation in LoRa, makes it a very robust over collision network. Experimental results show that traffic up to six time greater than a pure Aloha network can be transmitted in a LoRaWAN network.

2.2 Smart Water Grid (SWG)

In view of smart water grids there are few barriers that hinder the immediate adoption, they are installation cost and technology. Smart water grids are a necessity considering the potential benefits that it has in the long run. The benefits outweigh the cost. Since water is the lifeline for any society to survive, cost and privacy takes a back seat; and technology to bring down cost and find an effective low-cost smart water grid solution is always on the cards [12]. A small-scale deployment of SWG in [13] depicts the potential benefits of a large-scale deployment. The water quality and quantity were quantified and analyzed to predict the water usage pattern and the water quality. [14] Water management is based on integrated solutions to provide security and scalability.

3. Lora & Lorawan

3.1 Low Power Wide Area Networks (LPWAN's)

Internet of Things (IoT) is the current technology with an explosive growth with deployments in various fields like agriculture, logistics, structural health monitoring in smart cities, smart metering to name a few. An IoT application deployed requires the following network and radio characteristics, long range, ultra-low energy consumption, long battery life, secure data transmission, low latency. Traditional wireless local area network protocols lack the coverage area while offering low power consumption while wireless wide area network protocols like GSM, LTE, WiMAX has a large coverage area with shorter battery life [8], [15]. The LPWAN Protocols are categorically classified as shown in **Fig. 1**.

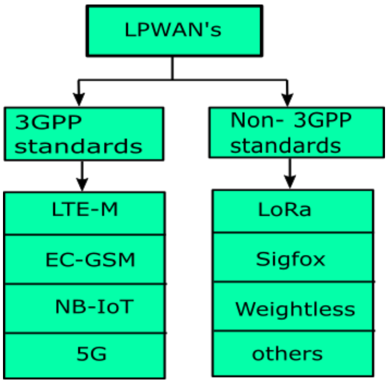

Fig. 1. LPWAN Classification

3.1.1 Introduction to LoRa:

LoRa is a patented proprietary communication protocol owned by Semtech. LoRa is a low power long range physical layer wireless communication link protocol. LoRa protocol uses a modified form of spread spectrum technique which is called Chirp Spread Spectrum (CSS) [16]. Frequency Shift Keying (FSK) is one of the preferred modulation schemes for achieving low power communication. For facilitating long distance communication with better signal to noise ratio (SNR) and low Bit Error Rate (BER), Spread Spectrum (SS) technique has been in deployment for many years in space communication and military. LoRa Protocol retains the low power feature of FSK while utilizing the spread spectrum technique to cover long range.

3.1.2 Introduction to LoRaWAN (Long Range Wide Area Network)

LoRaWAN outlines a communication architecture with LoRa in its physical layer. The LoRa alliance group is dedicated to developing the LoRaWAN architecture. In a LoRaWAN architecture the end devices communicate with a LoRa enabled gateway. The Gateway in-turn is connected to a network server and to the application server. A simple LoRa based deployment is shown in **Fig. 2**. The basic building blocks of a LoRaWAN architecture is made up of End device (remote Node), gateway, Network Server, and an application server. Communication between the end device and the gateway is established with the LoRa Radio and an IP (Internet Protocol) backhaul to connect to the network server. IP Backhaul may include any 4G or Wi-Fi networks or even wired broadband networks [17].

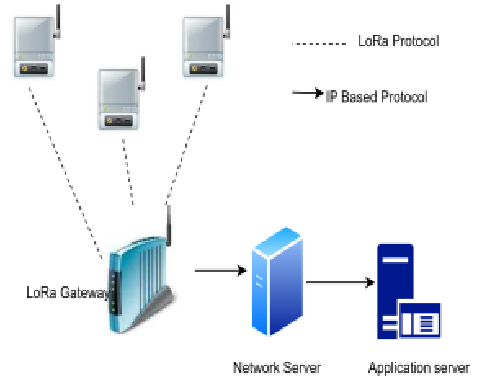

Fig. 2. LoRaWAN Architecture

3.2 LoRa Radio and LoRaWAN Specifications

3.2.1 Understanding LoRa Modulation:

To understand LoRa modulation it is necessary to understand the basics of spread spectrum modulation and Shannon-Hartley theorem. The Shannon-Hartley theorem (SHT) provides the maximum achievable bitrate for a given channel bandwidth, additive noise, signal power for which the information signal can be transmitted with very reduced bit error rate [18]. The SHT equation is given by

$$C_{bits} / S = B * \log_2 (1 + P / N) \tag{1}$$

Where, P/N = Signal to Noise ratio, B= Signal Bit rate.

