Intra-System Interference Avoidance for Packet-Level Index Modulation in Internet of Things

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***Abstract*—The packet-level index modulation (PLIM) has been proposed as the efficient method to increase a few transferring bits in addition to data transmitted by packet. The time and frequency indexes are utilized to transmit additional bits. Moreover, in Internet-of-Things (IoT), Low Power Wide Area (LPWA) has been expected to be used. In IoT, the data transmission with PLIM leads to periodic packet loss when each node periodically transmits packets with the same indexes of PLIM. In this study, the method is proposed to avoid a periodic interference caused by PLIM for LPWA in IoT. The proposed method transmits packets with indexes shifted according to a node's ID and a transmission packet ID. Finally, this paper shows the simulation result to confirm the efficiency of the proposed method.**

I. Introduction

Internet of Things (IoT) is focused because various things (mainly electric applications and sensors) will be connected to the Internet for collecting sensors' data or information concerned with machines' condition to a server through the Internet. A huge amount of collected information is utilized to analyze the surrounding environment. Furthermore, in the future, the IoT system might be able to analyze the environment and control things toward the environment aware comfortable world. Therefore, the IoT technologies have been focused by many engineerings.

The main features of IoT system are that the transmit rate of information is low, the number of nodes which exists within a communication area of a fusion center is large, and a rule called a duty cycle is used for avoiding inter node interference with simple medium access control (MAC) protocol. In addition, each node controls its own transmission timing.The duty cycle is a proportion that is described by a fraction of transmission period. Therefore, IoT devices cannot communicate over time which is provided by the rule.

It is expected that a low power wide area (LPWA) is utilized for the communication system for IoT. The reason is that the applied environment of LPWA matches the used environment of IoT. One is the system has to work by a low power because IoT system drives with power of battery. Another one is the communication area is wide. Therefore IoT system can collect information from many nodes with wide area at a low cost because the number of base stations decreases even if its service area is wide. Therefore, the LPWA system has to efficiently work in order to collect many informations from a node that the energy is limited.

In LPWA the amount of transmit bit at once is limited in order to realize a long-term periodic transmission of the observed information at sensors due to the limit of the energy. Especially, in Japan, in order to avoid one node monopolizing the valuable frequency resources, the duration of continuous transmitting signal in each node is restricted by the rule. Moreover, each node has to obey the duty cycle and the packet modulation method for LPWA cannot change drastically to increase the transmittable information quantity at once. Then it is attractive that the number of transmittable bits per packet increases with keeping the current limitation of regulation rule. In oder to satisfy the above demands, a packet-level index modulation (PLIM) has been proposed [1], in which the packet level index modulation is used for adding transmittable bits with keeping regulatory issue of LPWA.

The researches of the index modulation have long history [2]-[4]. Some researches target to apply the index modulation to 5-th generation (5G) mobile communication systems [5], [6]. In the index modulation, symbols are assigned to the indexes of frequency domain and time domain. In general, the transmitter sends a tone signal with the frequency (channel number) at the time (slot number) which correspond to the transmission data. The receiver detects the both indexes from the received signal. Then the transceivers can communicate a few bits by just one tone signal. On the other hand, in the PLIM system, packets are transmitted by arbitrary frequency and arbitrary time. The receiver can demodulate the transmitted information with PLIM by detecting the frequency index and time index of the transmitted packets. In addition, the received packets are demodulated with the existing demodulation method because the packet is modulated by the existing modulation method of LPWA. Therefore the communication system by using PLIM can receive a few extra bits per packet. Then, the system can be realized with existing technologies of LPWA without drastic remodeling when the PLIM is applied. An example of the existing technologies of LPWA is LoRaWAN [7].

One feature of the PLIM is that the amount of the transmitted data except for data led by a packet are limited by a finite number of channel and a finite number of slot for the fixed transmit interval of the system. In addition, the data modulated by the PLIM can be detected when the packet is received. The packet is transmitted with obeying the duty cycle, so that the index data is stable for transmitting data of object which is not frequently changed for a long time or the difference of the data from the previous transmitted data is small.

