Proposal of interference power occupancy estimation method using chirp demodulation

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***Abstract*—In recent years, Low Power Wide Area (LPWA) has been attracting attention as being suitable for utilizing the Internet of Things (IoT). In Japan, LPWA has been standardized as a specific low power radio that uses the 920MHz band, and is a communication standard that enables long-distance communication with low power consumption. In the specific low power radio of the 920MHz band, since multiple radio standards share the same frequency, communication interruption due to the same frequency interference Co-Channel Interference (CCI) becomes a serious problem. Long Range (LoRa), which is one of LPWA, uses chirp modulation (spread spectrum technology) to suppress CCI. This modulation method is resistant to CCI because it expands the desired signal power after demodulation by wideband gain. However, when operating LoRa, it is necessary to determine the necessity of frequency sharing suitable for Signal to Interference Ratio (SIR) in consideration of interference from other systems, and to set the required diffusion rate. The authors have proposed a method for estimating desired signal power and interference power using chirp demodulation. In this paper, we have established a method for estimating the occupancy rate, which is the access ratio of other systems, with high accuracy from the probability distribution of interference power and noise power.**

I. INTRODUCTION

In recent years, sensing data has been uploaded to the Internet via wireless sensor networks for environmental monitoring. It is called the Internet of Things (IoT) and Cyber Physical Systems (CPS)[1][2]. Low Power Wide Area communication (LPWA) is attracting attention as a wide area and low power wireless sensor network[3]. LPWA uses the UHF band such as the 920MHz band in Japan and narrowly limits the communication band to achieve both low power consumption and long-distance communication. Long Range (LoRa)[4] and Sigfox[5] are being studied as LPWA standards. LoRa can autonomously install both information aggregation base stations and transmitting stations, enabling simple network formation. It is required to share the same frequency with other systems with the same standard as LoRa and other systems with different standards such as a Wireless Smart Utility Network (WiSUN).

WiSUN is a wireless standard that shares the same frequency band as LPWA in the 920MHz band in Japan. WiSUN is a packet transmission by OFDM modulation, which has a wider bandwidth and a larger throughput than LPWA, but has a shorter communication distance. However, in order to extend the communication distance, multi-hop deployment is possible via multiple relay stations. On the other hand, in LoRa, long-distance transmission is realized by narrowing the transmission band, and high-quality communication is realized by switching the access frequency called LoRa modulation to obtain a wide band gain. LoRa has a narrower instantaneous bandwidth than WiSUN, but the bandwidth increases by switching channels, so if LoRa and WiSUN access at the same time, mutual interference, which is a Co-Channel Interference (CCI), is a serious problem. become. Therefore, a LoRa access method that assumes frequency sharing with WiSUN is required. There are over ray type and under ray type access methods that enable frequency sharing with other systems. The over ray type is a method in which the power of CCI is small and LoRa can be demodulated without any trouble, and the multiple access method by spread spectrum technology is used [6]. On the other hand, the over ray type has a large power of CCI. Since it is difficult to demodulate LoRa at the same access, there is a method of transmitting information when another system does not access, such as Carrier Sense Multiple Access (CSMA). In either case, estimating the power and frequency value of CCI is indispensable for determining the access method of LoRa.

The authors have established a power estimation method using the characteristics of LoRa modulation / demodulation [7]. In the simultaneous access environment of LoRa modulated signal and WiSUN, the instantaneous frequency spectrum of LoRa modulation is narrower than that of WiSUN. Become. By using a short section FFT shorter than the symbol length of LoRa modulation, it is possible to detect the frequency transition due to LoRa modulation and estimate the interference power and noise power from the unoccupied band. On the other hand, the power obtained by adding the desired power, the interference power, and the noise power can be estimated from the occupied band of LoRa modulation. Therefore, the desired power can be estimated by subtracting from the estimated interference power and noise power. Assuming packet transmission, the average desired power, average interference power, and average noise power can be estimated by applying the averaging process to the modulated symbols in one packet. In order to estimate the frequency transition of LoRa modulation, the frequency transition is estimated by remodulation after bit determination after demodulation. However, in a simultaneous access environment by another system, the desired power to interference power ratio is low,

