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Interference Analysis Between LoRaWAN and the Wi-Fi HaLow (802.11ah)

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***Abstract*— The development of Internet of Things (IoT) technology has advanced significantly, with technologies like LoRaWAN, Sigfox, ZigBee, and next-generation next-generation IoT (NB-IoT) being widely used. Wi-Fi HaLow, which offers better range and speed than LoRaWAN, is one such technology, but Indonesia lacks infrastructure to support it. This study analyzes the viability of Wi-Fi HaLow in Indonesia and its interaction with other IoT technologies, such as LoRaWAN, under interference conditions. Two scenarios are examined: interference from Wi-Fi HaLow to a LoRaWAN gateway and vice versa, using SEAMCAT software at 923 MHz. In this scenario, Wi-Fi HaLow serves as the interfering system, while LoRaWAN experiences disruption. The power variations of Wi-Fi HaLow were tested to identify the most efficient. Results show no interference at 8 km with 24 and 25 dBm, but interference occurs at 10 km with 26 dBm. Additionally, interference tests with varying numbers of Wi-Fi HaLow access points (APs) revealed minimal interference when the distance between the systems was 9 km, with interference rates ranging from 20% to 100%.**

Keywords—Internet of Things, LoRaWAN, SEAMCAT, Wi-Fi HaLow

I. INTRODUCTION

Most individuals today use wireless mobile networks daily, and it is not easy to imagine life without them. Wireless communication is one of the fastest returning parts of dynamic communication [1]. Due to the development of cellular technology, communication with one another can be achieved anywhere through cellular phones connected to the internet. As a result, many gadgets have been integrated with diverse internet networks to create the Internet of Things (IoT). The International Data Corporation (IDC) released a research report stating that there was a 17.9% rise in IoT adoption over the previous year. Indonesia uses IoT technology in several fields, including industry, transportation, agriculture, and health [2]. The IoT connects to the network using various radio communication protocols. Some of these networks include Wi-Fi (wireless fidelity), Wi-Fi HaLow, and Long Range Wide Area Network (LoRaWAN) [3] [4].

Low Power Area Network (LoRa) is an IoT development method that maximizes battery life so that less power is used overall. LoRa uses the Chirp Spread Spectrum (CSS) modulation type, which serves to maintain low power characteristics for the sake of increasing the range of communication [5]. LoRa has the lowest data rate of 27 Kbps with a spreading factor and a 500-KHz or 50-Kbps frequency shift keying (FSK) channel with a bandwidth of 125 KHz. In addition, LoRa offers energy efficiency and long-distance coverage [6]. Nonetheless, the technology sector requires greater speed and capacity, the capacity to manage numerous devices, and flexibility in response to ever more advanced connectivity.

Therefore, Wi-Fi HaLow could be a more desirable solution in the future. HaLow's worldwide competitiveness stems from the widespread adoption of existing Wi-Fi. The IoT wireless standard Wi-Fi HaLow optimizes the balance between low power propagation, density, throughput, range, and implementation cost. It uses Sub 1 Gigahertz (S1G) wireless radios operating in the 750 MHz and 928 MHz frequency ranges, with the S1G spectrum freeing up the 2, 4, and 5 GHz spectra. The highest Wi-Fi HaLow data rate is 80 Mbps when four distinct streams are used at 4 MHz [7].

Industrial development in Indonesia has led to increased use of technology. However, interference between Wi-Fi HaLow and LoRa occurs in dense environments with various communication technology devices. Interference will result in performance disruption, reduced communication efficiency, and even data transmission failure. Therefore, the researchers analyzed the interference between Wi-Fi HaLow and LoRa. The analysis was conducted on a simulation basis using the Spectrum Engineering Advanced Monte Carlo Analysis Tool (SEAMCAT) software. The interference analysis aims to understand to what extent these two technologies can operate simultaneously without interfering with each other and to provide guidance for infrastructure developers and optimized connectivity in the future.

This paper is divided into four sections. The introduction is the first section. This paper addresses the methodology in the second section, discussing the steps involved in the simulation and the necessary simulation parameters. The third section presents the simulation results, and the last section presents the conclusions.

II. Literature Review

A. LoRaWAN

For wireless communication, long-range wide-area networks (LoRaWAN) use free spectrum in industrial, scientific, and medical (ISM) channels. In Europe, the European Telecommunications Standard Institute (ETSI) regulates access to ISM channels with frequency ranges of 868 and 433 MHz. However, the use of this frequency has certain limitations. That is, the transmitter transmit power Equivalent Isotropic Radiated Power (EIRP) cannot exceed 14 dBm.

