

Coexistence Study of Low-Power Wide-Area Networks based on Wi-Fi HaLow (802.11ah) and Narrowband Internet of Things (NB-IoT)

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Abstract—This study evaluates the possible coexistence between Wi-Fi HaLow (802.11ah) based Low-Power Wide-Area Networks (LPWAN) and non-no-technology (NB-IoT) systems. This study uses SEAMCAT software to analyze potential interference that may arise when both systems are operated simultaneously in the same environment. Both systems use the same frequency of 923 MHz, and the transmitting power used by Wi-Fi HaLow is 23, 24, and 25 dBm. The test results show that the interference probability of Wi-Fi HaLow to NB-IoT ranges from 20% to 100% when the number of active transmitters is varied from 1 to 5000. However, when varying the distance between the two systems, it was found that NB-IoT did not interfere with Wi-Fi HaLow when the distance was above 15 km, with 0% interference probability using 23 and 24 dBm power, while using 25 dBm power, mutual interference between Wi-Fi HaLow and NB-IoT still occurred up to a distance of 17 km, with 20% probability. The safe distance where no interference occurs is 18 km with 25 dBm power.

Keywords—802.11ah, Carrier to Interference, dRSS, iRSS, SEAMCAT

I. INTRODUCTION

In the "Internet of Things" (IoT) realm, interconnection refers to the interaction and exchange of data between devices and sensors. With the rapid growth of Internet of Things (IoT) technology, its practical applications are expanding to areas such as security, asset tracking, agriculture, smart meters [1], smart cities, smart factories [2], and smart homes [3]. IoT applications require low data rates, minimal energy consumption, and cost efficiency. Short-range radio technologies such as Bluetooth and ZigBee are not ideal for long-distance transmission, whereas cellular communication solutions such as 2G, 3G, 4G, and 5G [4] consume more power. Therefore, low-power-wide-area networks (LPWANs) are emerging to meet the needs of IoT applications.

Technologies such as WLAN, Bluetooth, and ZigBee are suitable for short-range sensor applications, whereas cellular networks such as 2G, 3G, 4G, and 5G [4] are more suitable for voice, data, and video communications [5]. The LoRa alliance created LoRaWAN for applications that require long-range and low-power-wide-area networks (WANs) [6][7].

Optimizing the coexistence between 802.11ah (Wi-Fi HaLow) and NB-IoT network standards is important to take advantage of their advantages [8]. Wi-Fi HaLow uses a sub-1 GHz frequency for better signal penetration and longer endurance than traditional Wi-Fi HaLow[9]. NB-IoT, with LTE frequencies and compatibility with GSM and UMTS, offers broad coverage and affordable costs, opening up significant new market opportunities [10][11].

In this research, a simulation will be conducted to determine the potential interference that will arise when Wi-Fi HaLow systems (802.11ah) co-exist with NB-IoT. This research explains IoT technology requirements. Section II describes the technologies and the parameters used by both technologies. Section III explains the concept of the technique used in the simulation and the calculations used. Conclusions are given in Section IV to summarize the results obtained.

II. LITERATURE REVIEW

A. 802.11ah

The Wi-Fi HaLow or IEEE 802.11ah is a wireless local area network standard developed to meet the needs of wireless communication technology. It works in the 2.4 GHz and 5 GHz frequency bands, and, like other IEEE 802.11 technologies, it uses an orthogonal frequency division multiplexing (OFDM)-based physical layer (PHY) and a carrier-sense multiple access with collision avoidance (CSMA/CA) medium access control (MAC) [8][12][13].

Examples of this problem include Wireless Sensor Network (WSN) and machine-to-machine (M2M) networks [14], Technologies that operate in the 1 GHz frequency band offer high data rates, are easy to develop, and feature lower costs, aligning with the parameters of Wi-Fi HaLow as outlined in Table 1. These technologies also provide greater coverage and improved energy efficiency. Similarly, IEEE 802.11 specifications for IoT have led to the emergence of various new technologies that incorporate specific features that appeal to different scenarios and applications, including Low Power Wide Area Network (LPWAN) technologies, such as LoRaWAN, Sigfox, and narrowband IoT (NB-IoT) [10][15][16].