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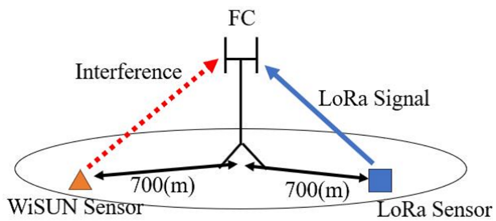

Fig. 1. system model

and demodulation errors are likely to occur. Demodulation errors cause errors in power estimates. Therefore, it is possible to avoid demodulation errors by estimating the power only when the packet demodulation is successful by using the packet detection using the Cyclic Redundancy Code (CRC). However, the desired signal power vs. the interference noise day for successful packet demodulation is evaluated, and the statistical evaluation is biased. On the other hand, as a highly accurate distribution estimation method, distribution estimation is proposed by the Expectation Maximization(EM) algorithm based on the Gaussian Mixed Model(GMM). The EM algorithm is the maximum likelihood condition of the Gaussian distribution model, and the mean and variance and The mixing ratio in a multiple Gaussian distribution can be estimated. The application of the EM algorithm is expected, but the compensation for the estimation error due to the demodulation error is limited.

In this paper, we propose a high-precision estimation method for interference due to demodulation errors, noise power distribution estimation, and access ratio of existing systems. In the proposed method, the interference plus noise power estimated by the power estimation method previously proposed by the authors is used. Noise power can be estimated when WiSUN is not accessed by histogram analysis of interference plus noise power at regular time intervals. When WiSUN is accessing, the combined distribution of interference power and noise power can be estimated as a frequency distribution. Here, the mixing ratio of the frequency distribution is obtained using the EM algorithm, and the WiSUN occupancy rate is promoted. In order to improve the occupancy rate estimation accuracy, the proposed method uses CRC to determine the presence or absence of bit errors in the packet. By using only the power of packets without bit errors, the occupancy estimation error caused by bit errors can be alleviated, but there is a risk of statistical bias. Therefore, in the proposed method, in addition to the power of the packet without the bit error, the power of the packet with the small number of bit errors among the packets judged to have the bit error by CRC was used for the occupancy rate estimation. As a result, the statistical bias can be alleviated, and the occupancy rate can be estimated with high accuracy.

II. System Overview

Fig. 1 shows the outline of the system assumed in this paper. It is assumed that the system complies with LoRa-WAN (Long Range-Wide Area Network) standard which is LPWA standard. A center of gathering sensing information (Fusion Center: FC) is deployed in the area, and one sensor is deployed in the area. The sensor transmits sensor information to the FC. The sensor generates a transmission signal from the sensing result by LoRa modulation which is a spread spectrum technique. In LoRa modulation, the frequency is switched within one symbol time. The frequency transition is switched according to the information bit to be transmitted. In LoRa modulation, in order to avoid a decrease in transmission rate due to spreading, the number of frequency transition patterns is increased and multiple bits of information are transmitted per symbol.

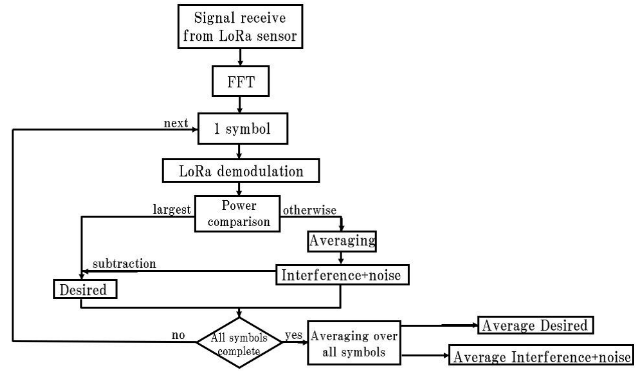

Fig. 2. Chirp demodulation flow

WiSUN is assumed as another system that shares the same channel. WiSUN is a packet access using OFDM modulation. Therefore, when a signal is detected at the IFFT detection time used for LoRa modulation, LoRa is a narrow band communication for a certain period of time but a wide spreading by sweeping the center frequency, whereas WiSUN spreads over the entire channel bandwidth by OFDM modulation. Therefore, when WiSUN and LoRa are simultaneously accessed, they interfere with each other, but the overlapping range of the frequency spectrum that causes interference is narrow and limited. In this paper, in order to simplify the system assumption, we assume that WiSUN does not detect the access of other nodes because of the large impact of building shield appears to CS. In addition, we set the access rate to WiSUN and assumed that it is equivalent to the packet generation rate.

