Cluttered Traffic Distribution in LoRa LPWAN

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ABSTRACT

Low Power WAN (LPWAN) is a wireless broad area network technology. It is interconnects using only low bandwidth, less power consumption at long range. This technology is operating in unauthorized spectrum [1] which designed for wireless data communication. To have an insight of such long-range technology, this paper evaluates the performance of LoRa radio links under shadowing effect and realistic smart city utilities clutter grid distribution. Such environment is synonymous to residential, industrial and modern urban centers. The focus is to include the effect of shadowing on the radio links while attempting to study the optimum sink node numbers and their locations for maximum sensor node connectivity. Results indicate that the usual unrealistic random node distribution does not reflect actual real-life scenario where many of these sensing nodes follow the built infrastructure around the city of smart buildings. The system is evaluated in terms of connectivity and packet loss ratio.

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1.   INTRODUCTION

Internet of Things is projected to ease human life. Every machine are interconnected with one another so less human resources are needed. The new wireless technologies have been produced by the name Low Power Wide Area (LPWA), with the special characteristics that suitable for the implementation of IoT applications which also include a simplified network topology, power optimized radio network, frame sizes transmitted several times in a day at ultra-low speeds and upstream communication model that enable the end-devices to stay in low energy mode [2].

With this setting, it enables a range of kilometers with longer battery life; which up to ten years of operation, low cost devices with plain but scalable deployments and thin foundation. The LPWA features, makes it possible for IoT to function well with only use a very low bit-rate of data for reporting and does not need frequent changes of the batteries because of the low-powered features of the LPWA [2].

The existing technologies do not promote low powered energy consumption with larger scale coverage. With the development of science and technology, the LPWA is the new trend and many researchers working forward to find the solution for the mentioned problem so that it will be implemented everywhere. LoRa is one of the solution for the problem which promising for lower energy consumption, higher data rate, easy installation and some more features.

The topic is concern about the performance of LoRa (Long Range) Radio Link which is one of the LPWA technologies which promising wide area for IoT technologies that was proposed by Semtech company and later being promoted by the LoRa Alliance. LoRa used chirp modulation technology, which allowing for long range transmission with low power and low cost for designing. This can be achieved by using the spread spectrum technique accommodating several devices in a channel. The termed LoRaWan has

been defined as the higher layers and system architecture on top the LoRa physical layers. With all these attributes, it makes LoRa suitable to be used for IoT [3].

The objective of this paper is to evaluate the performance of LoRa shadowed radio links, typical in urban and semi urban centers, together with clutter distribution and optimal sink node placement using measures of connectivity, packet loss ratios and Data Throughput. The paper is organized as follows. Section 2 is the background about this research. Section 3 discusses the research methodology. Section 4 presents the results and discussion and the paper concluded in section 5.

2. BACKGROUND
2.1. Long Range WAN (LoRaWAN)

LoRaWAN is one of the media access control (MAC) protocol which meant only for broad area network and it is aim is to allow low powered devices to interact with Internet-connected applications over long range wireless connections. This protocol can be mapped to the second and third layer of OSI model and implemented on top of Frequency Shift Keying (FSK) modulation or LoRa in scientific, industrial and medical (ISM) radio bands. Also, the protocol is defined by the LoRa Alliance and formalized in the LoRaWAN Specification and Regional Parameters [4].

The LoRa gateways utilized long range star network topology and being used in a LoRaWAN framework (see Figure 1). Due to the of properties of LoRa, the framework are multi-modem handsets, multi-channel and ready to demodulate on different channels simultaneously and demodulate various signals on the indistinguishable channel in the meantime.