[19] Spread Spectrum modulation involves the concealing of the information signal in a wide band spectrum. In general spread spectrum involves the use of a pseudo-noise (PN) sequence which is usually generated by a pseudo random sequence generator. The information signal is multiplied by the PN sequence resulting in a wideband signal. The small bits of information are referred to as chips. Consider the message signal as m(t) and the PN sequence as n(t), the resulting passband signal is given by p(t)

$$p(t) = m(t) * n(t) \tag{2}$$

The PN sequence generated is called the spreading code. Additive noise i(t) is added to the signal p(t) and the signal is sent over the channel. The resulting signal is given by S(t)

$$S(t) = p(t) + i(t) \tag{3}$$

Spread spectrum techniques are broadly classified as averaging type spread spectrum and avoidance type spread spectrum. The **Fig. 3** below shows the classification of different types of spread spectrum techniques that are available.

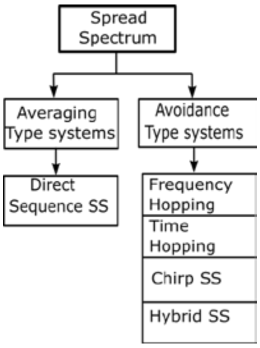

Fig. 3. Spread Spectrum techniques

Spread spectrum modulation used in LoRa is Chirp Spread Spectrum (CSS). Chirp Spread Spectrum involves the generation of chirp signals. The frequency of the generated chirp signals continuously varies with time. The receiver design complexity is reduced due to the fact that offsets in frequency and timing are equal between the transmitter and the receiver. The spectral bandwidth of the signal and the bandwidth of the chirp signal are equal. The formula to calculate the number of chirps generated is given by

$$Number\ of\ chirps = 2^{SF} \tag{4}$$

For example: spreading factor of 10 produces 1024 chirps for every symbol to be modulated. The relationship between chirp rate and the bit rate of LoRa modulation is given by (5).

$$R_C = 2SF * R_b \tag{5}$$

The bit rate (R_b) generated by a LoRa device is based on spreading factor (SF) and bandwidth (BW), therefore the equation for bit rate is given by

$$R_b = SF * [1/[2^{SF} / BW]] bits / \sec \tag{6}$$

The time period (T_s) of each symbol is given by the equation

$$T_s = 2^{SF} / BW \tag{7}$$

The symbol rate (R_s) of LoRa Modulation is given by taking the inverse of time period of symbol which is given by

$$R_S = 1 / T_S \tag{8}$$

3.2.2 Regulations in India

The operating frequency in India is from 865-867 MHz of the ISM (Industrial, Scientific, and Medical) Band contrast to Europe's 863-868 MHz and US 902-928 MHz The Indian sub-continent is entitled to use the assigned frequency. Though LoRa users are at the liberty to use any frequency within the specified bandwidth it is necessary that following frequency channels (865.0652, 865.4025 and 865.985) MHz are mandatory for any application [20]. LoRa gateways listen to these three channels by default. The default bandwidth in India is 125KHz although LoRa supports 250KHz and 500KHz it is not available for the Indian subcontinent. LoRa supports Bit Rate of (DR0- DR5) these are predefined data rates based on the Spreading Factor (SF) which will be discussed in the subsequent topic.

3.2.3 Spreading Factor (SF)

Spreading is the process of increasing the bandwidth of the message signal to maintain signal integrity over a noisy channel. In LoRa modulation chirp signals are generated in a higher rate than the actual data rate. The data signals are then modulated onto the chirp signals. The chirp signals in a LoRa modulation scheme varies in frequency. SNR and SF are directly related, higher the SF higher the SNR [21]. Spreading Factor selection for LoRa ranges from SF 7 to 12. A lower spreading factor gives a low SNR signal output whereas a SF 12 gives a high SNR signal. The formula to calculate the number of chirps generated is given by (4).

3.2.4 Bandwidth (BW):

Bandwidth in LoRa is the width of frequency occupied by the chirps. If the bandwidth is 125KHz then the number of chirps generated is equal to 125Kcps i.e. One chirp per Hz. In India, the regulatory norms restrict the user to only 125KHz bandwidth. Sensitivity and data rate are inversely related in LoRa. Higher data rate is obtained by higher bandwidth with lower sensitivity. To improve the sensitivity higher spreading factor value can be considered which leads to lower data rate but with higher sensitivity.

3.2.5 Coding Rate (CR)

Forward Error Correction (FEC) is used in LoRa data transmission. The FEC maintains the data integrity against sharp burst of noise signals that are stronger than the message signals. The available FEC coding rate options are 4/5, 4/6, 4/7, 4/8. Coding Rate is related with time on air. When a coding rate of 4/8 is selected the transmitted signals tends to have a higher airtime over a 4/5 coding rate.

3.2.6 Transmission Power (TP)

LoRa physical layer allows control over transmitted power. LoRa provides power control ranging from 2dBm to 20dBm. Transmission power increases when a higher SF is selected increasing airtime, in-turn increasing transmission power. Though LoRa offers a transmission power of up-to 20dBm. Practically power control can be exercised up to 17dBm due to duty cycle restrictions.

3.2.7 AirTime

Airtime in LoRa is the time interval between a signal transmitted from the end device to the time it reaches the gateway. Airtime depends on several LoRa transmission parameters i.e., SF, BW, CR. Airtime for different transmission parameters are shown in the **Table 1** below.

