LoRa-Hybrid: A LoRaWAN Based multihop solution for regional microgrid

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***Abstract*—Low Power Wide Area Network (LPWAN), such as LoRaWAN, has become the most fast-growing Internet of Things wireless solution in recent years. In April 2018, the city of Newcastle in Australia has rolled out a smart city initiative by adopting LoRaWAN. With its long-range, low power and low-cost features, it is ideal for a regional smart grid as an extension of the smart city project. Whereas, LoRaWAN single-hop topology hinders its further expansion because this mode would require more gateway installation to extend network coverage. It is foreseeably cost-effective if the message can be relayed by end devices while not sacrificing the performances. In this paper, we present a novel architecture by utilizing LoRaWAN MAC (media Access control) layer and application layer to overcome obstructions, such as buildings and hills, extending radio coverage. During our field test, we receive encouraging performance outcome when putting the system to test in a simulated grid environment.**

Keywords-IoT; LPWAN; Coverage; LoRa; Time on Air; Relay; Spreading Factor;

I. INTRODUCTION

The world is witnessing a radical transformation of the public electric system. The penetration of renewable energy, e.g. solar and wind, contributes to the creation of – prosumer, who consumes electrical energy and can produce the energy as well. The bidirectional energy flow goes up the challenge for the grid and consequently delay the process of smart electrification, especially in the regional area, where conventional architecture is still in operation.

For instance, Single-Wire-Earth-Return (SWER) lines have proved to be a cost-effective solution for supplying electric power in some countries in their parsley populated areas across the globe, such as Australia, New Zealand and the US. It contributes to the rural electrification with its unique feature: low cost, low maintenance, and speed of construction. Currently, there are over 200,000km of SWER lines installed in Australia and some of them have been serving for over 50 years.[1] Nonetheless, lacking fault detection units and communication infrastructure in remote areas makes condition monitoring, fault detection, and equipment maintenance much more challenging, as the SCADA (Supervisory Control and Data Acquisition) system heavily relies on the real-time information. In addition, the long-term aging effect makes the line impedances increase and leads or poorer voltage regulation, which results in low transmission efficiency.

To address that, some work has been done previously. D. Gay in his paper performed a comprehensive analysis of applying PLC (Power Line Communication) in regional SWER systems. Network monitoring, regulation, narrowband and broadband of PLC are reviewed in the work. [2] PLC seems to be a feasible solution except for the fact that it only functions when overhead power transmission lines are powered. Bushfire, which is commonly-seen in regional Australia, can easily cause the blackout.

The emerging LPWAN technologies, with its long range and low power features, can establish the connection within more than 10 kilometers. TABEL I. compares the various parameters of the popular LPWAN protocols.

TABLE I. LPWAN COMPARISON

	Sigfox	**LoRaWAN**	**NB-IoT**
Modulation	BPSK	CSS	QPSK
Frequency	Unlicensed ISM bands	Unlicensed ISM bands	Licensed LTE frequency bands
Bandwidth	100Hz	125kHz, 250kHz, 500kHz	200kHz
Maximum Data Rate	100bps	50kbps	200kbps
Bidirectional	Half-duplex	Half-duplex	Half-duplex
Maximum Payload Length	12 bytes (UL), 8 bytes (DL)	243 bytes	1600 bytes
Range	10 km urban), 40km (rural)	5 km (urban), 20 km (rural)	1 km (urban), 10km (rural)
Standardization	Sigfox Company	LoRa-Alliance	3GPP
Allow Private Network	NO	Yes	No

Sigfox and NT-IoT are proprietary solutions which means they are not flexible enough to customizations. [3] Compared to its counterparts, LoRa, is an open-source project with physical and network layer open to the public so that adoption of the technology and customization is realistic in this case.

Sungwook Ko with his team evaluated LoRaWAN network based on his PHY factors between tree farm and open area and draw the conclusion that the PDR ratio is higher in open area than in the tree farm.[4] While Adwait Dongare's work covered the LoRaWAN network coverage study and signal penetration in buildings, by setting up networks to record the RSSI (Received Signal Strength Indicator) and PDR (Packet Delivery Ratio). The statistics are accurate references for building RF planning. [5] However, neither of the work has proposed a solution to address the "blind spot" issue, where the bi-directional communication is unstable or unreachable due to obstructions, in both rural and urban areas. It becomes critical for micro-grid when monitoring power quality with renewable energy recourses being increasingly deployed.