The duty cycle regulated by ETSI in EUROPE is also limited to 1% (for devices) or 10% (for gateways), depending on the value of the sub-band used. The LoRaWAN architecture [8] [9].

LoRaWAN is a communication protocol and network architecture. LoRa is a physical layer that provides a remote communication link to the LoRa Alliance-certified network. LoRaWAN provides two-way communication, Mobility, and secure localization services [10][11].

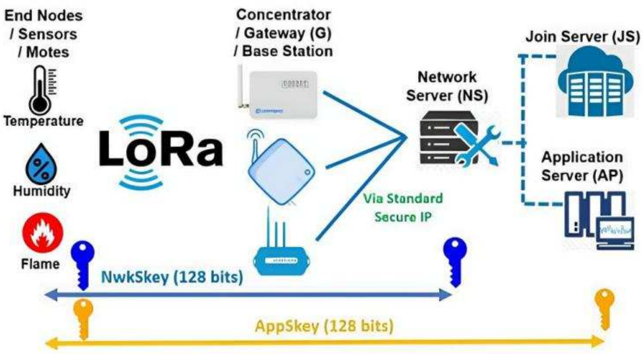

Fig. 1. The LoRaWAN architecture [12].

Figure 1. LoRaWAN architecture with a "star-of-star" topology. The gateway forwards the signal between the end device and the core device. The end device communicates using the gateway via LoRa, which is connected to the main server via standard IP. Therefore, communication is basically two-way [12] [13].

B. Wi-Fi HaLow

Wi-Fi HaLow, the designation for certified products incorporating IEEE 802.11ah technology, augments Wi-Fi by operating in a spectrum below 1 Gigahertz (GHz) to offer longer range and lower power connectivity. Wi-Fi HaLow uses Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM), which is suitable for very high data rates [14].

TABLE I. Comparing Wi-Fi 4/5/6 to HaLow [15]

Function	Wi-Fi 4/5/6 (IEEE 802.11n/ac/ax)	Wi-Fi HaLow (IEEE 802.11ah)
Operating frequency bands	2.4 GHz, 5 GHz, and 6 GHz (6E)	Sub-1 GHz (902 – 928 MHz in USA)
Channel width choices	20, 40, 80, and 160 MHz	1, 2, 4, 8 (16 optional) MHz
Maximum number of addressable STAs per AP	2007	8191
Single-stream MCS data rate range	6.5 Mbps-150 Mbps (.11n, Wi-Fi 4)	150 Kbps–43.3 Mbps (86.7 Mbps @16 MHz)
Typical range	~100 m	10x longer range than 802.11n 20 MHz
Link budget improvement (1 MHZ channel)	-	15–24 dB

Wi-Fi HaLow meets the unique requirements for the Internet of Things (IoT) to enable a variety of use cases in industrial, agricultural, smart building, and smart city environments. The Wi-Fi HaLow standard spans a huge number of possible IoT segments, including agriculture, home automation, transport, and more specifically, because of its range: Up to at least 1 Km of range at low data rates (the lowest is 150 kbps) has already been confirmed by Newracom. Conversely, for shorter range use cases, up to 80 Mbps of connectivity can be delivered via Wi-Fi HaLow. [15].

C. Interference

Interference occurs when a signal from an unwanted radio frequency prevents the reception of the signal. This can lead to signal loss and a decrease in the quality of data transmission due to interference [16]. Interference occurs between waves in an area and can be constructive or destructive.

If the different phases of the two waves are the same, a new wave is formed by summing the two waves. If the phase difference is 180°, the two waves eliminate each other. Interference can occur in wireless and wireless media. In a network, interference can also occur when two devices use the same frequency and channel [17].

D. SEAMCAT

The Spectrum Engineering Advanced Monte Carlo Analysis Tool (SEAMCAT) is a statistical simulation model that uses the Monte Carlo method to evaluate possible interference between various radio communication systems, including broadcasting, point-to-point, point-to-multipoint, radar, mobile networks, aeronautical, and satellite systems. SEAMCAT simulates a single Victim Link Receiver (VLR) connected to a Victim Link Transmitter (VLT) among a population of one or more Interface Link Transmitters (ILTs) coupled to Interference Link Receivers (ILRs). SEAMCAT tracks each event's interfering signal strength and calculates desired signals in separate data arrays. By comparing the desired and unwanted signals at the victim link receiver in each event to the pertinent interference criterion, such as C/I, SEAMCAT can determine the probability of interference [18].