Table 1. Airtime calculation for four different cases

Transmission Parameters	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Spreading Factor	12	12	7	7
Chirp (2^{SF})	4096	4096	128	128
Bandwidth	125	125	125	125
Code Rate	4/8	4/5	4/8	4/5
Payload	51 bytes	51 bytes	51 bytes	51 bytes
Preamble Length	8 Symbols	8 Symbols	8 Symbols	8 Symbols
Airtime	3547.14ms	2465.79ms	151.81ms	102.6ms

Consider case1 and case2 where SF, BW and the payload load remains the same, the change occurs in the Forward Error correction i.e., Coding Rate (CR) where a 4/8 CR has got a higher airtime than the 4/5 in the case 2. By contrasting case 1 and 2 the inference is that code rate influences airtime.

Consider case 1 and 3 where all the other parameters are same except for the spreading factor which is 12 in case 1 the highest spreading factor supported by LoRa and the least in case 3 which is 7. Observe the variation in the airtime due to the number of chirps per symbol. In a deployment scenario case 1 has a better range and sensitivity than case 3.

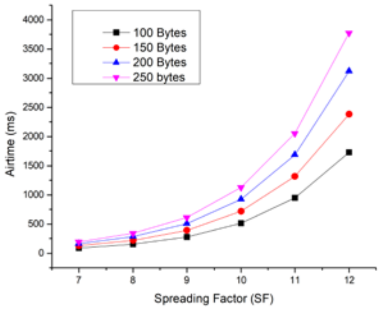

Fig. 4. Airtime vs Spreading Factor

In the **Fig. 4** graph is plotted between the SF and airtime in which the airtime gradually increases from nearly 100ms for the least SF to 2500ms for the highest SF. The airtime is also dependent on the size of the payload. It can be inferred that when the spreading factor is low (SF-7) there is no significant difference in airtime even when there is change in the size of the payload. On the other hand, when the spreading factor is maximum there is a significant change in the airtime.

3.2.8 LoRa Packet Format

In LoRa, data transmission is of two types Uplink messages and Downlink messages. The Uplink messages are initiated by the end-devices to gateway. The Downlink messages are initiated by gateway to the end-device.

Preamble	Physical Header	Physical Header CRC	Physical Payload	CRC

Fig. 5. LoRa Packet format

Fig. 5 represents the frame format of an Uplink frame structure. The preamble contains chirps inside which a sync word is encoded. The sync word differentiates one network from the other using the same frequency. In case of sync word mismatch the decoder or the receiver prevents from listening further to receive the message. The header is optional but it is transmitted with a FEC code rate of 4/8 which is the most reliable for a header which stores information on the payload size in bytes, payload CRC is optional(Uplink). The payload is limited in size to 255bytes.

3.3 LoRa Transmission Considerations

3.3.1 Free Space Path Loss

Path loss in radio transmission is the amount of energy lost in free space while a signal travels from the transmitter to the receiver. When the distance between the transmitter and the receiver is large, the amount of energy lost is higher. In other words, the energy at the receiver side is lower when the distance between the transmitter and the receiver is large. The equation to represent path loss is given by

$$Pathloss = (44\pi df / c)^2 \tag{9}$$

d= distance between transmitter and receiver in meters
f= frequency in Hertz
c= speed of light representing the path loss equation in terms
Equation (10) represents pathloss in terms of decibels.

$$Pathloss(dB) = 20\log 10(d) + 20\log 10(f) - 147.55 \tag{10}$$

Energy lost is a function of distance ’d’ with additional factors like reflection and refraction of signals.

3.3.2 Other transmission loss

As discussed earlier in the previous section 3.2.3 the signal to noise ratio depends on spreading factor. Chirps which are phase shifted in frequency are used to encode the data in the transmitter. The encoded data inherits the characteristics of chirps which are insensitive to interference. The chirps provide better resiliency towards pathloss, multipath propagation and fading in highly dense urban conditions. This research paper considers highly dense urban condition, in this case path loss is affected by many factors including absorption, reflection and refraction. Consider for example a 868MhZ LoRa signal can easily penetrate buildings and travel for longer distance while a 2.4 GHz Wi-Fi Signal travels less. Absorption due to obstacles affects the distance travelled by a radio signal. This drop in distance is due to attenuation of the signal strength. For example, materials like glass, concrete wall, wood absorb radio waves at different levels. Glass introduces a loss of up to 2dB based on its thickness whereas a thick concrete wall has an attenuation up to 35dB. Other factors include multi path fading due to reflection of signals by objects present between transmitter and receiver.

3.4 Performance Evaluation

3.4.1 Hardware for practical Evaluation

LoRaWAN architecture is built around three main components, a Gateway, wireless LoRa transceiver and a network server. The **Fig. 6** Gateway used for this experiment consists of two boards viz LoRa Gateway Core Module and Gateway Radio module by Microchip. The Radio board is built around two SX1257. The SX1257 is an integrated In-Phase and Quadrature Phase modulator/Demodulator multi-PHY mode integrated RF to front end digital transceiver. SX 1257 [22] can operate over a wide frequency range of 862 to 960MHz.It is power efficient and offers both narrow band and wide band modes of operation. It supports both full-duplex and half duplex modes of communication. The SX1257 provides a maximum channel bandwidth of 500KHz. The radio board is attached to a 9dB omnidirectional antenna.