LoRaWAN is operating line-of-sight condition and in a star-of-starts topology, which means no multihopping mechanism among its nodes. To achieve a greater range of the network and close to 100% coverage of the area, this paper presents a novel approach by utilizing LoRa physical layer characteristics to communicate P2P (Peer to Peer) between LoRa devices: LoRa-Hybrid. In the next section, LoRa and LoRaWAN will be briefly introduced, together with the field test. In the third section, we will cover how LoRa-Hybrid works and, in the end, the result will be compared with LoRaWAN to evaluate the performance.

II. LoRa and LoRaWAN

LoRa™ is a wireless modulation for long-range, low-power applications developed by Semtech. It is a proprietary spread spectrum modulation scheme that is derivative of Chirp Spread Spectrum modulation (CSS). While LoRaWAN is MAC (Media Access Control) Layer protocol typically in a star-of-stars topology in which gateways replay messages between end-devices and the gateway.[6] Fig. 1 presents the relationship and differences between the two.

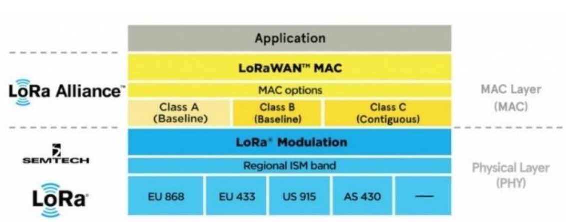

Figure 1. LoRa PHY and MAC layer

A. LoRa (Long Range)

LoRa is a PHY layer protocol with several transmission parameters to operate on, especially the SF (Spreading Factor) and data rate. They are the trade-off between robustness and data rate.

- SF (Spreading Factor 7…12)

SF is the ratio between symbol rate and chip rate.

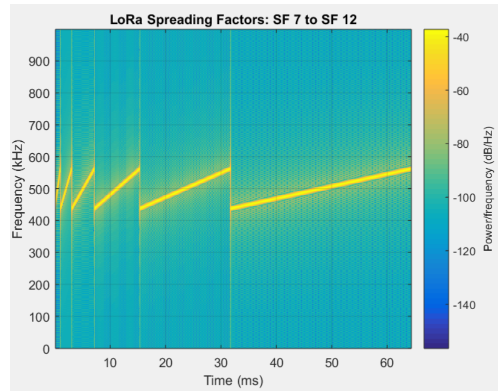

Figure 2. LoRa modulation simulation with different SF

Fig. 2 illustrates the time that takes to transmit a symbol from SF7 to SF 12 with bandwidth equa1s to 125kHz. The higher the SF, the longer the time-on-air.

- Transmission Power (TP)

There is a limitation to LoRa transmission power of 20dBm the maximum to avoid congestion and interference. As in the LoRaWAN specification, low power devices communicate with each other in industrial, scientific and medicine (ISM) radio bands, which are widely shared by other applications.

- Regional Frequency

LoRa spectrum ranges from 137MHz to 1020MHz with different regulations in different counties/regions. For example, Australia is running on the 915-928MHz ISM band, while 863-870MHz for Europe. [7]

- Bandwidth (BW)

LoRa modulation is bandwidth scalable with possible configurations either 500 kHz, 250 kHz or 125 kHz. The higher the bandwidth, the higher the chip rate (data rate). But a higher bandwidth will give a lower sensitivity. [8]

B. LoRaWAN overview

LoRaWAN is the MAC (Media Access Control) layer protocol developed and maintained by LoRa Alliance, which is a non-profit association of more than 500 companies.

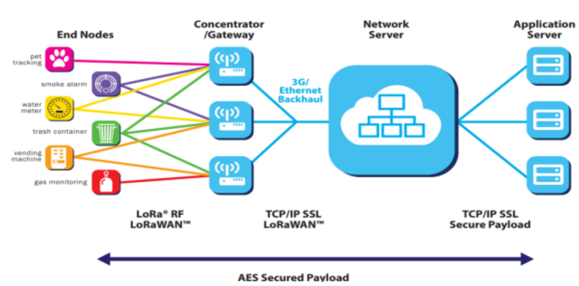

Figure 3. LoRaWAN network archtecture

As shown in Fig 3, LoRaWAN supports star topology with IP backhaul to the network server and application server with AES secured connection enabled. It is optimized for battery-powered end-devices that may be either mobile or mounted at a fixed location. To address the fast-growing demand of the data from micro-grid, LoRaWAN has been chosen as the LPWAN solution in both regional and urban areas to transmit sensor data back to the operation room. By establishing a private LoRaWAN network as above, connectivity tests are performed with gateway setup in Tyree Energy Technologies Building (TETB) in UNSW with 4G connectivity as the backhaul.