The endpoint utilizes distinctive radio frequency with the getaways to permit high limit and execute as a straightforward extension handing-off messages between the end-gadgets and a central system server. End-gadgets utilize a hop remote correspondence to the portals while gateways associated with the system server through standard Internet Protocol (IP) associations. The portal has numerous adaptations and it is relying upon the use limit and coveted establishment area (e.g.: tower versus home) [5].
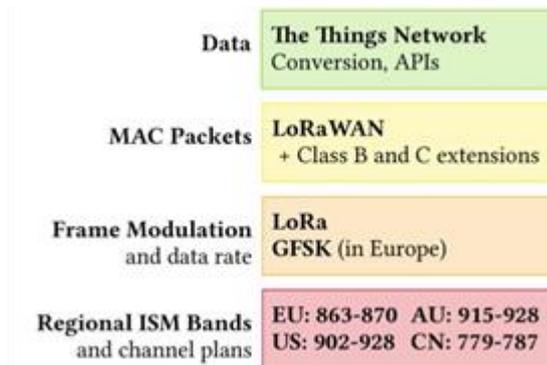
Figure 1. LoRaWAN stack [4]
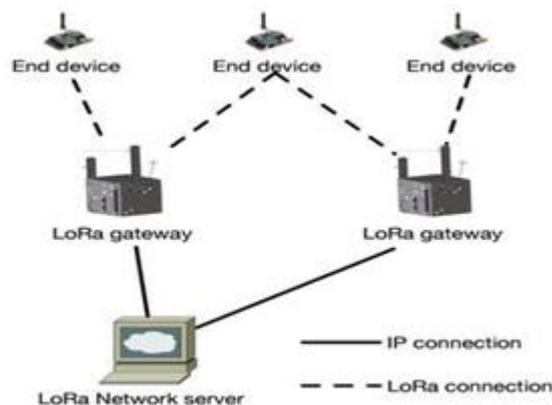
Figure 2. The architecture of LoRa which include three dissimilar devices [6]

2.2. LoRaWAN Air Interfaces

LoRa Alliance has released the air interface specific document, which are:

- LoRaWAN air interface v1.0.0
- LoRaWAN air interface v1.0.1
- LoRaWAN air interface v1.0.2 (in final review)
- LoRaWAN air interface v1.1 (in development)

With the development of LoRaWAN air interface specification, the level of security and privacy has guaranteed. The application provider is solely responsible for the encryption of the entire application payload using the AES128 Application Session Key. With this feature, it confirms the security of the payload. Next, 32bit signature has been added which result in computed the entire frame by using a Network session key. This attribute guarantees the originality of the devices and the frame cannot easily modify [7].

The security on the air does not assure whether the network server can easily be hacked, or the device is anti-temper. To get an anti-temper device, a hardware secure element must use to store and derive the keys. In addition, to implement the cryptographic functions in the network server, it is advisable to use a Hardware Key Management system [7]. The Table 1 shows the air interface version compliance matrix.

Table 1. An Air Interface Version Compliance Matrix [7]

	v1.0.x device	v.1.1 device
v1.0.x network server	Default case today	Device will behave as a v1.0.1 device
v1.1 network server	Server will behave as a v1.0.1 server	Full support of v1.1 functionalities

2.3. Long Range and Shadowing Effect

The LoRaWAN communication is expected to cover longer distances; hence, frames can be lost due to propagation loses, and some physical phenomenon such as shadowing effect, reflection, and scattering. All of this need to be taken into account whenever we do the simulation because there is no "perfect" things in real life.

Shadowing is the effect that the received signal power varies due to objects blocking the propagation path between transmitter and receiver. These variations are experience on local-mean powers, that is, short-term averages to remove variations due to multipath fading. The shadowing effect is needed in our calculation so that we can emulate real-life system performance and we can predict what will happen in the future and find a solution for it.

3. METHODOLOGY

We had used several methods to achieve the objective of the research. First of all, the simulator that had been used through all the works was provided by paper [8]. We had made several changes to the simulator so that it will improved the results and in line with our research. Here are the further discussion of the modification that had been made to the simulator.

Firstly, the propagation model was been altered follows the paper [9], [10] measurement due to its realistic representation of real-life application scenario in a modern urban center. Table 2 shows the details of propagation model characteristics.