III. Interference and Noise Power Estimation

The power estimation method we have proposed before will be explained. In the simultaneous access environment of LoRa modulation and WiSUN, the instantaneous frequency spectrum of LoRa modulation is narrower than WiSUN. Therefore, the spectrum component in which LoRa modulation does not exist can be detected by detecting the spectrum of the received signal of LoRa modulation by FFT with the shorter detection than one symbol length. An interference component such as WiSUN and a noise component exist in the frequency component in which the LoRa modulation

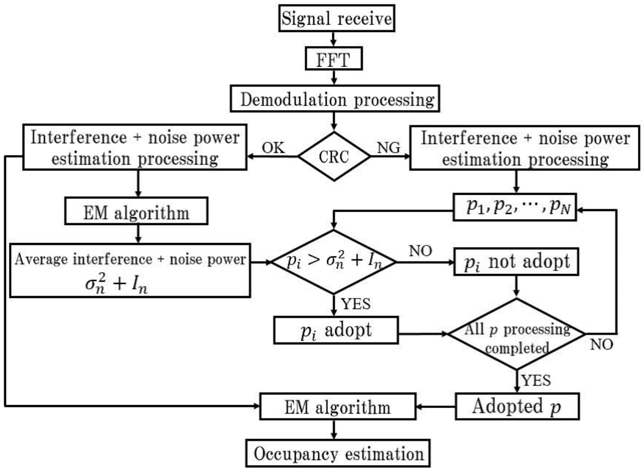

Fig. 3. Occupancy estimation method processing flow

frequency component does not exist, and the power can be estimated in a state in which these components are added. On the other hand, in the spectral component in which LoRa modulation exists, component detection becomes possible with the desired component and the undesired component added. In the proposed power estimation, the average power ratio between the desired component and the undesired component is estimated using this feature.

Fig. 2 shows the processing flow of the power estimation method. The received signal is demodulated for one packet according to the LoRa demodulation process. Here, it is assumed that the signal detection timing can secure the timing synchronization by utilizing the header portion of the packet. Next, after demodulation processing, LoRa modulation processing for reproducing a transmission signal from one packet of information bits obtained by the demodulation processing is performed. The received signal used in the demodulation process is copied and the frequency spectrum is detected from the copy of the received signal using the FFT. Next, the frequency spectrums of the transmitted signal and the received signal reproduced by the demodulation processing are compared. From the frequency spectrum of the transmission signal reproduced by the demodulation process, the frequency spectrum number of the signal selected in LoRa modulation can be recognized. Therefore, the powers of the components other than the frequency spectrum number are calculated and linearly combined. The average power of the undesired signal is calculated by averaging by the combining process. On the other hand, the power of the component having the frequency spectrum is similarly linearly combined. The sum of the desired power and the undesired power is obtained from this combined component. From this result, the desired power can be calculated by subtracting the average power of the undesired power.

IV. Proposed occupancy estimation method

By histogram analysis of the interference plus noise power estimated by the power estimation method we proposed earlier at regular time intervals, the noise power can be estimated used as the frequency distribution when WiSUN is not accessed, and the combined power of the interference power and noise power can be estimated used as the frequency distribution when WiSUN is accessed. In an environment where the power difference between the interference power and the noise power is large, the average, variance, and mixing ratio of the histogram can be obtained for the frequency distribution using the EM algorithm. The WiSUN occupancy rate can be estimated from the mixing ratio obtained here.