Fig 10. shows the impact of different terrains. LoRaWAN performs expectedly in line-of-sight condition (Point C and Point G) even the distance is much further than the other two (Point D and Point E), where the rise of terrain obstructs communication. Even when TP set to its maximum power 20dBm, and SF set to 12, there is no connection (NC) between the gateway and point D and E, not to mention data transmission. C means connecting successfully to gateway.

III. CASE STUDY LORA-HYBRID

All the LoRaWAN end devices must be activated before they can communicate with the gateway. There are two ways of activation: Over the Air Activation (OTAA) and Activation By Personalization (ABP).

A. OTAA

Fig. 4 illustrates the OTAA process that end device (EN) initiates by sending a join request message to the network server, then receives the encrypted message.

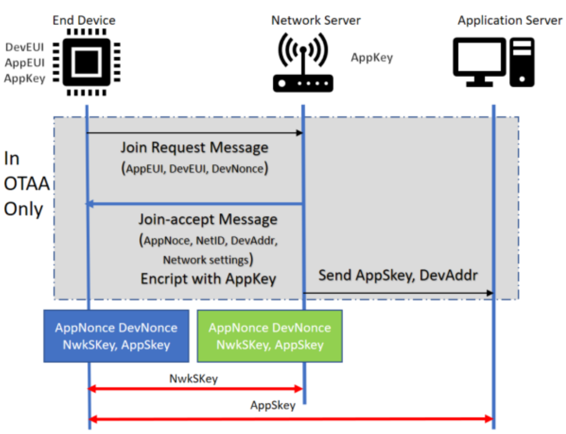

Figure 4. Sequence LoRa device joins network

The AppKey is used to generate NwkSKey (Network Session Key) and AppSKey (Application Session Key) by AES-128 encryption algorithm.

B. ABP

In ABP, NwkSKey and AppSKey are stored in the end node directly before use, instead of the "join request and join accept" procedure. ABP works as in Fig. 4, excluding the grey area, which is OTAA mode.

In the LoRaWAN specification, it requires that each device should have a unique set of NwkSKey and AppSKey. Without the exchange of keys, it is exactly how symmetric encryption works in theory. Instead of connecting to the server, the LoRa transceiver devices can talk to each other with careful programming and configuration.

C. Lora-Hybrid

In this section, we describe LoRa-hybrid, which combines OTAA and ABP features to realize the multi-hop function. Fig. 5 shows the interaction between different components.

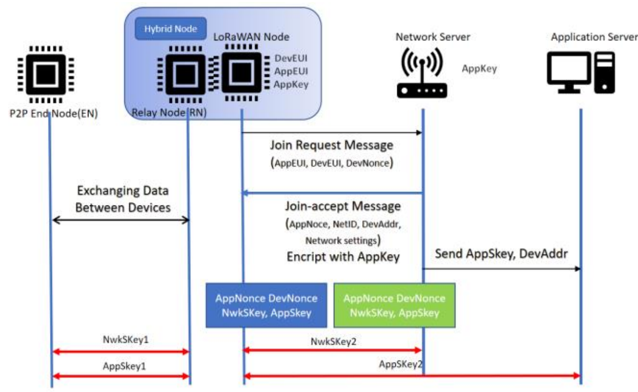

Figure 5. LoRa-Hybrid mechanism

LoRaWAN node connects the gateway and maintains the connection with OTAA, while Relay Node (RN) keeps listening to the message from end node (EN) with ABP. This design can ensure no message lost as there are dedicated chips responsible for listening and transmitting respectively.

D. Hardware configuration

Lora-Hybrid is put to test with the following settings. We select Multitech mDot which comes with ARM Mbed libraries for radio control. Fig. 6 shows how the LoRa chip is mounted to a hybrid node. With the xBee shield and adapter, two mDot (LoraWAN Node and Relay Node) are mounted to National Instrument Myrio. Fig. 7 shows the LoRa end node sending high voltage data collected from the optical sensor to the gateway at the interval of 10 seconds.