Fig. 6. Gateway setup
(Image Courtesy: https://www.microchip.com/Developmenttools/ProductDetails/dv164140-1)

The concentrator in the radio module is SX1301 digital baseband signal processing engine. The SX1257 passes on the received in-phase and Quadrature phased digitized bit streams to the SX1301 where demodulation takes places using one or more demodulators and it presented to the packet handler. The demodulated packets are then sent to the LoRa Core Board. The objective of the core board is to convert the received packets from the radio board to TCP/IP based packets. This process is enabled by the PIC24 microcontroller which controls the flow of packets to the encoder ENC624J600 where the demodulated information bits are packed as TCP/IP packets. Communication between the LoRa Gateway and the network server is established through ethernet communication. The TCP/IP packets from the encoder are sent through a RJ 45 ethernet port to the network server.

Fig. 7. Remote Node

The **Fig. 7** LoRa wireless transceiver module (Remote Node) was developed by a company KrishTec using Arduino architecture. The transceiver is an Arduino based design with a MICROCHIP’s RN2483A LoRa Transmitter/Receiver. A 3dB antenna is connected to the transceiver and is powered by a portable battery power bank. The transceiver is programmed to send out pings at regular intervals. The RN2483A provides -146dBm of receiver sensitivity and maximum power output of 14dBm.

3.4.2 Range Test

The experimental setup follows a regular LoRaWAN architecture as shown in **Fig. 2**. The experimental setup is intended to test the performance of the network in a dense urban area with relatively tall buildings and a varying topography. The antenna and gateway are setup on the open terrace of a 14-story building which is about 50m tall. The wireless transceiver module is carried on a bike. The test was conducted from 4 PM IST to around 9PM IST when the vehicle traffic and interference at its peak. The temperature was around 32°C, with 45% humidity and precipitation at 59%. The tests showed that in highly dense urban conditions the maximum range covered by a single gateway was 4Km. Data pings were sent from a wireless LoRa transmitter from different ranges from the gateway. The **Fig. 8** shows the locations from which the data pings were sent and the distance between the transmitter and the gateway. It was observed that larger payloads farthest away from the gateway were lost whereas smaller payload size of 56Bytes were successfully received.

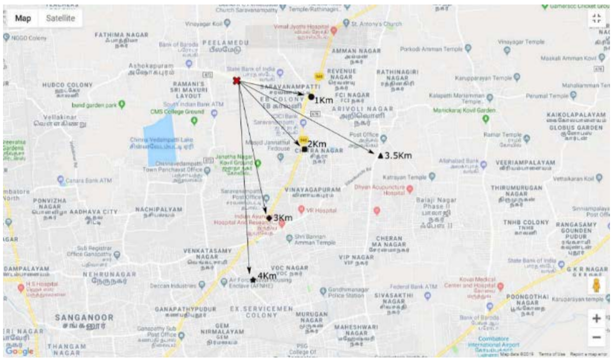

Fig. 8. Range test

3.4.3 Receiver Sensitivity and RSSI

The factors that affect the sensitivity of a received signal depends on the transmit power, terrain, spreading factor. In general, LoRa receivers can receive signals with RSSI as low as -146dBm. The sensitivity of receiver depends on the bandwidth used, the noise figure of the receiver and the SNR limit. The noise figure depends on the hardware used, the noise figure for the receiver SX1257 used in this experimental setup in 7dB. The bandwidth specified as per [20] is 125Khz for India. The mathematical relation used to calculate the receiver sensitivity is given by

$$S = -174 + 10\log 10(BW) + NF + SNR_{Limit} \tag{11}$$

The following **Table 2** shows the spreading factor, SNR limit and the receiver sensitivity. It has been observed that for every subsequent increase in spreading factor the receiver sensitivity increases by -2.5dB.

Table 2. Receiver sensitivity for different spreading factor

Spreading Factor	SNR (dB)	Calculated Receiver Sensitivity (dBm)
SF 7	-7.5	-123.5
SF 8	-10	-126
SF 9	-12.5	-128.5
SF 10	-15	-131
SF 11	-17.5	-133.5
SF 12	-20	-136

The receiver sensitivity shown in the **Table 2**, corresponds to the absolute limit the receiver can receive and demodulate the signal. It can be inferred that the receiver sensitivity increases as the spreading factor increases.