TABLE I. WI-FI HaLOW PARAMETERS FOR INTERFERENCE CALCULATION [10]

No	Parameter	UL	DL
1	Frequency Band	923 MHz	
2	Bandwidth	2000 KHz	
3	Actual Tx Power	-98 dBm	24 dBm
4	Gain of the antenna (Tx)	3 dBi	
5	Height of Antenna (Tx)	1.5 m	25 m
6	Receiver Sensitivity	-98 dBm	-98 dBm
7	Noise Figure	7 dB	7 dB

B. Narrowband Internet of Things (NB-IoT)

In response to industry requests, 3GPP has extended its long-term evolution (LTE) radio technology specifications in recent years. Two complementary technologies, Narrowband IoT (NB-IoT) and LTE-MTC (LTE-M), are being introduced for the Internet of Things (IoT) and machine-type communications (MTC). With its introduction in 3GPP Release 13, NB-IoT aims to cover a large region for IoT applications, especially those involving smart sensors and their communication [17][18]. NB-IoT will continue to coexist and work well with new 5G networks, which means it will support LTE-IoT deployment scenarios [19][20].

NB-IoT is a 3GPP standard designed for machine-type communication (MTC) that significantly reduces energy consumption in IoT applications. As a narrowband radio technology tailored for Low Power Wide Area (LPWA) applications, it provides long-range cellular coverage, scalability, and low data rates, making it ideal for efficiently connecting a vast number of devices. NB-IoT supports ultra-low-end applications such as smart meters, remote sensors, and smart health systems, ensuring reliable communication even in challenging environments. Additionally, it can be integrated into 5G New Radio (5G-NR) networks, enhancing connectivity and paving the way for advanced features like edge computing and real-time data analytics, thus contributing to a more interconnected and intelligent future [18].

This drives the creation and deployment of smart IoT. NB-IoT, also known as LTE-Cat-NB1, has optimized and simplified enterprise-level technical requirements to minimize radio overhead by transmitting both IP and non-IP data. By taking up space in physical resources, NB-IoT can coexist optimally with existing networks. The 180-kHz block for downlink (DL) and uplink (UL) operations or by swapping a

single 200-kHz GSM carrier without affecting the performance of the host network is aligned with the NB-IoT parameters in Table 2 [18].

TABLE II. NB-IoT PARAMETERS FOR INTERFERENCE CALCULATION [21]

No	Parameter	UL	DL
1	Frequency Band	923 MHz	
2	Bandwidth	200-khz	
3	Actual Tx Power	15 dBm	43 dBm
4	Gain of the antenna (Tx)	17 dBi	
5	Height of Antenna (Tx)	1.5 m	30 m
6	Receiver Sensitivity	-141 dBm	-141 dBm
7	Noise Figure	7 dB	7 dB

C. SEAMCAT

Spectrum Engineering Monte Carlo Analysis Tool (SEAMCAT) simplifies your research by providing a pre-built library, so you do not have to start from scratch with every analysis. This simulation simulates the operation of one or more *Interfering Link Transmitters* (ILT) connected to an *Interfering Link Receiver* (ILR) and one *Victim Link Receiver* (VLR) connected to a *Victim Link Transmitter* (VLT). These interfering parties may be part of the victim's system, another system, or a mix of the two. Dispersed randomly or according to a user-specified pattern based on the victim's position, interferers' locations are scattered around the victim [22][16]. Operates between the *secondary mobile station transmitter* (SMSTx), which acts as an interferer to the primary user's spectrum or channel, and the *primary mobile station transmitter* (P-MSTx), which is connected to the primary base station receiver (P-BSRx), which determines the primary user connection.

