Estimation of Desired power and Undesired power Using Chirp Demodulation and Evaluation of Accuracy

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***Abstract*—In recent years, Low Power Wide Area (LPWA) has attracted attention for utilizing Internet of Things (IoT). LPWA is a standard of wireless sensor network for wide area coverage and low power consumption. Even in an environment where it is difficult to secure a power source, LPWA can be used for a long time with a battery, so its maintenance cycle can be a large period. The wireless systems including LPWA share the common frequency channel and thus the co-channel interference (CCI) among them is serious problem. Long Range (LoRa), which is one of the standards of LPWA, uses chirp modulation (spread spectrum technology) to suppress CCI. In this modulation method, the resistance to CCI can be strengthened by increasing the spreading factor of the signal, but at the same time, the transmission rate decreases. Therefore, it is necessary to design an appropriate spreading factor that matches the required Signal to Interference Ratio (SIR). In this paper, we propose the estimation scheme for the desired and the undesired power in the LPWA receiver. It is based on LoRa modulation scheme. From the computer simulation, the accuracy of the proposed estimation scheme is evaluated.**

I. Introduction

Recently, the sensing information is uploaded to the Internet through the wireless sensor networks and thus the environmental monitoring is accomplished through the Internet. It is referred to as Internet of Things (IoT) and Cyber Physical Systems (CPS)[1][2]. Low Power Wide Area communication (LPWA) is attracting attention as the wireless sensor networks with wide area and low power [3]. The LPWA uses the UHF band, such as 900MHz, enables longer communication than Wifi of 2.4GHz, and the power consumption of sensor node is significantly low level. In addition, the propagation distance is expanded by narrowing the transmission band. LoRa[4], Sigfox[5], etc. have been selected as the wireless standards of LPWA. Since both the information gathering station and the transmitting station can autonomously be installed, Long Range (LoRa) can easily construct the wireless sensor networks. However, since it can be placed close to the other wireless system that shares the same frequency band, it is indispensable to study a frequency sharing method with other systems.

A Wireless Smart Utility Network (WiSUN) is a wireless standard that shares the same frequency band as LPWA[6]. WiSUN is a packet transmission by OFDM modulation, has a wider band and a larger throughput than LPWA, but the communication distance is shorter. However, multi-hop deployment is possible via multiple relay stations for extending the communication distance. On the other hand, in LoRa, long distance transmission is realized by narrowing the transmission band, and the high quality of communication can be achieved by obtaining wideband gain by switching the access frequency called LoRa modulation[7]. Compared with WiSUN, LoRa has a narrow instantaneous bandwidth, but the bandwidth is widened by switching channels, so when WiSUN and LoRa access simultaneously, mutual interference, which is co-channel interference (CCI), becomes a serious problem[6].

It is effective to model the CCI from WiSUN to LoRa in order to decide the frequency sharing between them is available or not [6]. Depending on the CCI model, it is possible to switch between underlay type frequency sharing by simultaneous access and overlay type frequency sharing used for exploiting vacant time period. As a result, the spatial and temporal frequency utilization efficiency can be improved. Therefore, the model of CCI is composed of signal power and activity rate, where the activity rate is the accessing probability to the channel in each timing. In measuring the signal power and the activity rate of WiSUN, LoRa cannot access to the channel. In addition, as a usage condition of WiSUN, when the position of the transmitter and receiver moves, the transmission power increases, or the transmission opportunity changes, the observation of WiSUN should be performed, again. Re-observation loses communication opportunities and LoRa throughput drops significantly. Therefore, it is necessary to establish a method that can estimate the CCI power of WiSUN even during communication.