3.4.4 Real time RSSI distribution

The received signal strength for a spreading factor of 12 which corresponds to data rate (DR-0) has an average received signal strength of -113dBm for a transmitter 1Km away from the gateway. It can be observed that practical RSSI **Fig. 9** stays around a maximum of -115dBm for an urban city with high rise building and uneven topography and the gateway was never in line of sight with the transmitter nodes. consider data rate 4 across different ranges, comparing the RSSI value between 1Km and 2Km ranges the RSSI is higher for 2Km range because of the topography. It can be inferred that selection of spreading factor for nodes deployed for real time monitoring can be based on the location, elevation, and distance from the gateway. considering a default spreading factor of 12(SF-12) will drain the battery faster because of the higher transmit power and larger airtime as seen in **Fig. 4**.

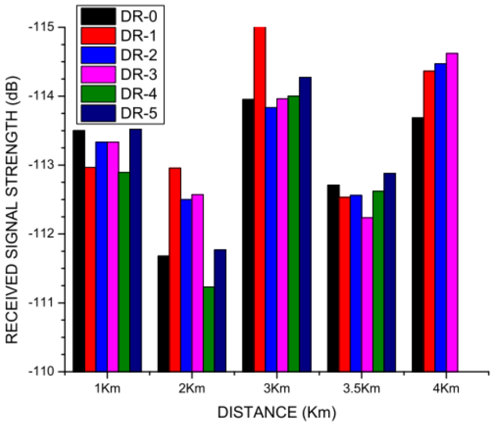

Fig. 9. RSSI Distribution

3.4.5 Signal to Noise Ratio

It is desirable that the SNR value stays above the noise floor. Whenever a transmitted signal falls below the noise floor the information gets corrupted. The receiver sensitivity in LoRa lies below the noise floor. Chirp Spread Spectrum allows LoRa to operate below the noise floor. In LoRa the SNR value lies between +10dB to -20dB. LoRa allows signals from -7.5dB to -20dB to be demodulated. The theoretical SNR for spreading factor is shown in **Fig. 10**, it can be inferred from the graph that the noise floor decreases as the spreading factor increases.

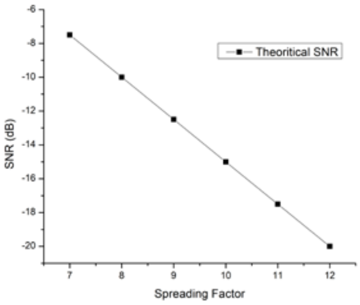

Fig. 10. Theoretical SNR vs Spreading Factor

In the **Fig. 11** shows the practical SNR against spreading factor. From the graph it can be observed that signal to noise ratio of 3.5Km is better than that of 3Km. For the 3Km range performance analysis the transmitter by deliberately placed behind a high-rise shopping mall complex completely blocking any line-of-sight path between the transmitter and the gateway. The radio waves had a take a path above and around the building, a small valley before it reached the gateway.

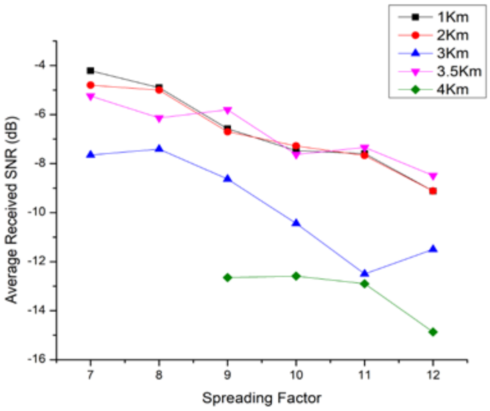

Fig. 11. Practical SNR Distribution

3.4.6 Packet Delivery

In a LoRaWAN network packet delivery ratio is high due to Adaptive Data Rate (ADR). The gateway manages the data rate of the end nodes. Every Wireless transmission is subjected to transmission loss; whenever an end node transmits a data packet, and it fails to reach the gateway it is considered that the packet is lost. To overcome this transmission loss, the gateway updates the Data Rate (DR) of the end nodes. The gateway incrementally updates data rate until there is successful transmission. The devices switch to a lower data rate where the spreading factor is high, for example if the device is operating with a data rate 3 (SF-9) and there is transmission loss the gateway updates the end nodes to data rate 0 (SF-12). It can be observed from the **Fig. 12** that whenever the data rate (DR-0) is used (black color bars) there is a higher packet delivery ratio compared to the other data rates. For non-critical application where data loss is acceptable lower data rates can be used with results in a longer battery life.