Metode Minimum Coupling Loss (MCL)

$$\text{Isolasi} = P_t - P_r + G_t + G_r - L_o \quad (1)$$

Where:

P_t = Power Transmitter

P_r = Sensitivity receiver

G_r = Receiver Antenna Gain

L_o = Loss

SEAMCAT can define numerous system parameters required for simulation as a probability distribution function so that an interference scenario between diverse radio communication systems can be analyzed in a manner similar to an actual environment. The basic interference scenario in SEAMCAT is the desired received signal strength (dRSS), interference received signal strength (iRSS), and carrier to interference (C/I) [16].

- Desired Received Signal Strength (dRSS)

dRSS. In the SEAMCAT system, the victim link propagation generates an array, where the dRSS represents the received signal between the victim link transmitter (VLT) and the victim link receiver (VLR). The VLR sensitivity value was used to calculate the dRSS value [23].

$$dRSS = Pe + Ge + Gr - L \quad (2)$$

Where:

Pe = Desired Transmitter Power

Ge = Gain Transmitter interference

Gr = Gain receiver victim

L = Pathloss

Where:

$$L = 69.6 + 26.2 \log(f) - 13.82 \log(\max\{30, hb\}) + [44.9 - 6.55 \log(\max\{30, Hb\})] \log(d) a - a(Hm) - b(Hb)$$

d = Distance between transmitter and receiver

- **iRSS (interfering Received Signal Strength)**

iRSS is the interference signal received by a victim receiver from multiple interfering transmitters [24].

$$iRSS = Pe + Ge + Gr - L \quad (3)$$

L = Pathloss

Where:

$$L = 69.6 + 26.2 \log(f) - 13.82 \log(\max\{30, hb\}) + [44.9 - 6.55 \log(\max\{30, Hb\})] \log(d) a - a(Hm) - b(Hb)$$

- **Carrier to Interference (C/I)**

C/I, a measure used to determine the speed between signal quality (strength) and interference, has received more attention [25]. C/I represents the quality of the bit error rate (BER). The higher the C/I value, the lower the BER. Conversely, if the carrier-to-interference value is low, the greater the value, the higher is the bit error rate [26][27].

II. RESEARCH METHOD

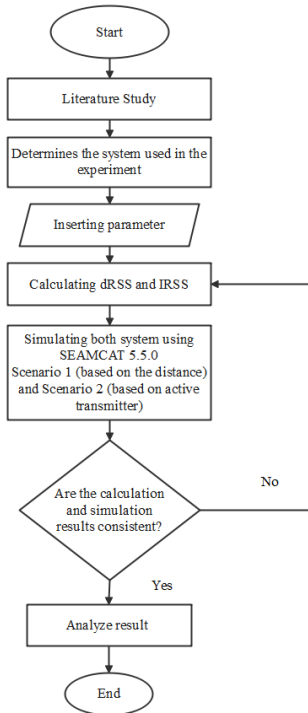


Fig. 1. Research flowchart

To gain a better understanding of the coexistence between Wi-Fi HaLow and NB-IoT, this research begins by collecting comprehensive technical data about both technologies,

following the research flowchart depicted in Figure 1. The collected data include performance parameters such as operating frequency, modulation characteristics, and other technical elements crucial for co-existence analysis. A careful network configuration is then performed using SEAMCAT software, encompassing the network settings, interfaces, and protocol parameters for both Wi-Fi HaLow and NB-IoT.

In-depth coexistence simulations will also be conducted considering various variables, including bandwidth allocation, interference levels, and node density. The performance analysis will thoroughly assess metrics such as throughput, delay, packet loss, and other metrics. The results of Wi-Fi HaLow and NB-IoT will also be compared across various relevant scenarios. The findings of this analysis can serve as a basis for optimizing network configuration to enhance the coexistence and efficiency of LPWAN networks. Whenever possible, the simulation results will be validated through practical measurements to ensure the accuracy of the model and the obtained analysis results.