III. Methodology

To construct the coverage design and test parameters dRSS, iRSS, C/I, and interface probability. In this study, a simulation technique was used with SEAMCAT 5.5.0 software. Before running the simulation, important information must be collected, such as LoRaWAN path loss and suburban values.

A. Flowchart of the study

Figure 2 is a flowchart for the research process that will be conducted. The study starts with a thorough review of the existing literature to gain a better understanding of the current understanding and identify any research gaps. From this review, the most suitable system for the experiment was selected. Subsequently, relevant parameters were entered into the system to accurately reflect the experimental conditions. The next step involves calculating the Received Signal Strength (dRSS) and interfering received signal strength (iRSS), which are crucial for evaluating signal interactions. Subsequently, the calculated values of distance are used in conjunction with the active transmitter settings to model system performance using SEAMCAT 5.5.0 software. The first case focuses on the interference caused by the geographical spacing between LoRaWAN and Wi-Fi HaLow, and the second case highlights the interference determination between the two systems depending on the number of active transmitters.

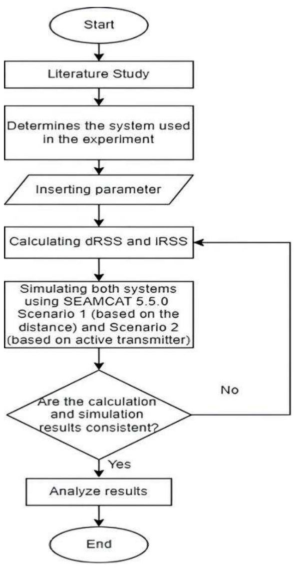

Fig. 2. Flowchart of research.

The simulation results were then compared with the preliminary computations to check for consistency. If the results are consistent, the study advances to a detailed analysis of the findings. However, if discrepancies are detected, the process is reviewed to modify the parameters or re-evaluate the system. The study concludes with a comprehensive analysis of the consistent results, confirming that the research objectives were achieved. SEAMCAT was used to enter data for simulation with the dRSS and iRSS values of the parameters to be examined. The study's ultimate outcome is a deployment strategy for LoRa that does not impede the effectiveness of cellular connectivity using Wi-Fi HaLow technology [19].

B. Parameters of LoRaWAN and HaLow

In the simulation, to overcome the possibility of interference, it is necessary to add a guard band and separate the geographical locations of the two systems. To ensure that the ratio between dRRS and iRSS is greater than or equal to the protection ratio, the distance between the transmitter interface and the victim receiver was altered in this study.

TABLE II. LORAWAN PARAMETERS [20]

Parameter	Tx	Rx
Frequency band	923 MHz	
Bandwidth	125-khz	
Power (dBM)	15	20
Antenna gain (dBi)	0	
Antenna height (m)	1.5	
Sensitivity (dBm)	-124.53	
Cell radius	0.74	1.39
Noise figure	6	6
Antenna patterns	GSM 900	

Based on the parameters in Tables II and III of the established standards. Determining the Desired Received Signal Strength (dRSS) and interfering received signal strength (iRSS) is how SEAMCAT simulations are run. In this study, the signal strength obtained from the Wi-Fi HaLow base station is known as the iRSS, and the signal strength received by the LoRaWAN base station is known as the dRSS, which is the signal strength received if there is no interference in the system.

TABLE III. WI-FI HALOW PARAMETERS [20]

Parameter	Tx	Rx
Frequency band	923 MHz	
Bandwidth	2 MHz	
Power (dBM)	-98	24
Antenna gain (dBi)	3	3
Antenna height (m)	1.5	25
Sensitivity (dBm)	-98	
Cell radius (KM)	0.1	
Noise figure	7	7
Antenna patterns	LTE 800 MHz	

C. Cost 231 Extended Hatta Model

The Cost 231 Hatta propagation model extends the Okumura Hatta model. This propagation model has a range of working frequency specifications from 1500 to 100 MHz for use in medium-to-small cities. In addition, this model has a base station antenna height of up to 4-50 m and a mobile station of 1-3 m [21]. The LoRaWAN path loss can be calculated using the following equation (1):

$$P_{LO} = 69.6 + 26.2\log(f) - 13.82\log(\max\{30, Hb\}) + [44.9 - 6.55\log(\max\{30, Hb\})]\log(d)^{a} - a(Hm) - b(Hb) \tag{1}$$