The concrete processing flow of the proposed occupancy rate estimation method is shown in Fig. 3. The signal received from the LoRa sensor is fast Fourier transformed, and demodulation processing is performed using the previously proposed power estimation method. Next, the Cyclic Redundancy Check (CRC) is used to check if there is a bit error in the packet, and the packet is divided into a packet that does not contain the bit error and a packet that contains the bit error. If CRC is used, the occupancy rate can be estimated using only the packets for which no bit error has occurred, but there is a risk that the estimation will be statistically biased. Therefore, we focused on packets containing bit errors. Our proposed method is to alleviate the statistical bias by using the interference plus noise power of the packet with few errors among the packets with bit errors in addition to the interference plus noise power of the CRC OK packet.

In the proposed method, of the CRC NG packet interference plus noise power, the power larger than a certain threshold was adopted for the occupancy rate estimation. This is because when the main factor that causes a bit error is the effect of interference, the signal component and the interference component interfere with each other in a non-phase in a packet in which the interference plus noise power is below the threshold value, causing cancellation. It is thought that there is. The power of the canceled parts is underestimated, and in this case, it is considered that many bit errors occur. On the other hand, when the interference plus noise power exceeds the threshold value, the bit error is relatively small and the estimation accuracy of the interference power is considered to be high, so it was adopted to increase the number of samples for occupancy estimation. This time, the average interference plus noise power of the CRC OK packet obtained by the EM algorithm was set as the threshold value.

V. Simulation result

In this paper, we compare the estimation accuracy when all the packets received from the LoRa sensor are used in the WiSUN occupancy estimation, when CRC is used and only the packets that do not include bit errors are used, and when the proposed method is used. Table I shows the simulation specifications. The propagation model is the same as in Ref. [8]. In the system model, one WiSUN sensor and one LoRa sensor, which are interference sources, are distributed, and the

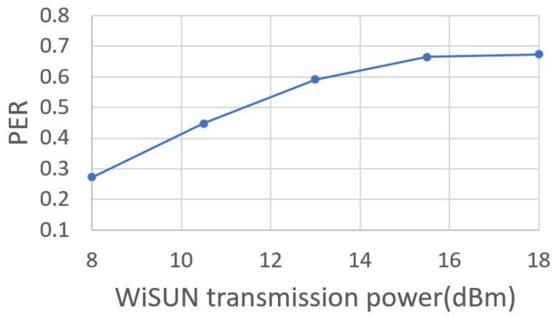

Fig. 4. Packet error rate at various WiSUN transmit powers

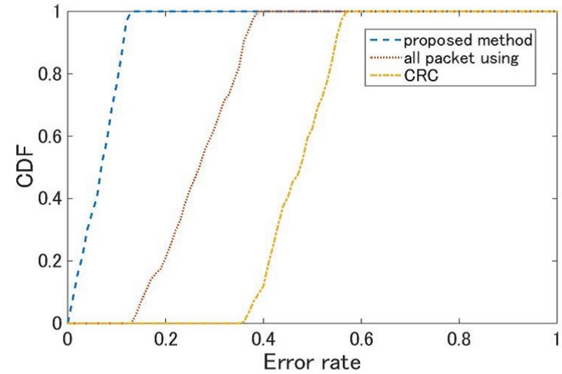

Fig. 5. CDF of the occupancy estimation error rate at WiSUN transmission power 18[dBm]

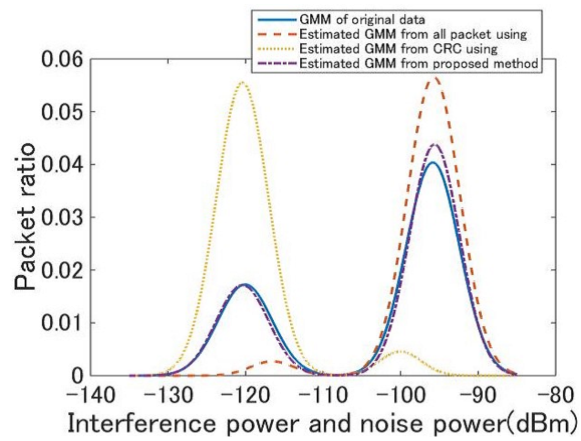

Fig. 6. Power frequency distribution at WiSUN transmission power 18[dBm]

LoRa sensor transmits packets 1000 times. The WiSUN sensor sends a signal according to the access probability of 0.7. In addition, we set two patterns of transmission power of the WiSUN sensor and estimated the occupancy rate.