Table 2. Propagation Models Characteristics

Ref No.	Path Loss Exponent (n)	Shadowing Effect, σSF	Mean Path Loss, Lpl(d0)
[9]	2.32	7.8dB	128.95
[8]	2.08	-	127.41

The simulator is a discrete-event simulator based on SimPy. SimPy is a process-based discrete-event simulation framework based on standard Python and its event dispatcher is based on Python's generators. It was created to simulating collisions in LoRa networks and to analyze scalability. The purpose of the research studies was to identify the number of required sink node gateways to provide connectivity for clutter sensor node distribution in a typical residential city area. Furthermore, we would like to investigate the effect of shadowing on the links while doing so to make our simulation more realistic. Hence, the performance metric would be the number of connected nodes, the Shadowing Effect on the number of lost packets, the Data

Throughput. Furthermore, we have followed the four experiments done in [9] by changing the setting parameters for the air interface according to Table 4.

Nodes are placed equally-distant around the sink such that all nodes can reach the sink with the prearranged setting SN if shadowing effect is not included. The three transmitter configurations SN1, SN2 and SN3 are given in Table 4.

In all settings, it is being imagined that a 20-byte packet is being sent by each node every 16.7min representing a realistic application. The chosen setting for SN1 is the most robust LoRa transmitter settings which leads to transmissions with the longest possible airtime of 1712.13ms, with SN2; the transmission setting leads to the shortest airtime of 7.07ms and with SN3 the chosen setting is the one which is used by common LoRaWAN deployments [9]. Table 3 below shows the major adjustment that had been made to the simulator including justification to the alteration.

Table 3. Changes made to the simulator

No.	Settings	Original simulator	Alteration	Justification
1.	Minimum Sensitivity	See Table II [8]	Modified according the model in [9]	As mentioned earlier in the methodology section
2.	Shadowing effect	None	Added to the simulator with input parameters derived from [9]	Adding the shadowing effect will give the realistic output with regards to the environment rather than ideal case only

To describe the path loss model in a built up area, we choose to use the log-distance path loss model because it is commonly used in free space area. It matches with LoRa environment where LoRa technology claimed to be used in built-up area, free space and larger area. Below is the log-distance path loss equation:

$$Lpl(d) = Lpl(d0) + 10nlog(d/d0) + \sigma SF$$

where,

$Lpl(d)$	: the path loss in dB,
$Lpl(d0)$	: the mean path loss at the reference distance $d0$,
n	: the path loss exponent,
$\sigma SF \sim N(0; \sigma^2)$	: the normal distribution with zero mean, $\sigma 2$ is the variance to account for shadowing effect [8].

3.1. Research Method

Firstly, seven trial have been conducted using the same setting with differing the number of sinks in every run. The sensor nodes were placed corresponding to the smart city environment. Total of 1200 sensor nodes were distribute into three clutters with 400 sensor nodes in every clutter. The remaining 400 sensor nodes was distributed scattered inside the scale. The number of sinks or base stations we increased in every trial and every experiment set. There are five sets of experiments and each experiment consists of seven trials. Every experiment has different settings implemented which were:

Table 4. Experiments' Settings [8]

Exp.	Spreading Factor, SF	Bandwidth, BW	Coding Rate, CR	Details
0	12	125	4/8	Settings with slowest data rate
1	12	125	4/8	Same with Exp. 0 but use a random choice of 3 transmit frequencies
2	6	500	4/5	Settings with fastest data rate
3	12	125	4/5	Settings as defined in LoRaWAN
4	6 or 12	125 or 500	4/5 or 4/8	Optimize the setting per node and transmit power based on distance from gateway.

Other than that, the trials correspond to seven different placements of base stations which are one, two, three, four, six, eight, and 24. In the first set of experiments we evaluate the standard capacity of LoRa using a simple setup where N nodes transmit to one sink. In these experiments, standardized transmitter configuration set SN = {TP, CF, SF, BW, CR} will be used (see Table 4 for definition of air interface parameters).