Where:

L = Path loss (dB)
f = Frequency (MHz)
H_b = Transmitter antenna height above ground (m)
H_m = Receiver antenna height above ground (m)

d = Distance between transmitter and receiver (Km)
$a(H_m)$, $b(H_b)$ = Antenna height correction factors, which are defined as follows equation (2):

$$a(Hm) = (1.1log(f) - 0.7)min\{10, Hm\} - (1.56log(f) - 0.8) + max\{0,\ 20log(Hm10)\}$$

$$b(Hb) \quad = min\{0,\ 20log(Hb30)\} \qquad (2)$$

The exponent α is a distance correction factor for distances > 20 Km, defined as follows (3):

$$a = \begin{cases} 1\ for\ d \leq 20\ km \\ 1 + (0.14 + 1.87 \times 10 - 4f + 1.07 \times 10 - 3Hb) \times \\ \times (log\dfrac{a}{20})^{0.8} for\ 20\ km < d \leq 100\ km \end{cases} \qquad (3)$$

With the following model restrictions (4):

f = 30 MHz to 3000 MHz
H_b = 30 m to 200 m
H_m = 1 m to 10 m
d = 0.1 Km to 100 Km, but in practice, it is recommended to use it up to 40 Km.

Suburban [20]:

$$L = L(urban) - 2\left\{log\left[\frac{min\{max\{150,f\},2000\}}{28}\right]\right\}^2 - 5.4 \qquad (4)$$

dRSS the desired received signal strength of the VLT sent from the Tx Power LoRaWAN to the Rx LoRaWAN. dRSS values were obtained by calculating the signal received by the VLR, which is the sensitivity value of the LoRaWAN receiver [22]. The following is LoRaWAN's dRSS calculation from the formula (5).

$$dRSS = Tx\ power + Gain\ Tx + Gain\ Rx - Pathloss \quad (5)$$

Here, Tx Power is the transmitter power of LoRaWAN, Gain Tx is the transmitter gain of LoRaWAN, Gain Rx is the receiver gain of the LoRaWAN, Pathloss obtained from the formula equation (1).

iRSS is an interfering received signal from a victim receiver from several interferent transmitters. The following is LoRaWAN's desired received signal strength (dRSS) calculation from the formula (5).

$$iRss = Tx\ power + Gain\ Tx + Gain\ Rx - Pathloss \quad (6)$$

Here, Tx Power is the transmitter power of Wi-Fi HaLow, Gain Tx is the transmitter gain of Wi-Fi HaLow, Gain Rx is the receiver gain of Wi-Fi HaLow, and Pathloss is obtained from the formula equation (1).

IV. Results and Analysis

A. Interference Simulation Results Received from Wi-Fi HaLow to LoRaWAN

Table IV shows the difference between the dRSS and iRSS calculations with the simulation results at 24, 25, and 26 dBm power on the Wi-Fi transmitter. At a power of 24 dB m, there was a difference between the dRSS calculation and simulation (0.29%) and the iRSS (0.49%). Then, at a power of 25 dBm, there is a 1.13% difference in dRSS, followed by a 0.60% difference in iRSS. For the latter at a power of 26 dBm, the difference was calculated and simulated as 0.78%, compared to the difference in the iRSS of 4.10%.

TABLE IV. Comparison of dRSS and iRSS values obtained from calculation and simulation of Wi-Fi leak to LoraWAN Interference

Tx Power (dBm)	dRSS (dBm)		iRSS (dBm)	
	Calculation	*Simulation*	*Calculation*	*Simulation*
24	-92.72	-92.45	-89.27	-90.16
25	-92.72	-91.68	-89.27	-88.19
26	-92.72	-92	-89.27	-86.19

In five simulations, the position of LoraWAN remained at the same distance. However, the position of the Wi-Fi HaLow transmitter shifted randomly. This random position causes dRSS and iRSS to differ from the calculation.

B. Simulation Results of Interference Simulation by Distance from Wi-Fi HaLow to LoRaWAN (Scenario 1)

In the table IV, the data collected is collected using a simulation with a radius of 1 Km, with the distance between the ILT and VLR regulated by the path distance factor. The number of events is 5, and the number of active transmitters is 1.

TABLE V. Table V. With a simulation radius of 1 Km, using path distance factor (constant), the number of events was 5, and the number of AP events was 1.