In this paper, we propose the estimation scheme of desired and undesired signal component during the simultaneous access of LoRa sensors and other systems, where the desired and undesired signal components are the signal of LoRa and the CCI of the WiSUN, respectively. In LoRa modulation, the center frequency is swept in 1 symbol time length. Therefore, the carrier wave of the LoRa modulated signal can be detected and the unoccupied frequency component can be identified

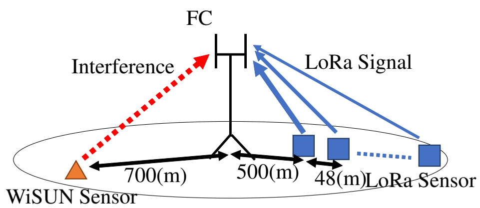

Fig. 1. system model

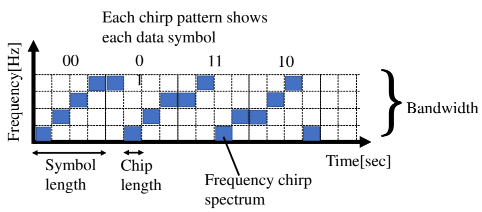

Fig. 2. LoRa modulation

by using the spectrum analysis of the short time period. The frequency components of the WiSUN signal are detected from the unoccupied frequency components. Since WiSUN uses OFDM modulation, the average power is common for all the subcarriers. Therefore, the average power of the whole frequency bandwidth in WiSUN can be estimated from the power of the partial band. In the proposed method, the signal power of WiSUN plus noise can be measured in the unoccupied frequency component of LoRa. After that, the desired signal power of LoRa plus the undesired signal power of noise and interference can be measured in the occupied frequency components of it. Since the interference power and the noise power can be estimated from the unoccupied band, the desired power can be estimated by arithmetic operation. Since the LoRa is packet communication, power estimation is performed from all the symbols in a packet, and a stable average power is estimated by the averaging process. Since the proposed method assumes simultaneous access of WiSUN and LoRa, packet demodulation may be erroneous due to interference from WiSUN to LoRa. At that time, by using the error detection code, it is expected that the influence of the estimation error due to the packet demodulation error is mitigated. On the other hand, in power estimation, since averaging can be performed within one packet, there is a possibility that averaging can reduce decision errors of several symbols. Therefore, we perform the comparison of proposed estimation with and without the error detection.

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 many sensors are deployed in the area. The sensor transmits sensor information to the FC. It is a star-type network configuration that sends information from many sensors to 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. The examples of LoRa modulated symbols are shown in Fig. 2. Here, in order to realize the frequency switching by the baseband signal processing, the frequency is switched at every detection cycle by using the inverse fast Fourier transform (IFFT). 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. The number of bits B that can be transmitted has the following relationship.

$$B = \log_2 M = \log_2 2^{N_{SF}} = N_{SF} \quad (1)$$

where, M is the number of chirp patterns, and one symbol is composed of 2^{SF} chirps. In addition, N_{SF} is the spreading factor, which is equal to the number of frequency transitions within one symbol.

Each sensor performs carrier sense (CS) in channel access. In CS, an energy detector is used that detects the amount of power in the corresponding channel and, if it has a certain level of power or more, the energy detector determines that other nodes are accessing it[8]. A packet in which a plurality of symbols are concatenated is generated and information is transmitted. Assuming LoRa in the 920MHz band, long-distance propagation is possible in a line of sight (LOS) environment, but the propagation distance is limited to short when there is an obstacle-shielding.[9] In particular, when the sensor is deployed on the ground, the building shields strongly and blocks radio waves, so the amount of energy detected by the energy detector becomes small. As a result, the amount of energy becomes smaller than the determination threshold, and miss detection occurs, which determines that the channel is idle even when another node is accessing. The interference from other access results in packet collision[8]. It becomes difficult to demodulate the signal. This is called a hidden node state.

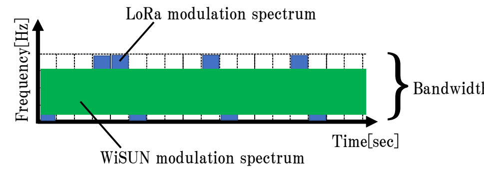

Fig. 3. LoRa WiSUN duplication

In LoRa of 920MHz band, in order to avoid the hidden node state, a transmission ratio (Duty Cycle: DC) that limits the access time ratio of a node is set. Depending on the DC ratio, the access time occupied by one node is limited to a short time, and the time that other nodes can access is secured.