This research aims to deepen the understanding of the co-existence dynamics of Wi-Fi HaLow and NB-IoT in the context of low-power LPWAN networks using a robust and detailed methodology.

III. SIMULATION RESULTS AND DISCUSSION

A. Interference Comparison between Calculated and Simulated NB-IoT and Wi-Fi HaLow

The simulation results presented in Table 3 indicate that the Wi-Fi HaLow system can cause interference with the NB-IoT system. However, the dRSS value of a Wi-Fi HaLow system tends to remain stable within the range of the transmitted power.

TABLE III. COMPARISON OF THE dRSS AND iRSS FROM THE CALCULATION AND SIMULATION OF THE Wi-Fi HaLow OF NB-IoT

Wi-Fi HaLow Power	dRSS (dBm)		iRSS (dBm)	
	Calculation	Simulation	Calculation	Simulation
23	-84.72	-87.02	-90.72	-91.17
24	-84.72	-84.3	-89.72	-90.79
25	-84.72	-83.27	-88.72	-88.98

Calculation of dRSS from Table 2:

$$dRSS = Pe + Ge + Gr - L \quad (2)$$

$$dRSS = 15 + 0 + 17 - 116.72 = -84.72$$

Calculation of iRRS from Table 2:

$$iRSS = Pe + Ge + Gr - L \quad (3)$$

- Power 23

$$iRSS = 23 + 3 + 0 - 116.72 = -90.72$$

- Power 24

$$iRSS = 24 + 3 + 0 - 116.72 = -89.72$$

- Power 25

$$iRSS = 25 + 3 + 0 - 116.72 = -88.72$$

Table 3 shows the difference in dRSS of 1.45% and iRSS of 0.45% between the simulation and calculation results, with 5 transmitters used during the simulation. A difference in the

dRSS and iRSS values occurs because the transmit power of the Wi-Fi HaLow changes during the simulation at a distance of 1 km from the NB-IoT.

B. Interference based on Active Transmitter from Wi-Fi HaLow to NB-IoT

Simulations were conducted at a 20-km distance between the Wi-Fi HaLow AP and NB-IoT 8 times. The number of AP transmitters was varied from 1 to 5000 in each experiment. The simulation results indicate that Wi-Fi HaLow can interfere with an NB-IoT system at a frequency of 923 MHz when it transmits power in the range of 23 to 25 dBm.

TABLE IV. Wi-Fi HaLow Tx INTERFERENCE PROBABILITY FOR NB-IoT WITH Tx = 23 dBm, DISTANCE = 20 KM, RADIUS = 1 KM, EVENT = 5

Amount of Active Wi-Fi HaLow APs	dRSS Power	iRSS Power	C/I Power	Interference Probability
1	-112.59	-135.68	23.08	40
100	-117.05	-94.95	-22.1	100
1000	-107.04	-83.05	-24	100
2000	-112.02	-77.17	-34.84	100
3000	-113.2	-77.15	-36.05	100
4000	-112.74	-74.95	-37.79	100
5000	-114.17	-74.5	-39.67	100

TABLE V. Wi-Fi HaLow Tx INTERFERENCE PROBABILITY FOR NB-IoT WITH Tx = 24 dBm, DISTANCE = 20 KM, RADIUS = 1 KM, EVENT = 5

Amount of Active Wi-Fi HaLow APs	dRSS Power	iRSS Power	C/I Power	Interference Probability
1	-114.52	-147.22	32.7	20
100	-113.29	-93.19	-20.1	100
1000	-110.2	-81.97	-28.23	100
2000	-114.1	-76.98	-37.12	100
3000	-115.32	-75.14	-40.18	100
4000	-114.63	-73.54	-41.09	100
5000	-117.82	-72.8	-45.02	100

TABLE VI. Wi-Fi HaLow Tx INTERFERENCE PROBABILITY FOR NB-IoT WITH Tx = 25 dBm, DISTANCE = 20 KM, RADIUS = 1 KM, EVENT = 5