Table 5. Experiments' Set of Parameters [8]

Parameter	SN1	SN2	SN3
Spreading Factor, SF	12	6	12
Carrier Frequency, CF	868	868	868
Transmit Power, TP	14	14	14
Bandwidth, BW	125	500	125
Coding Rate, CR	4/8	4/5	4/5

Figures 3 show the placement of sensor nodes and base stations for clutter distribution.
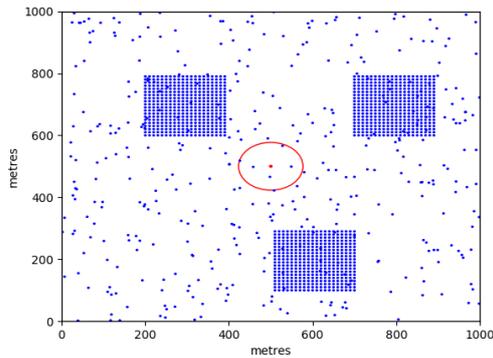
Figure 3. The number of sink is 1, and the number of nodes are 1600
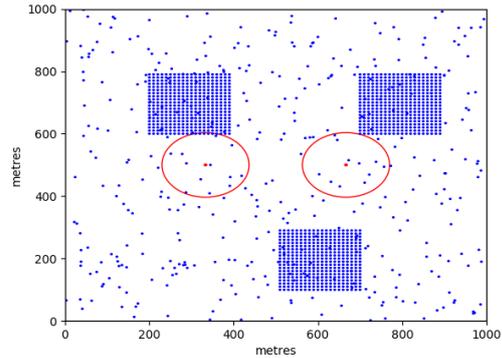
Figure 4. The number of sink is 2, and the number of nodes are 1600
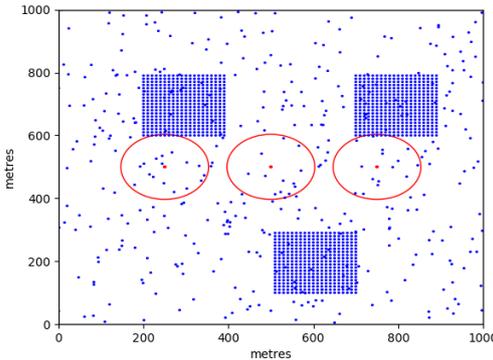
Figure 5. The number of sink is 3, and the number of nodes are 1600
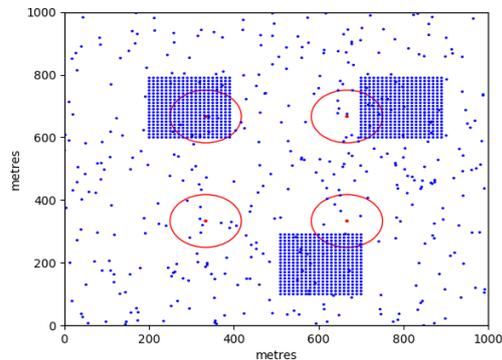
Figure 6. The number of sink is 4, and the number of nodes are 1600
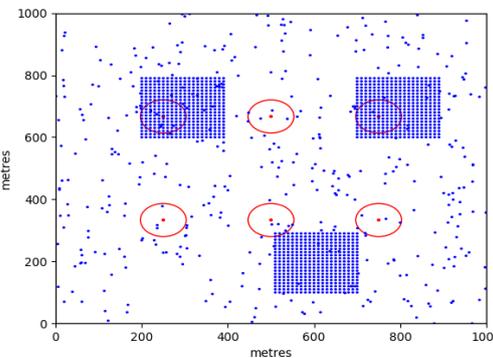
Figure 7. The number of sink is 6, and the number of nodes are 1600
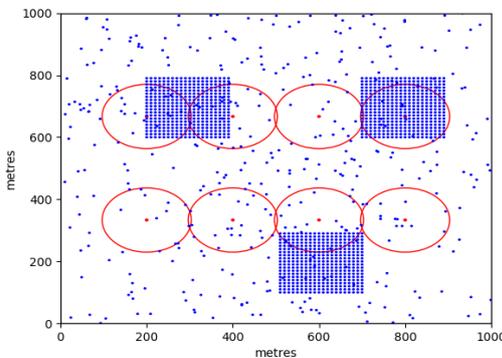
Figure 8. The number of sink is 8, and the number of nodes are 1600
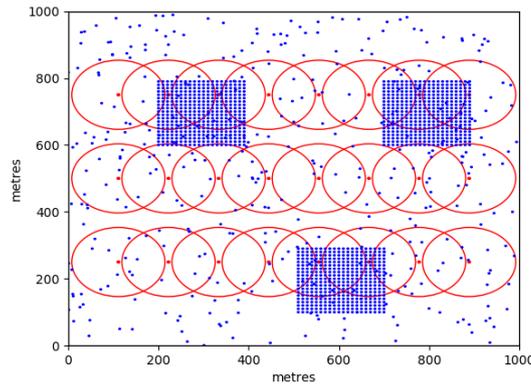
Figure 9. The number of sink is 24, and the number of nodes are 1600