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 T_c used for LoRa modulation, LoRa is a narrowband communication in stantant 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.(Fig. 3)

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. Proposed Estimation of Desired and Undesired Power

The principle of the estimation method of desired power and undesired power proposed in this paper is explained. As shown in Fig. 3, 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 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 noise power estimation, the average power ratio between the desired component and the undesired component is estimated using this feature.

A. Basic Process of Proposed Estimation

Fig. 4 shows the processing flow of the proposed 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, error detection decoding processing is performed in order to evaluate the accuracy of detection. On the other hand, 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. Note that the detection time width of the FFT is $1/N_{SF}$ shorter than the 1-symbol modulation time width of LoRa modulation. As a result, N_{SF} types of FFT detection results can be obtained from one symbol. Here, when the number of symbols per packet is N_{sym}, $N_{SF} \cdot N_{sym}$ spectrums are obtained.

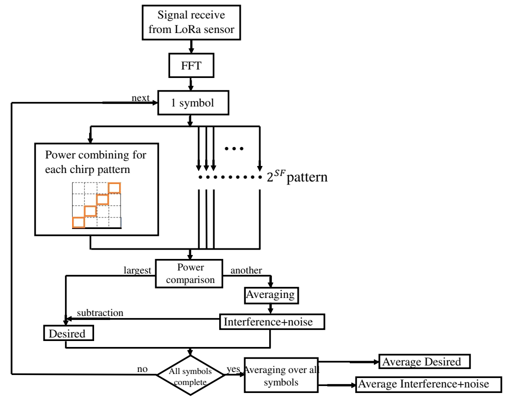

Fig. 4. Chirp demodulation flow

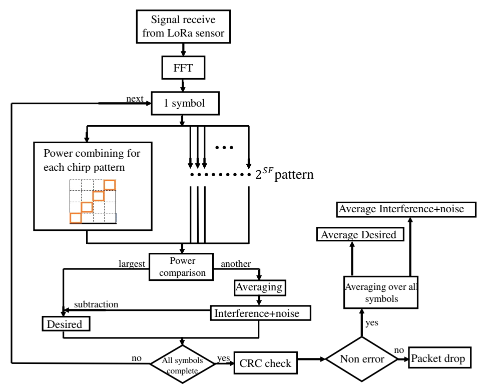

Fig. 5. Chirp demodulation flow(CRC)

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 number of components to be combined is $(N_{SF} - 1) \cdot N_{SF} \cdot N_{sym}$. 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 number of components to combine is $N_{SF} \cdot N_{sym}$. 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.

B. Error Detection

The proposed method handles error detection in the demodulation process. If an error is detected, it is estimated that the undesired component and the desired component are interfering with each other in order to recognize the incorrect arrangement of the frequency spectrum. This interference causes one of the estimation errors. In this paper, we investigate a method not used for signal power estimation when a decoding error occurs as a result of error detection and decoding. This method has advantages and disadvantages. As an advantage, interference between the undesired component and the desired component due to the demodulation error can be avoided. As a drawback, the power is estimated only when the demodulation is successful. If the desired power and the interference power fluctuate due to the effect of multipath fading and the desired power to undesired power ratio is low, the demodulation fails. Since the desired power and the undesired power at this time cannot be estimated, the statistic amount of the power estimated value is biased. The bias of statistics is optimistic that the success of demodulation is high when determining the condition of frequency sharing, and thus the actual communication quality is determined to be low.

In order to avoid the bias of this statistic, a method of estimating the power from all demodulated symbols without using the error detection and decoding result will be examined. This method has a problem that interference between a desired component and an undesired component caused by a decoding error occurs, but since there is an averaging process for a plurality of symbols in a packet, the influence of interference may be mitigated.