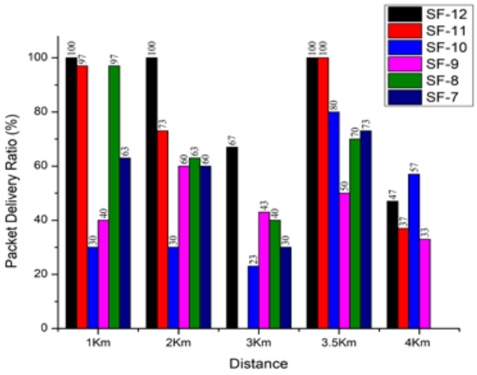

Fig. 12. Successful Packet Delivery

4. Common Automated Metering Platform(CAMP)

Common Automated Metering Platform (CAMP) is a smart metering platform that provides flexible deployment as a single utility platform or as a multi utility metering platform (here “utility” denotes public essential infrastructure like water, gas, power, etc.). The platform is built around an open sourced ESP32 module and RN2483A LoRa Module. The system is integrated into the LoRaWAN stack. The RN2483A LoRa Module communicates to a Radio Concentrator connected to the LoRaWAN Gateway. Transfer of data from the gateway to the network and application server is enabled through Ethernet. The LoRaWAN stack provides security through Advanced Encryption Standard (AES) security protocol. Secure connection is established between the end node and the network server and the application server with two independent 128-bit AES encryption key. The Network Session key and Application session key form the security backbone to the CAMP. The architecture and working principle of CAMP is explained in the subsequent sections. The CAMP platform is tested in a dense urban condition.

4.1 Architecture of CAMP

The Common Automated Metering Platform (CAMP) shown in **Fig. 13** is built around a [23] Espressif Systems is built around an Xtensa® Microprocessor with 34 Pins General Purposes Inputs Outputs and advanced peripherals like 12 bits Analog to Digital Convertor, 3 UART’s, it also supports ethernet MAC interface. ESP 32 is enabled with two communication protocols one is Wi-Fi and Bluetooth. To enable Long Range communication the ESP 32 is complemented with RN 2483A LoRa physical Radio.

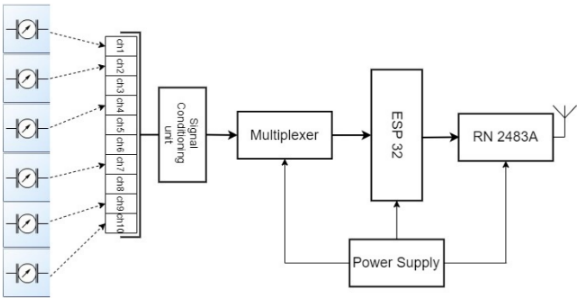

Fig. 13. Common Automated Metering Platform

The Signal Conditioning Unit (SCU) **Fig. 14** is constructed around an Instrumentation amplifier. This is done to accommodate a variety of sensors operating at different voltage levels. The signal conditioning unit also compensates for the transmission loss in wires. Sometimes sensors may be far away from the CAMP module a long haul wired connection may result in signal degradation. The gain of the incoming signal is increased so that signal loss can be compensated. [24] The SCU is a precision adjustable high gain instrumentation amplifier AD 620. The amplifier has an adjustable gain ranging from 1 to 10,000. It operates between +/- 2.3V to +/- 18V. AD620 is well suited for multiplexed application due to the low settling time of 15μs to 0.01% enabling one in-amp per channel due to the low cost.

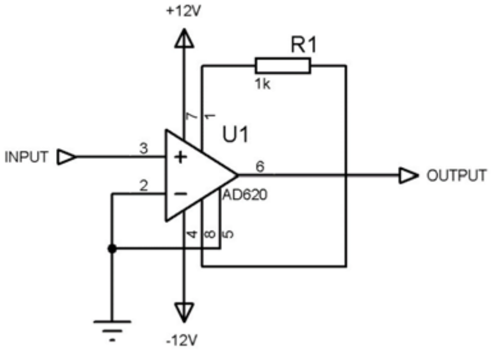

Fig. 14. Signal Conditioning Unit

4.2 General Deployment architecture with CAMP Module

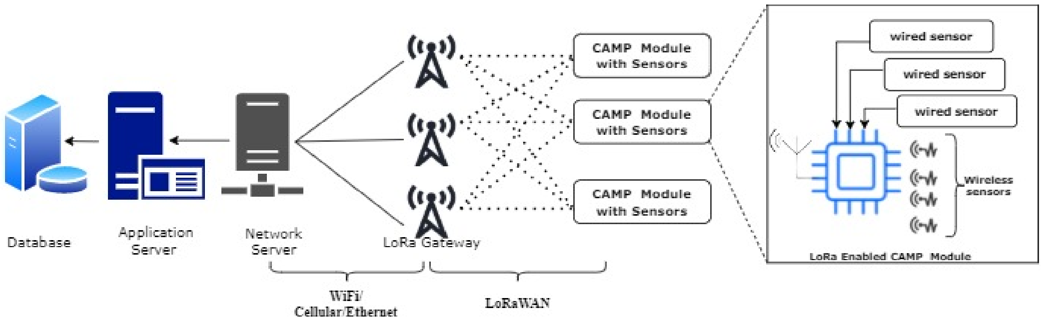

Fig. 15. LoRaWAN deployment with CAMP Module

4.2.1 Sensor to CAMP Module.

The **Fig. 15** shows a LoRaWAN architecture with CAMP module. Sensors connected to the CAMP module can be wired or wireless. Wi-Fi present in the ESP32 receives data from wireless sensors, data from the wired sensors received through a signal condition unit as shown in **Fig. 14** to compensate for the losses. A multiplexer is used to sequentially fetch the data from all the wired sensors through the digital pins. The sensor data is received as an array inside the firmware. The data are then encapsulated with the respective node id and then sent to the RN2483A LoRa module. The LoRa RF protocol transmits the to the LoRaWAN gateway. Security is provided by 128-bit Advanced Encryption standards (AES).