The results of the above experiments consist of two different parameters. Firstly, we want to identify the number of connected nodes. Secondly, we want to investigate the Shadowing Effect on the number of lost packets from all 35 outputs we got from seven trials for every experiment. Finally, we want to see the Effect of Shadowing on the Data Throughput which are consists of Data Extraction Rate (DER), Data Extraction Rate (DER); is the ratio of received messages to send messages over period. The achievable is depending on the number, position and behavior of LoRa sensor nodes and gateways which is defined by SN, M and N and its value is between 0 and 1. The more effective LoRa deployment is the reading which is closer to 1 and vice versa. [8] The metric is looking at the network deployment and not recording the individual node performance. the number of receive packets, collided packets and sent packets. Our results will be compared to cluttered distribution (without effect of Shadowing) result and from that, we will come out with the conclusion for this research. All the discussion of the results will be available in the next section.

4.　RESULTS AND DISCUSSION

Results of the experiments consists of various part, which were; firstly, Number of Connected Nodes. Secondly, Shadowing Effect on the Number of Lost Packets. These results were reported in [10]. Thirdly, the Data Throughput

4.1.　Number of Connected Nodes

This section presents the effect of shadowing on the number of connected (covered) nodes. From the results presented in Figures 10 and 11, there are no much differences between the two results which were without applying the shadowing effect and with applying the shadowing effect. Also, the result shows the number of sensor nodes covered were increase gradually as the number of sinks increase. It is true because, as the number of sinks increase, the nodes tried to reach either one of the sinks so that it can transfer the packets directly to the sinks.

NUMBER OF NODES COVERED
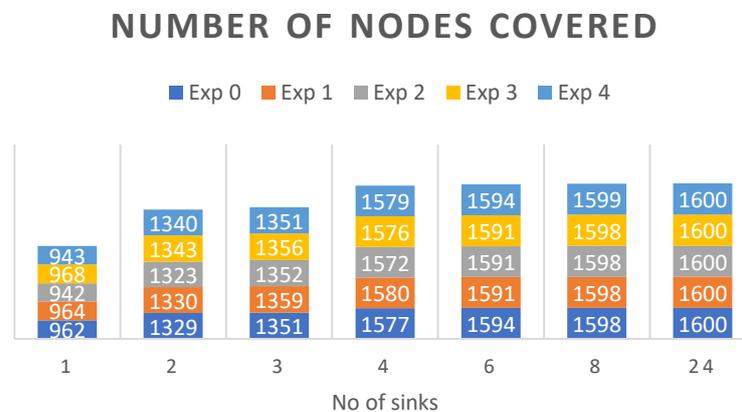
Figure 10. Number of Connected Nodes without Shadowing Effect

NUMBER OF NODES COVERED

■ Exp 0 ■ Exp 1 ■ Exp 2 ■ Exp 3 ■ Exp 4

No of sinks	1	2	3	4	6	8	24
Exp 4	964	1327	1352	1580	1595	1599	1600
Exp 3	965	1326	1361	1571	1590	1600	1600
Exp 2	961	1327	1368	1575	1588	1597	1600
Exp 1	754	1130	1417	1584	1588	1600	1600
Exp 0	961	1339	1371	1579	1594	1599	1600
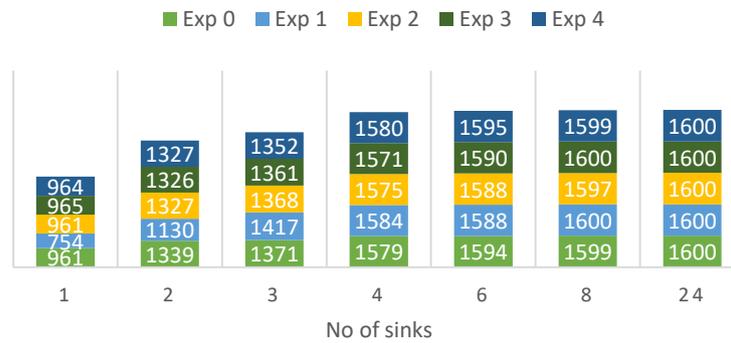
Figure 11. Number of Connected Nodes with Shadowing Effect