IV. Simulation result

A. Cyclic Redundancy Check (CRC)

A type of error detection code. After the bit string is regarded as the coefficient of the polynomial, the transmitting side sends the data by adding a remainder so that it can be divided by a predetermined polynomial. On the receiving side, the data is divided using the same generated polynomial, and if it is not divisible, it is judged that there is an error. It is characterized by high accuracy of error detection.

B. Improvement of power estimation accuracy by CRC

We evaluate the Root Mean Square Error (RMSE) of interference power using the power estimation methods shown in Fig. 4 and Fig. 5. Here, the simulation is performed assuming that a 1024bit packet was transmitted 10,000 times without considering noise. Fig. 6 shows the performance between Signal to Interference power Ratio (SIR) and RMSE, where the SIR is defined as the signal power of Lora to the signal power of WiSUN ratio. If CRC is not used, power estimation is possible even in low SIR, but when SIR decreases, demodulation errors in packets increase and RMSE deteriorates. Next, since CRC has a property of rejecting a packet in which a bit error has occurred, low RMSE, that is, high estimation accuracy can be secured when using CRC. However, due to its nature, CRC rejects all packets at low SIR and cannot

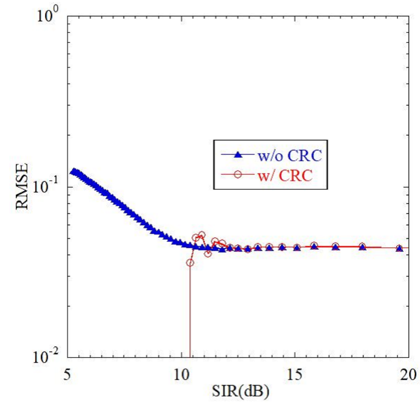

Fig. 6. RMSE evaluation of estimated interference power with and without CRC

perform power estimation. In this paper, we investigate the change in estimation accuracy due to the distance between FC-LoRa sensors when CRC is not used.

C. Evaluation Results in Various Location of LoRa Sensor

In this paper, we investigate the relationship between the distance between LoRa sensor and FC and the estimation error of desired signal power and interference plus noise power in the system model shown in Fig. 1. Table I shows the simulation specifications. The propagation model is the same as in Ref. [10]. In the system model, one WiSUN sensor and 20 LoRa sensors, which are interference sources, are distributed, and sensor numbers 1 to 20 are assigned in order from the LoRa sensor close to FC. The LoRa sensor sends a packet 1000 times.

We describe how to investigate the estimation error of the desired signal power. For each LoRa sensor, the desired signal power is estimated for each packet transmission using the proposed method, and the error rate from the true value is obtained. Next, in order to investigate the relationship between the distance between the LoRa sensor and FC and the estimation accuracy, the average error rate is calculated for each of the 20 LoRa sensors.

Next, the method of investigating the estimation error of the interference plus noise power is described. For each LoRa sensor, the sum of interference power and noise power is estimated for each packet transmission using the proposed method. The average value of the estimated power is calculated after each of the 20 LoRa sensors finishes transmitting once. At this time, the number of sensors used for averaging is changed. At first, only the LoRa sensor near the FC is used for averaging, and gradually the distant sensors are also used for averaging. Next, for each average value of the sum of the estimated interference power and noise power, the error rate from the true value is obtained. Finally, in order to investigate the relationship between the distance between the LoRa sensor and FC and the estimation accuracy, the average error rate is calculated for each sensor used for averaging.

If P_e and P_r are estimated values and true values, the error rate E can be calculated below.

$$E = \frac{P_e - P_r}{P_r} \cdot 100 \quad (2)$$

Fig. 7 shows the Packet Error Rates (PER) of LoRa sensors with sensor numbers 1 to 20. The larger the sensor number, the larger the distance between FC and LoRa sensor. Therefore, the PER tends to deteriorate as the distance from the sensor increases. It is considered that this is because the transmitted signal is affected by the distance attenuation as the sensor is farther from the FC.