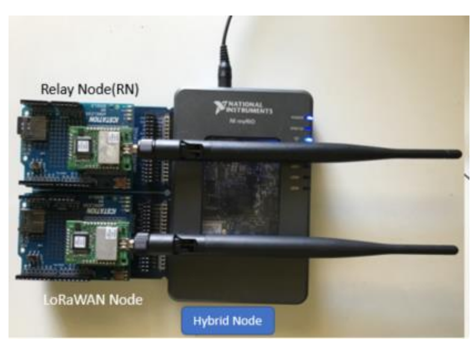

Figure 6. Lora-Hybrid node connected by Myrio

Figure 7. LoRa end node receives optical sensor data

Myrio forwards message from RN to the OTAA activated node. So that soon as the message received from RN, it will be sent to LoRaWAN Node and transmitted immediately.

IV. PERFORMANCE EVALUATION

LoRa-Hybrid performances will be evaluated against several key measurements of LPWAN protocols: time-on-air, duty cycle, and PDR.

A. Time on Air (TOA)

Time on air measures the time the sender takes to transmit the signal until received by the receiver. To effectively plan Lora network and design constraints, it is necessary to calculate the time on air.

The duration of a symbol T_{sym}, spreading factor and bandwidth can be linked by

$$T_{sym} = \frac{2^{SF}}{BW}. \quad (1)$$

LoRaWAN specification describes the LoRa packet format as in Fig. 8.

Figure 8. LoRaWAN packet formatting

The payload duration $T_{payload}$ is calculated as

$$T_{payload} = T_{sym}(8 + \max(\text{ceil}(\frac{8PL-4SF+28+16-20H}{4(SF-2DE)})(CR+4), 0)).$$

(2)[9]

With the following dependencies:

- PS is the number of payload bytes.
- SF The spreading factor.
- H=0 header is enabled H=1 header not enabled.
- DE=1 low data rate optimization is enabled, DE=0 for disabled.
- CR is the coding rate from 1 to 4 (1 by default).

Then the time on air can be given by

$$T_{total\ toa} = T_{preamble} + T_{payload}. \quad (3)$$

Set bandwidth to 125kHz, CR=1, H=0, DE to enabled, preamble = 8 Symbols, CRC to enabled. According to the regional parameters for Australia, 11,53 and 126 bytes are selected to calculate among various spreading factor. Those numbers of bytes are the maximum payload length for different data rate code, as shown in Fig. 9.

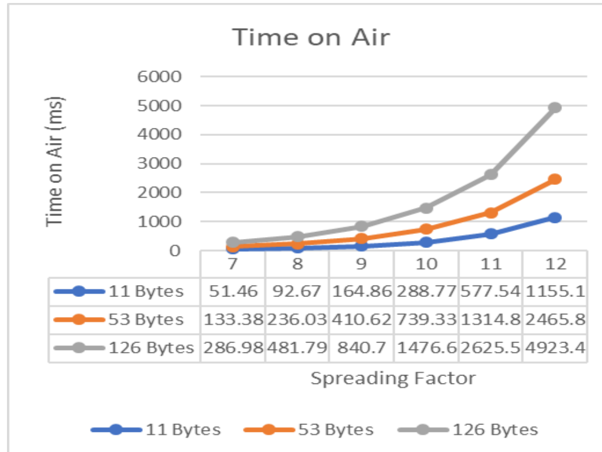

Figure 9. Time on Air results from Spreading factor 7 to 12

With bandwidth equals to 500kHz, it will see a big drop of time on air. For instance, SF = 10 and payload length = 53, the result is 184.83ms, compared to 739.33ms when BW = 125kHz.

In Fig. 9, if T_n is the time on air for different spread factors, n is the spreading factor, it is not hard to calculate that $T_n > T_{n-1} + T_{n-2}$ with the same bandwidth. This means that transmitting message with two hops, that modulated by a lower spreading factor, can always reduce the time on air, which is imperative in a real-time system.

B. Duty cycle

Duty cycle refers to the fraction of time a resource is busy. In some regions, e.g. Europe, has 1% duty cycle for ISM band, which means if LoRa end device transmits an 11 bytes message with the TOA 1.155 seconds at SF12. It must wait for 1.155*99 equals to 114 seconds to be able to transmit again. while it takes 2*51.46*99 equals to 10.2 seconds for SF7 to be able to transmit again. Of course, it neglects the communication distance when calculating. Lora-Hybrid is a feasible solution when the communication problem happens within LoRa range due to obstruction, such as trees, hills and buildings, not distance.