4.2. Shadowing Effect on the Number of Lost Packets

This section presents the effect of channel shadowing on the number of lost packets. Based on the result above in Figures 12 and 13, with the shadowing effect, the packet lost were increasing as the number of sinks increase. It is because, the sensor nodes tried to reach each one of the sinks to transfer the packets, which leads to greater loss in the packet transfer. Without shadowing effect, there were no much differences in terms of lost packets that we had identified from the experiments conducted.

NO OF LOST PACKETS FOR CLUTTER DISTRIBUTION

■ Exp 0 ■ Exp 1 ■ Exp 2 ■ Exp 3 ■ Exp 4

No. of Sinks	1	2	3	4	6	8	24
Exp 0	2162	3061	3043	3368	3434	3527	3570
Exp 1	2272	3017	2947	3378	3498	3554	3660
Exp 2	2366	3069	3123	3379	3540	3539	3602
Exp 3	2338	2997	3049	3437	3423	3565	3618
Exp 4	2404	2973	2992	3408	3572	3485	3591
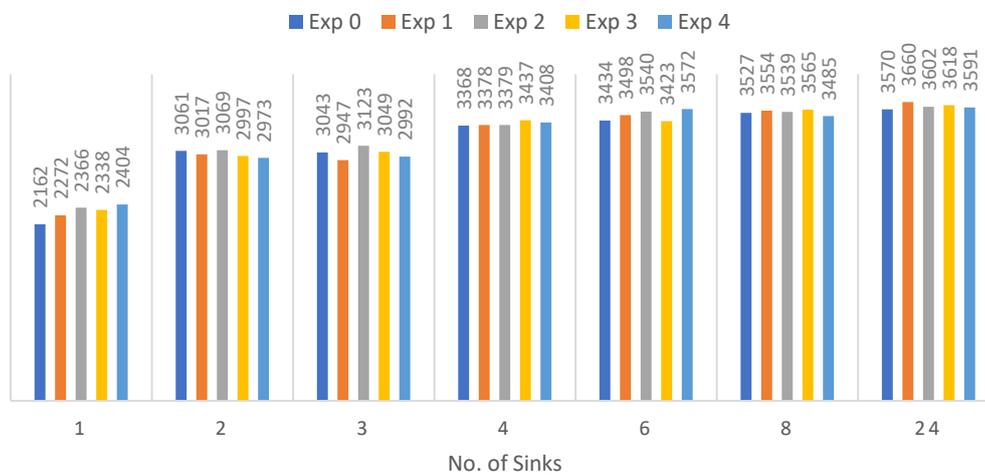
Figure 12. Number of lost packets without shadowing

NO OF LOST PACKETS FOR CLUTTER DISTRIBUTION
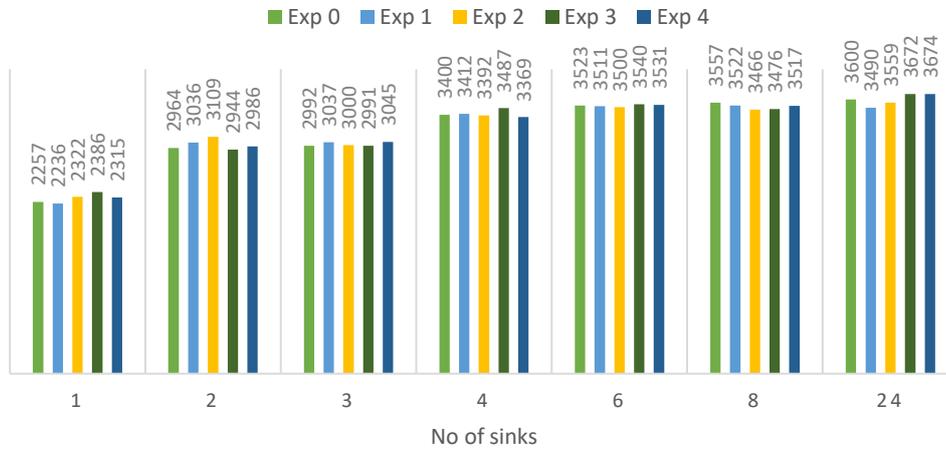
Figure 13. Number of lost packets due to shadowing