Fig. 8 shows a graph of the average error rate of each LoRa sensor for the desired signal power. It can be said that the average error rate deteriorates as the sensor number increases, that is, as the sensor becomes farther from the FC. Like the bit error rate, it can be considered that the sensor located farther from the FC is affected by the distance attenuation of the transmitted signal and demodulation error occurs, which deteriorates the estimation accuracy. However, even if the average error rate deteriorated, it is less than 10 percent, so demodulation errors did not occur much in this simulation, and it is considered that the estimation accuracy of the desired signal power increased.

Fig. 9 shows a graph of the number of sensors used for average power estimation and the average error rate for interference and noise power. It can be confirmed from the graph that the average error rate tends to deteriorate as the number of adopted sensors decreases. This is thought to be because the number of sensors used for averaging is not sufficient and a statistical bias occurred. We do not confirm the deterioration of estimation accuracy due to packets containing demodulation errors from the LoRa sensor far from FC. This is because the WiSUN sensor, which is the interference source, is sufficiently far from the FC, and the demodulation error due to CCI does not occur much.

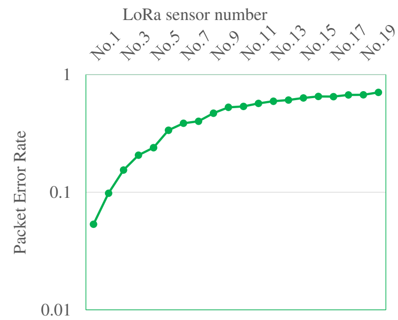

Fig. 7. Packet Error Rate (PER) for each LoRa sensor

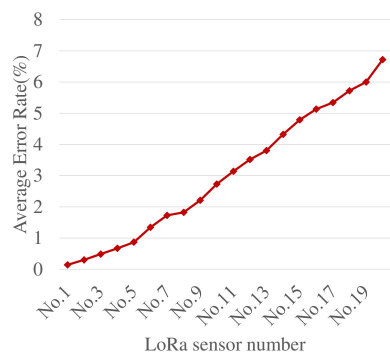

Fig. 8. Average error rate of estimated desired signal power

V. Conclusion

In this paper, assuming the area expansion of LoRa FC, we investigated the relationship between the distance between LoRa sensor and FC and the estimation error of desired signal power and undesired signal (interference plus noise) power. In the estimation result of the desired signal power, the estimation accuracy deteriorated as the distance between FC and LoRa sensor increased, due to the demodulation error due to the distance attenuation. The estimation accuracy of the interference and noise power deteriorated due to statistical bias when the sensors used for power averaging are not sufficient. In the future, it is necessary to investigate the changes in the estimation accuracy of the desired signal power and the interference plus noise power when the distance between the FC and the WiSUN sensor that is the interference source is closer.

TABLE I
Simlation Specifications

Noise power density	-174[dBm/Hz]
Noise power bandwidth	125[kHz]
LoRa sensor transmission power	13[dBm]
Number of LoRa sensors	20
LoRa sensors interval	48[m]
WiSUN sensor transmission power	13[dBm]
FC-WiSUN sensor distance	700[m]
Shadowing deviation	3.48[dB]
SF	7

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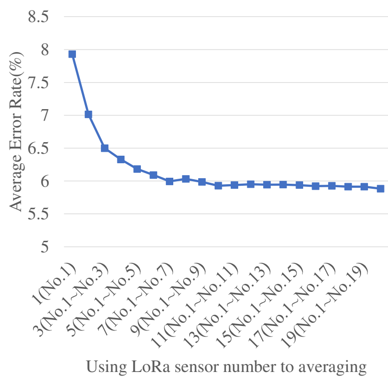

Fig. 9. Average error rate of estimated interference plus noise power

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