Amount of Active Wi-Fi HaLow APs	dRSS Power	iRSS Power	C/I Power	Interference Probability
1	-108.73	-145.53	36.8	20
100	-113.93	-89.89	-24.04	100
1000	-113.2	-77.87	-35.34	100
2000	-115.06	-75.52	-39.54	100
3000	-115.63	-73.98	-41.56	100
4000	-115.73	-72.81	-42.92	100
5000	-116.05	-70.81	-45.23	100

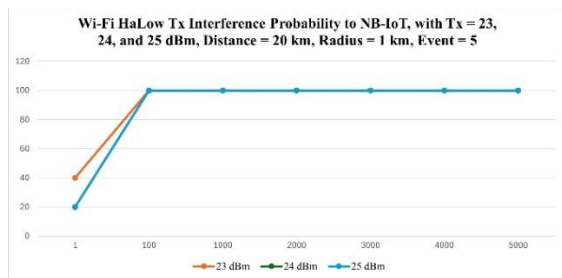


Fig. 2. Wi-Fi HaLow Interference probability for NB-IoT at 23, 24, and 25 dBm

Based on the simulation results shown in Figure 2, we conclude that the more active users are, the higher the interference generated. This can be seen from the interference probability values, which reach 23, 24, and 25 dBm.

C. Interference Simulation Results by Distance from Wi-Fi HaLow to NB-IoT

The probability of interference received by NB-IoT from Wi-Fi HaLow at different distances at 23 dBm power is shown in Table 7. The probability of interference received by NB-IoT from Wi-Fi HaLow with varying distance and power between the two systems can be seen in Tables 7, 8, and 9, with a total of 1 active transmitter, an NB-IoT antenna height of 30 m, and a Wi-Fi HaLow antenna height of 1.5m. The first experiment was conducted using 23 dBm power, which is given in Table 7.

TABLE VII. RECEIVER PROBABILITY INTERFERENCE = 23 dBm

Distance Between Nb-IoT and Wi-Fi HaLow(km)	dRSS (dBm)	iRSS (dBm)	C/I (dB)	Interference Probability (%)
1	-114.57	-100.77	-13.8	100
2	-114.57	-104.28	-10.29	100
3	-114.57	-115.99	1.42	100
4	-114.57	-116.44	1.87	100
5	-114.57	-116.70	2.13	80
6	-114.57	-120.68	6.11	80
7	-114.57	-125.52	10.95	60
8	-114.57	-129.14	14.57	60
9	-114.57	-132.79	18.22	60
10	-114.57	-133.10	18.53	40
11	-114.57	-135.30	20.73	40
12	-114.57	-136.23	21.66	40
13	-114.57	-138.89	24.32	40
14	-114.57	-146.71	32.14	40
15	-114.57	-158.61	44.04	0

Based on the simulation results shown in Table 7, the C/I value for NB-IoT ranged from 13.8 to 44.04 dB. When the distance between the two systems was 7 km, the interference probability was 60%. If the distance between the systems is increased to 10 km, the probability of interference decreases to 40%. The interference probability will reach 0% when the distance between the systems is increased to 15 km. In the next simulation, the Wi-Fi HaLow power was increased to 24 dBm to reduce the probability of interference at various distances. The results are given in Table 8.

TABLE VIII. RECEIVER PROBABILITY INTERFERENCE = 24 dBm

Distance from Nb-IoT and Wi-Fi HaLow (km)	dRSS (dBm)	iRSS (dBm)	C/I (dB)	Interference Probability (%)
1	-107.88	-92.09	-15.8	100
2	-107.88	-101.52	-6.6	100
3	-107.88	-110.46	2.58	100

4	-107.88	-115.53	7.65	80
5	-107.88	-116.06	8.18	80
6	-107.88	-118.67	10.79	60
7	-107.88	-120.71	12.83	60
8	-107.88	-122.54	14.66	60
9	-107.88	-125.85	17.97	60
10	-107.88	-134.87	26.99	40
11	-107.88	-140.48	32.6	40
12	-107.88	-142.16	34.28	20
13	-107.88	-146.69	38.81	20
14	-107.88	-150.51	42.63	20
15	-107.88	-151.42	43.54	0