Tx Power (dBm)	Distance (Km)	dRSS (dBm)	iRSS (dBm)	C/I (dBm)	Interference Probability (%)
24	1	-118.21	-97.69	-20.52	100
24	2	-115.46	-117.37	1.92	80
24	3	-119.59	-126.94	7.35	80
24	4	-115.57	-127.51	11.93	80
24	5	-115.8	-129.45	13.65	60
24	6	-115.73	-132.9	17.17	60
24	7	-122.16	-145.66	23.51	40
24	8	-109.78	-156.47	46.96	0

The above data is taken using the power of Tx 24 dBm with a distance of 1–8 km. In table V, we can see an increase in iRSS about the gap between the two systems. The smallest iRSS value was at a distance of 1 Km with a value of -97.69 dB m, and the greatest iRSS value was at a distance of 8 Km at a speed of 156.47 dB m.

The increased C/I value is also affected by the distance from ILT to VLR, which at 1 km is worth -20.52 dB, whereas at 8 km the distance is 46.96 dB. Based on the data obtained at the 1-Km gap between the ILT and VLR, interference is observed. This shows 100% that at 1 Km, both systems will be interrupted, and temporarily at 8 Km, the probability of interference at such distances will reach 0% between both systems.

TABLE VI. With a simulation radius of 1 Km, using path distance factor (constant), the number of events was 5, and the number of AP events was 1.

Tx Power (dBm)	Distance (Km)	dRSS (dBm)	iRSS (dBm)	C/I (dBm)	Interference Probability (%)
25	1	-118.26	-102.77	-15.49	100
25	2	-111.27	-105.71	-5.56	80
25	3	-108.81	-108.41	-0.39	80
25	4	-115.53	-115.34	-0.19	80

25	5	-118.04	-122.43	4.39	80
25	6	-118.85	-130.49	11.64	60
25	7	-113.7	-133.99	20.29	40
25	8	-115.12	-136.38	21.27	40
25	9	-108.88	-137.64	28.77	0

The smallest iRSS value was at 1 km with a value of -102.77 dBm, and the greatest IRSS value was at a distance of 9 Km with a value of -137.64 dBm. In this experiment, the C/I values varied between 15.49 and 28.77 dB.

Based on the results of the experiment obtained at a distance of 1 Km between the ILT and VLR, if an interference occurs whose probability value reaches 100%, this indicates that at 1 Km the two systems will experience quite high interference, whereas at 9 Km the probability of interference shows the interface probability value to be 0%, which indicates that at that distance both systems do not interfere.

TABLE VII. WITH A SIMULATION RADIUS OF 1 KM, USING PATH DISTANCE FACTOR (CONSTANT), THE NUMBER OF EVENTS WAS 5, AND THE NUMBER OF AP EVENTS WAS 1.

Tx Power (dBm)	Distance (Km)	dRSS (dBm)	iRSS (dBm)	C/I (dBm)	Interference Probability (%)
26	1	-113.91	-104.41	-9.5	100
26	2	-117.1	-113.89	-3.21	80
26	3	-116.77	-118.18	1.41	80
26	4	-116.11	-122.05	5.93	80
26	5	-114.43	-125.25	10.78	80
26	6	-120.84	-132.85	12.01	40
26	7	-109.99	-138.38	28.15	20
26	8	-109.2	-142.92	33.72	20
26	9	-113.48	-146.87	33.39	20
26	10	-120.99	-157.63	36.65	0

From table V, VI, and VII show how different transmission powers (Tx) affect signal quality and interference at different ranges. The direct received signal strength (dRSS) and interference received signal strength (iRSS) both improved and became less negative when Tx power rises from 24 to 26 dBm. The carrier-to-interference ratio (C/I) noticeably increased as a result, indicating that the signal was stronger than interference, especially at longer distances. The interference probability, however, is high (100%) at shorter distances (1-2 Km) at all Tx power levels, suggesting substantial interference near the source.

The C/I values improved as the distance exceeded 4 km at all power levels, and the highest signal-to-interference performance was observed at 26 dBm. Higher transmit power results in a more noticeable decrease in the likelihood of interference, particularly over longer distances. For example, with Tx power levels of 25 and 26 dBm, the interference probability decreases to 0% over distances of 8 Km and beyond. Consequently, increasing the transmit power not only improves signal quality but also successfully lowers the interference at greater distances while not lessening the interference at close quarters.