Fig. 4 shows the packet error rates at various WiSUN transmission powers. Fig. 5 shows the CDF of the occupancy estimation error rate in each method when the WiSUN transmission power is 18 [dBm]. Fig. 6 shows the GMM of noise power and interference plus noise power created using the EM algorithm, and it is said that the power difference between noise power and interference power is large because the distribution of noise power and interference plus noise power is different. When all the packets received from the LoRa sensor are used, it is considered that the estimation accuracy deteriorates due to the influence of packets containing many bit errors. When CRC was used and only packets containing no bit error were used, the estimation accuracy deteriorated due to the influence of statistical bias, and the error rate became very large. On the other hand, the proposed method gave a result with an error rate of 10% or less, confirming high estimation accuracy. From this result, it is considered that the proposed method is effective when the power difference between the noise power and the interference power is large.

Fig. 7 shows the CDF of the occupancy estimation error rate in each method when the WiSUN transmission power is 8 [dBm]. Fig. 8 shows the GMM of noise power and interference plus noise power created using the EM algorithm, and the power difference between noise power and interference power is small because the distributions of noise power and interference plus noise power are close to each other. When all the packets received from the LoRa sensor were used, the estimation accuracy deteriorated due to the influence of packets containing many bit errors. When CRC was used and only packets containing no bit error were used, the estimation accuracy deteriorated due to the influence of statistical bias. When the proposed method was used, the estimation accuracy was improved compared to the case where all packets were used and the case where CRC was used, but the error rate was 10% or more. It is considered that this is because when the power difference between the interference power and the noise power is small, the threshold setting is not appropriate and the statistical bias cannot be alleviated. Therefore, we optimized the threshold value this time. Fig. 9 shows the noise power and interference plus noise power GMM created using the EM algorithm after threshold optimization. By optimizing the threshold value, a high estimation accuracy with an error rate of 10% or less could be confirmed, and it is considered that the statistical bias could be further alleviated.

TABLE I
SIMLATION SPECIFICATIONS

Spreading factor	7
LoRa bandwidth	250[kHz]
WiSUN bandwidth	200[kHz]
LoRa transmission power	13[dBm]
WiSUN transmission power	8, 18[dBm]
WiSUN access rate	0.7
LoRa sensor transmission count	1000
Number of bits per packet	200[bit/packet]

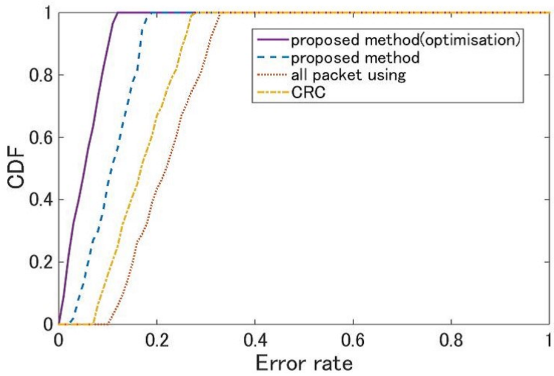

Fig. 7. CDF of the occupancy estimation error rate at WiSUN transmission power 8[dBm]

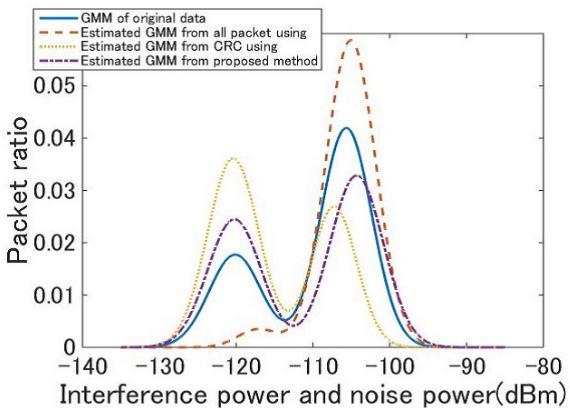

Fig. 8. Power frequency distribution at WiSUN transmission power 8[dBm]