Based on the simulation results shown in Table 8, the simulation results show that the C/I value for NB-IoT ranges from 15.8 to 43.54 dB. When the distance between systems reaches 6 km, the interference probability is 60% with a C/I value of 10.79 dB. The interference probability decreased to 20% when the distance between systems was increased to 12 km. The interference probability value will reach 0% with a C/I of 43.54 dB when the distance between systems is increased to 15 km. From the results given in Table 8, the distance between systems must be greater than 15 km to avoid interference. Compared to the previous simulation depicted in Table 7, Table 8 shows that the interference probability reached 20% at a distance of 12 km. In the next simulation, the Wi-Fi HaLow power was increased to 25 dBm to reduce the probability of interference at various distances. The results are given in Table 9.

TABLE IX. RECEIVER PROBABILITY INTERFERENCE = 25 dBm

Distance Between Nb-IoT and Wi-Fi HaLow(km)	dRSS (dBm)	iRSS (dBm)	C/I (dB)	Interference Probability (%)
1	-115.54	-95.72	-19.82	100
2	-115.54	-104.46	-11.08	100
3	-115.54	-107.83	-7.71	100
4	-115.54	-115.19	-0.35	100
5	-115.54	-123.3	7.76	80
6	-115.54	-129.79	14.25	80
7	-115.54	-131.64	16.1	60
8	-115.54	-133.08	17.54	60
9	-115.54	-133.64	18.1	60
10	-115.54	-134.41	18.87	60
11	-115.54	-135.1	19.56	40
12	-115.54	-135.5	19.96	40
13	-115.54	-135.69	20.15	40
14	-115.54	-137.98	22.44	40
15	-115.54	-138.87	23.33	40
16	-115.54	-148.6	33.06	20
17	-115.54	-152.28	36.74	20
18	-115.54	-152.83	37.29	0

Based on the simulation results shown in Table 9, the C/I values for NB-IoT ranged from 19.82 to 37.29 dB. The results show that the probability of interference is 40% when the distance between systems is 11 km. The interference probability decreased to 20% when the distance between systems was 16 km. Unlike the simulation results described

in Tables 7 and 8, in Table 9 the new interference probability is obtained when the distance between systems is increased to 18 km. The distance between systems increased by 3 km from the previous simulation due to the additional power of 25 dBm, which caused a wider area to be covered.

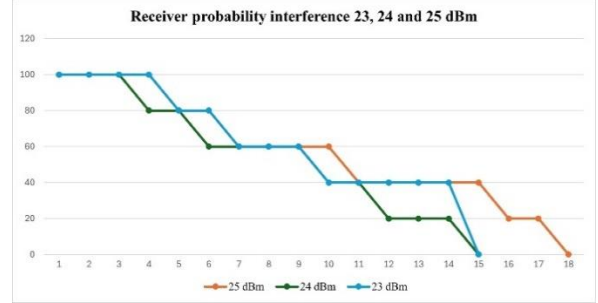


Fig. 3. Interference Ability of 23 dBm, 24 dBm, and 25 dBm

The greater the power, the wider is the range. The graph in Figure 3 shows that the interference capability decreases as the distance increases for the three transmission power levels: 23 dBm, 24 and 25 dBm, which is consistent with Figure 3. At distances between 1 and 4 km, all power levels have the maximum interference capability (100%). However, at distances 5-9, the interference capability for 23 and 24 dBm power decreases faster than that for 25 dBm power. At longer distances (more than 9 km), the 25 dBm power maintained better interference capability. Higher transmission power can maintain the signal strength better; thus, the signal remains stronger and more capable of interfering. Factors such as signal attenuation, environmental interference, and physical obstacles also affect the interference capability but higher transmission power provides an advantage at longer distances.

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