C. Result of Interference based on active transmitter from Wi-Fi HaLow to LoRaWAN (Scenario 2)

The probability of interference received by the LoRaWAN gateway of Wi-Fi HaLow with the number of active Wi-Fi HaLow transmitters varied between the two systems, as shown in Tables V, VI, and VII.

TABLE VIII. WI-FI HALOW TX INTERFERENCE PROBABILITY FOR THE LORAWAN GATEWAY WITH TX POWER = 24 DBM, DISTANCE = 9 KM, RADIUS = 1 KM, EVENT = 5

Number of Active Wi-Fi Halow Transmitters	dRSS (dBm)	iRSS (dBm)	C/I (dBm)	Interference Probability (%)
1	-122.14	-138.52	16.38	40
10	-114.79	-111.09	-3.69	100
100	-114.98	-95.74	-19.23	100
1000	-116.63	-80.99	-35.64	100
2000	-113.33	-77.28	-36.05	100
3000	-121.49	-74.43	-47.06	100
4000	-124.35	-75.55	-48.8	100
5000	-122.59	-72.45	-50.14	100

TABLE IX. WI-FI HALOW TX INTERFERENCE PROBABILITY FOR THE LORAWAN GATEWAY WITH TX POWER = 25 DBM, DISTANCE = 9 KM, RADIUS = 1 KM, EVENT = 5

Number of the Active Wi-Fi HaLow Transmitter	dRSS (dBm)	iRSS (dBm)	C/I (dBm)	Interference Probability (%)
1	-121.41	-127.24	14.83	40
10	-122.53	-106.55	-15.97	100
100	-116.87	-88.02	-28.84	100
1000	-118.36	-78.7	-39.67	100
2000	-117.43	-74.91	-42.53	100
3000	-118.44	-71.72	-46.72	100
4000	-118.94	-71.63	-47.31	100
5000	-117.86	-69.73	-48.13	100

TABLE X. WI-FI HALOW TX INTERFERENCE PROBABILITY FOR THE LORAWAN GATEWAY WITH TX POWER = 26 DBM, DISTANCE = 9 KM, RADIUS = 1 KM, EVENT = 5+

Number of Active Wi-Fi Halow Transmitters	dRSS (dBm)	iRSS (dBm)	C/I (dBm)	Interference Probability (%)
1	-121.55	-151.19	29.64	20
10	-116.69	-108.52	-8.17	100
100	-118.33	-91.52	-26.82	100
1000	-118.78	-77.25	-41.53	100
2000	-115.91	-74.33	-41.58	100
3000	-116.52	-70.37	-46.15	100
4000	-117.26	-69.07	-48.18	100
5000	-119.12	-68.9	-50.23	100

In tables VIII, IX, and X are the results of simulations with 3 different types of parameters, power used, namely 24 dBm, 25 dBm, and 26 dBm, and the distance between the victim and the interfering source is 9 Km. In, this simulation test, we will look at the interference resistance generated with the number of active parameters on the Wi-Fi Halow. When only one Wi-Fi HaLow transmitter was operational, the C/I ratio varied between 16.38 dB and -50.23 dB, suggesting different amounts of interference. Severe interference was indicated by a negative C/I score, and in certain instances, the chance of interference approached 100%.

If the number of active Wi-Fi HaLow transmitters is increased to > 10 Km, then the chance of interference is 100%, and the C/I value will also be increased as a result of which the Wi-Fi HaLow system can interfere with the LoRaWAN gateway. Based on the results of the analysis of the three experiments described above, the smallest probability interface value was found at the strength of the Tx power at 26 dBm with the number of active Wi-Fi HaLow transmitters C/I of 29.64, and the probability value of the interface reached 20%.

For further research, it is hoped that it will compare the results of simulations with tools that are carried out in real time so that the results of errors between the simulations used and real conditions can be obtained. The experiment described above was conducted using a smart meter with varying transmission (TX) power levels. Interference between the two systems resulted in the loss of some data transmitted by the sender, which caused the data received by the receiver to be incomplete or erroneous. Interference can occur in dynamic networks with multiple devices and locations. This is particularly relevant for LoRaWAN and Wi-Fi HaLow devices, which operate on the same frequency band. The likelihood of interference increases with increasing distance between devices or increasing number of active transmitters. However, interference can be minimized at distances greater than 8 km or by reducing transmission power, according to simulations. Effective interference management is crucial for maintaining smooth communication. This can be achieved by separating frequencies or employing specific strategies for device placement.

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