4.2.2 Gateway.

The gateway receives the LoRaWAN packet from the LoRa enabled CAMP modules. The gateway then encapsulates the LoRaWAN packet as a TCP/IP packet and transmits through any of the available internet backhaul. Security over the internet is provided by Transport Layer Security (TLS 1.2). The gateway also acts as a packet forwarder in a closed loop environment when implemented on a custom local server.

4.2.3 Network Server.

The network server is the manage engine for a LoRaWAN network. The Network server is responsible for transporting the IP traffic from the gateway to the application server. Apart from the traffic routing the network server is also responsible for managing data traffic from multiple gateways. The Networks server eliminates duplicate data packets from other gateways. The network server manages both the uplink and downlink traffic, where in uplink data from the end device is forwarded to the appropriate application server and in downlink the traffic from the application server is forwarded to the appropriate end device. Adaptive Data Rate (ADR) is managed by the Network server.

4.2.4 Application Server.

The application server is a web-interface. It offers interface to access deployed end nodes, gateways, and gateway management tools. Application Programming Interface (API) are implemented to connect to third party databases or applications. Application server also lets users to add/ remove/manage new nodes, gateways, applications, it also provides application or network administrators to activate or deactivate a device using Over The Air Activation (OTAA). Communication to the application server is over a JSON packet using MQTT (Message Queue Telemetry Transport) protocol.

4.3 Algorithm

The algorithm subsection contains two algorithms the first pertains to the CAMP module where the data fetching, and processing occurs. The second algorithm runs in the LoRa Module where the data from the serial port is fetch and transmitted over the network with the appropriate LoRa transmission parameters. LoRaWAN Packet transmission is enabled by the configuring the end nodes with the Device Address (DevAddr), Network Session Key (NwkSKey) and Application Session Key (AppSKey) for Activation By Personalization (ABP). For Over the Air Activation (OTAA) the end nodes are configured with the DevEUI which is a 64-bit end device unique identifier and the AppEUI which is also a 64-bit application identifier. OTAA is considered more secure than ABP. The DevEUI is a dynamically assigned to the device.

```
Algorithm 1: fetching sensor data

  Input: analog value
  Output: Volume of water in Liters
float $x \leftarrow 0$
$A \leftarrow Pin14$
$B \leftarrow Pin15$
$C \leftarrow Pin16$
$D \leftarrow Pin17$
$A, B, C, D \leftarrow Output$
$A \leftarrow 0, B \leftarrow 0, C \leftarrow 0, D \leftarrow 0$
/* run a loop to fetch data from all the channels in the 16 Ch mux */
foreach $i=0;\ i <= 15, i{+}{+}$ do
/* ch1=0,ch2=1,ch3=2.....ch16=15 */
    if If $i=1$ then
```

```
            /* change the number to binary 0001*/
            $A \leftarrow 0, B \leftarrow 0, C \leftarrow 0, D \leftarrow 1$
            $Delay\ (1000)$
            $Read\ x \quad ch1$
        end
        $print(ch(i) + "x" + ^\circ C)$
    end
    Terminate Program
```

Algorithm 2: LoRaWAN Packet transmission

Input: Integer data

Output: LoRaWAN Packet

```
Initialize the header for LoRaWAN communication
Initialize the LoRaWAN transmission parameters
/* for OTAA                                  */
Add the DevEUI
Add the AppEUI, AppKey from TTN or ChirpStack Server
/* for ABP                                   */
set the DevAddr
Set the NwkSKey and appSKey Send join request transmitthedata
    Repeat steps to send data
```

4.4 CAMP with LoRaWAN architecture for Smart Water Grid

The **Fig. 16** shows the real-time build of the CAMP module. The module is built to accommodate up to 30 channels. The CAMP module is supplied with a constant regulated DC supply of 5V,2A. The CAMP module communicates with a LoRaWAN gateway.

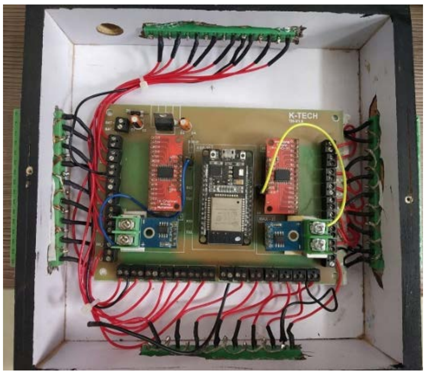

Fig. 16. CAMP Module

4.5 Real Time Data access

Real time data access is at the pinnacle of any Internet of Things infrastructure. Storage and access to real time data define a new area of research and technology like data analytics. Internet of things deployment generate a lot of data from single or multiple sensors with homogeneous or heterogeneous data types. Real time data access in IoT is enabled by MQTT (Message Queuing Telemetry Transport) protocol which is a publish and subscribe model. A MQTT broker connects the publisher which is the sensor nodes and a subscriber which can be a python server with a database management system.