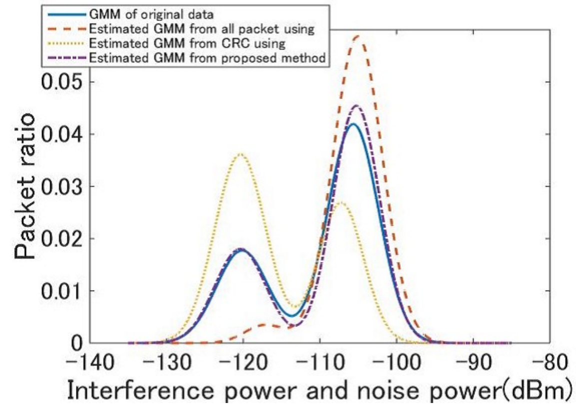

Fig. 9. Power frequency distribution at WiSUN transmission power 8[dBm] (after threshold optimization)

VI. CONCLUSION

In this paper, we proposed a method for estimating the occupancy rate of the interference source (WiSUN) for the purpose of determining the necessity of frequency sharing of LoRa. In an environment where the power difference between noise power and interference power is large, the occupancy rate estimation accuracy by the proposed method is high, and it can be said that the proposed method is effective. In an environment where the power difference between the noise power and the interference power is small, the occupancy rate estimation accuracy by the proposed method was low, so it was necessary to optimize the threshold value. In the future, it will be necessary to devise a threshold optimization method in an environment where the power difference between noise power and interference power is small.

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REFERENCES

[1] S. Ziegler, S. Nikoletsea, S. Krco, J. Rolim and J. Fernandes, ”Internet of Things and crowd sourcing - a paradigm change for the research on the Internet of Things,” 2015 IEEE 2nd WF-IoT, pp. 395-399, 2015.

[2] I. Akkaya, P. Derler, S. Emoto and E. A. Lee, ”Systems Engineering for Industrial Cyber Physical Systems Using Aspects,” in Proceedings of the IEEE, vol. 104, no. 5, pp. 997-1012, May 2016.

[3] Q. M. Qadir, T. A. Rashid, N. K. Al-Salihi, B. Ismael, A. A. Kist and Z. Zhang, ”Low Power Wide Area Networks: A Survey of Enabling Technologies, Applications and Interoperability Needs,” in IEEE Access, vol. 6, pp. 77454-77473, 2018.

[4] A. Furtado, J. Pacheco and R. Oliveira, ”PHY/MAC Uplink Performance of LoRa Class A Networks,” in IEEE Internet of Things Journal, vol. 7, no. 7, pp. 6528-6538, July 2020.

[5] A. Lavric, A. I. Petrariu and V. Popa, ”Long Range SigFox Communication Protocol Scalability Analysis Under Large-Scale, High-Density Conditions,” in IEEE Access, vol. 7, pp. 35816-35825, 2019.

[6] R. Ma, H. Chen and W. Meng, ”Dynamic Spectrum Sharing for the Coexistence of Smart Utility Networks and WLANs in Smart Grid Communications,” IEEE Network, vol. 31, no. 1, pp. 88-96, Jan. /Feb. 2017.

[7] Gaku Kobayashi, Osamu Takyu, Koichi Adachi, Mai Ohta, Takeo Fujii ”Estimation of Desired power and Undesired power Using Chirp Demodulation and Evaluation of Accuracy,” APSIPA ASC 2020 Dec.

[8] N. Aihara, K. Adachi, O. Takyu, M. Ohta, T. Fujii, “Non-Supervised Outside Interference Detection and Wireless Resource Reallocation in LoRaWAN” Technical Reports of IEICE, RCS 2019-275, pp. 57-62, 2020.