C. PDR (Packet Delivery Ratio)

A field test was carried out with end note at point D and hybrid mode at point H, as shown in Fig. 11. PDR equals to 0 when testing in point D in Fig. 10. With LoRa-Hybrid, we have reached 100% PDR with the hybrid node placed at point H running for 30 minutes with 10s as the interval, which means no packets lost.

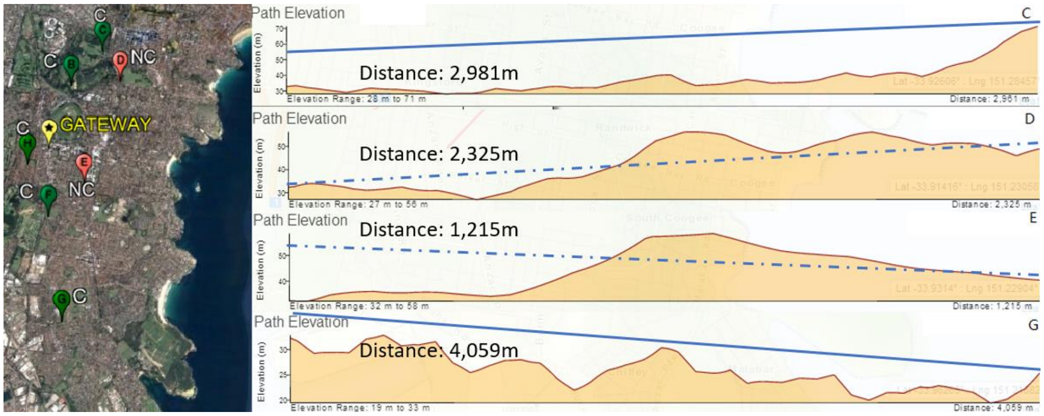

Figure 10. Field test map and elevation information

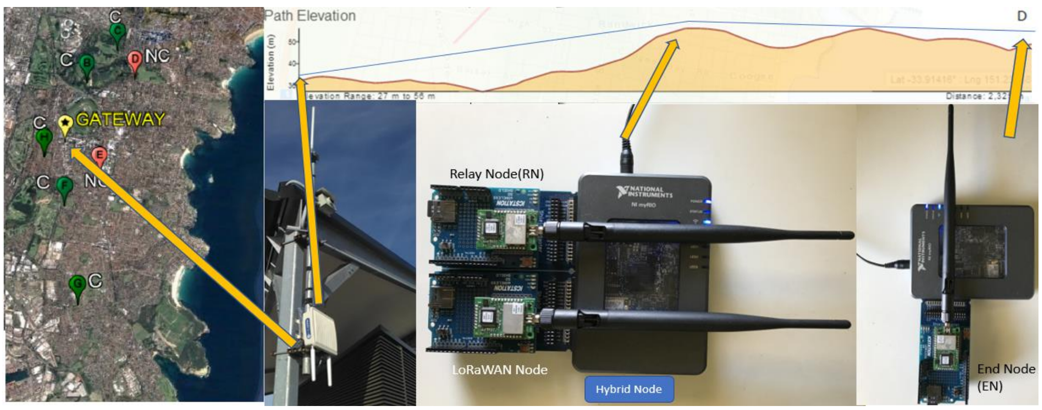

Figure 11. Field Test with Lora-Hybrid for Point D

V. CONCLUSION AND FUTURE WORK

Lora-Hybrid has proved its capability in solving LoRaWAN dilemma between data rate and coverage with the cost of adding one more LoRa chip into the network. By successfully transferring an ABP node into a P2P device, it makes possible for LoRaWAN to add the second hop, from device to device, to its specification. With improved PDR and TOA, it becomes realistic for microgrid to embrace this new protocol for a smarter grid.

How much we can expand LoRaWAN in multi-hop pattern is not studied, neither the performance in the bushland. Our future research will focus on the capacity of LoRa-Hybrid, especially the hopping mechanism, to explore its extreme coverage in mountainous areas for the regional microgrid.

VI. ACKNOWLEDGMENT

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