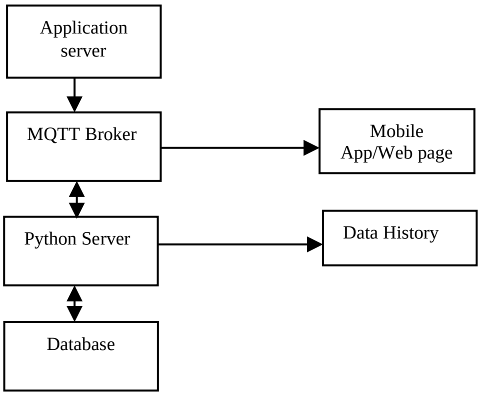

Fig. 17. Real Time Data Access

The block diagram shown in **Fig. 17** depicts the interaction between an application server, a dynamic mobile application, and a database management system. There are several MQTT brokers available in the market. The MQTT broker serves as a platform to receive the subscribed data from the application server to the database management system hosted on a desktop PC or a Raspberry Pi running a small server based on python. The subscribed data are stored in the database for real-time data analytics and further data processing. A dynamic real-time mobile application or a web-based application can be developed using Dove dash. The dynamic application is for data visualization in real time but does not store data. Data history can be retrieved by establishing a communication with the database system. A dynamic web-based application which can run on any web browser is represented in **Fig. 18**.

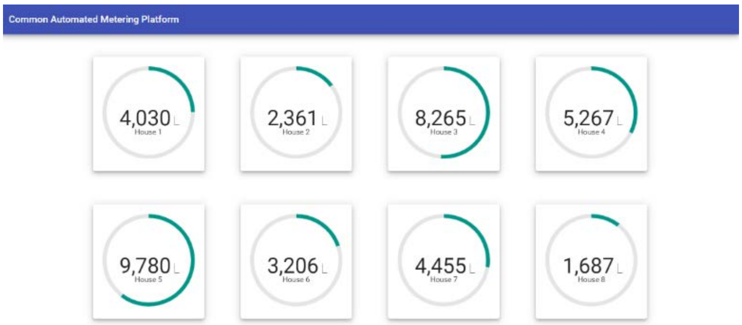

Fig. 18. Webpage

4.6 Smart Water Grid architecture using CAMP

The Architecture depicted in **Fig. 19** supports both wired and wireless water meters in the same network. This star of star topology improves scalability in Internet of things. Without the CAMP module in place each node will communicate individually to the LoRa Gateway. Considering the **Fig. 19** as an example with the CAMP module in place only three LoRa nodes communicates with the gateway. Each LoRa node aggregates the data from all other sensors and transmits to the Gateway.

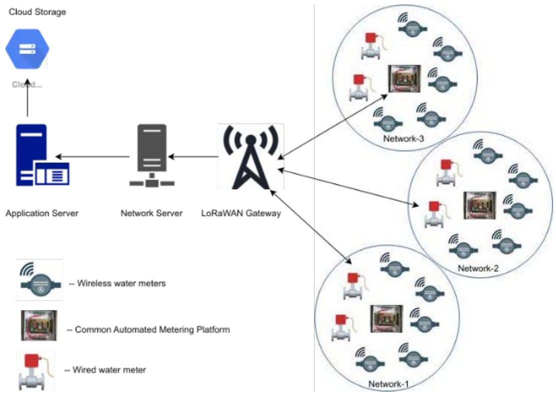

Fig. 19. SWG deployment using CAMP Module

To contrast the case without the CAMP module, 21 (the numbers mentioned here are for example) remote wired and wireless Water meters communicates with the LoRa Gateway. There is an 85 % reduction in the number of nodes that communicates with the gateway. This can lead to large scale integration of sensors under a single LoRa gateway there by improving the scalability under an existing infrastructure.

5. Conclusion and Future Work

This paper described a detailed experimental analysis of a LoRaWAN deployment in a highly dense urban condition with medium to small high-rise buildings and an uneven terrain. The experimental results show that SNR and packet delivery depends on the location of the node with respect to the gateway. There is no standard textbook method to set physical layer parameters for an end node, rather a survey of the particular location, availability of power to the remote node, knowledge of the SNR and RSSI between the end node and gateway would enable correct physical layer settings for maximum battery life. Although there is assured successful packet delivery with Data Rate 0 (DR-0) battery life is a tradeoff unless the nodes are sufficiently powered by a battery with solar energy or a regulated power supply. Further a Common automated metering platform was developed and found successful as a sensor aggregating platform which leads to the reduction in the number of sensors deployed. This can lead to considerable cost cutting in the sensor deployment and can lead to overall IoT infrastructure deployment cost. Further research ca be carried out in assessing the strategic placement of End node or the sensor node and predicting battery life through machine learning. Development of a handheld hardware device to find RSSI and SNR for strategic end node placement is a key requirement for those who deploy LoRaWAN services.

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