4.3. Effect of Shadowing on Data Throughput

This section presents the channel shadowing effect on the link throughput. From the results presented in Figures 14 and 15, one can deduce that the effect of shadowing on the channel throughput can be mitigated by increasing the number of sinks in the network. This strongly reflected in the received, sent and collided packets statistics below in Figures 16, 17 and 18.

CHANNEL THROUGHPUT FOR CLUTTER DISTRIBUTION
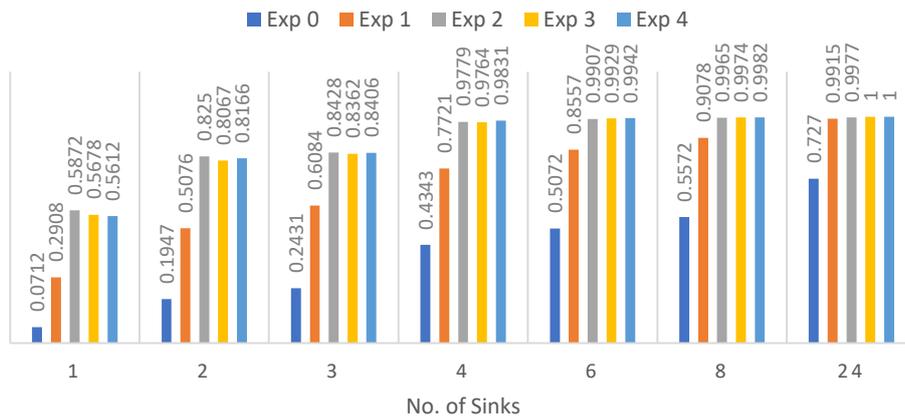
Figure 14. Channel Throughput Degradation without the effect of Shadowing

CHANNEL THROUGHPUT FOR CLUTTER DISTRIBUTION

■ Exp 0 ■ Exp 1 ■ Exp 2 ■ Exp 3 ■ Exp 4
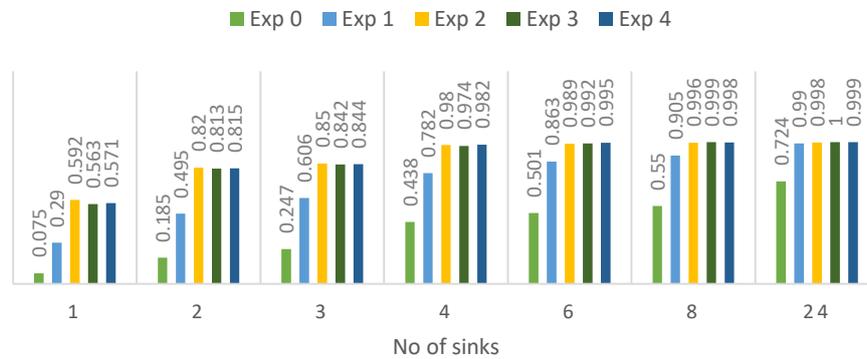
Figure 15. Channel Throughput Degradation because of Shadowing

NUMBER OF RECEIVE PACKETS FOR CLUTTER DISTRIBUTION

■ Exp 0 ■ Exp 1 ■ Exp 2 ■ Exp 3 ■ Exp 4
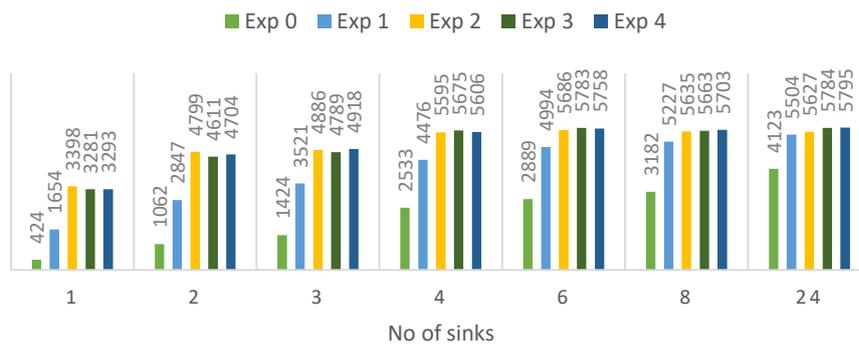
Figure 16. Number of receive packets due to the Shadowing

NUMBER OF COLLIDED PACKETS FOR CLUTTER DISTRIBUTION

■ Exp 0 ■ Exp 1 ■ Exp 2 ■ Exp 3 ■ Exp 4
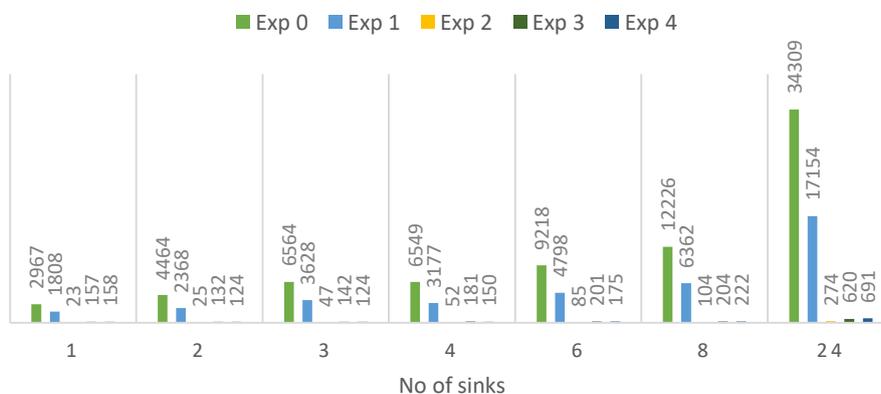
Figure 17. Number of collided packets because of Shadowing

NUMBER OF SENT PACKETS FOR CLUTTER DISTRIBUTION
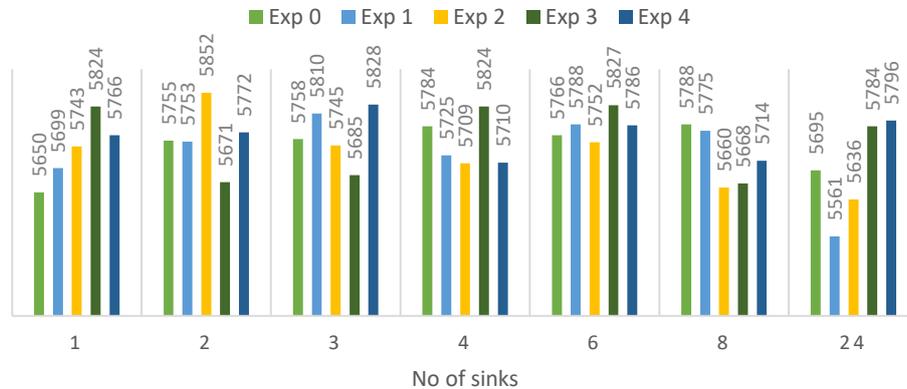
Figure 15. Number of sent packets due to Shadowing

5. CONCLUSION

The research shows that by applying the shadowing effect, only 50% of the sensor nodes were connected at any moment while this percentage has increased gradually as the number of sinks increased. Also, there are no much differences in output gathered if we are applying or we not applying the Shadowing Effect to the network.

Shadowing effect plays a considerable role in determining the overall network performance of LoRa LPWAN. Malaysian smart city environment is rich with shadowing clutter such as jungle and foliage in office and residential areas. This certainly plays a major role in limiting the network coverage and continuous connectivity. Hence, careful consideration is necessary in network planning and transmit power budgeting.

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