However, when the transmitted data is not frequently changed or the difference of the data from the previous transmitted data is small, the transmitters will use the same or similar indexes every time. Then the receiver could periodically lose an arbitrary packet at a regular interval by packet collisions. In the case that some nodes transmit the same data by using PLIM simultaneously, the packet collision occurs and the collision is repeated. In addition, there is a possibility to cause packet collisions between nodes which has the data with high correlation even though the time slot index of the transmitted data is different. Moreover, there is a possibility that the packet collision occurs continuously or periodically, because the data of the transmitted packet is not frequently changed for a long time as mentioned above. This packet collision is more important issue as the number of nodes is large.

Therefore the transmitter needs to avoid packet collisions. In our proposed method, the packets are transmitted by using indexes shifted every transmission. However, the indexes for PLIM cannot be selected randomly even though it is one of formulations which can avoid the periodic packet collision. If the indexes are shifted randomly, the receiver of the packet cannot demodulate the data transmitted by PLIM are assigned to the frequency and time indexes. The transmitter of the packet using PLIM must shift the indexes with the way which can demodulate at the receiver. Therefore our proposed method decides the frequency and time shift of indexes according to its own node identification (ID) and packet ID. The transmitted packets with indexes which are shifted by node and packet IDs can decrease the periodic collisions of intra-system because the indexes change every transmission with the unique ID even though the data transmitted by PLIM does not change. In this paper, we show the simulation results which evaluates the effect of the our proposed method.

II. Packet-Level Index Modulation

In this section, we briefly introduce the packet-level index modulation (PLIM) for IoT [1]. The IoT system assumed in this paper consists a number of nodes equipped with the wireless communication system in which LPWA system is one of candidates. In the IoT system, some nodes periodically transmit a packet to a gateway which gathers sensor informations. However, the transmission period of each node is limited by a duty cycle which decides the time ratio that a node can occupy wireless resources. The node has to satisfy the duty cycle while its system is working.

Therefore, the IoT system cannot increase the data rate with the present LPWA techniques. Then in order to improve the data rate by adding several bits without modification of current PLWA packet, the PLIM has been proposed in [1]. The features of PLIM are that the same periodic packet transmission can be kept, the duty cycle can be satisfied, and the existing transmitter and receiver can deal with the modulation and demodulation for each packet.

In the PLIM, resources in a frequency domain and a time domain are divided as frequency channels and time slots, respectively. The both channel index and time slot index

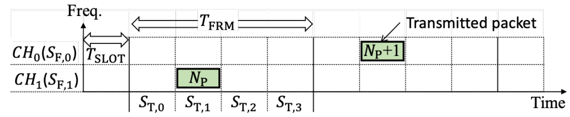

Fig. 1. Image of concern with packet transmission and PLIM.

indicate the data transmitted by PLIM. The transmitter decides these indexes according to the data which are transmitted by PLIM. The receiver can confirm the transmitted data with PLIM by detecting the indexes in a frequency domain and time domain. We define the parameter B_{ONE} is the number of bits by a transmitted packet, which is given by

$$B_{\mathrm{ONE}} = B_{\mathrm{PCKT}} + B_{\mathrm{PLIM}}, \tag{1}$$

where B_{PCKT} indicates the number of bits in which an original LPWA packet is composed, and B_{PLIM} indicates the number of bits which are transmitted by PLIM. Here, B_{PLIM} is denoted by

$$B_{\mathrm{PLIM}} = B_{\mathrm{F}} + B_{\mathrm{T}}, \tag{2}$$

where B_{F} and B_{T} indicate the numbers of bits per packet in the frequency domain and the time domain, respectively. When the number of selectable indexes in the frequency domain and in the time domain are given by S_{F} and S_{T}, the numbers of bits are defined by

$$B_{\mathrm{F}} = \log_2 S_{\mathrm{F}}, \tag{3}$$

and

$$B_{\mathrm{T}} = \log_2 S_{\mathrm{T}}, \tag{4}$$

where the kind of symbol in the frequency domain is equal to or less than the number of channel, note that the kind of symbol has to be the exponent of 2. Moreover the kind of symbol in the time domain is defined by deciding the number of time slots per PLIM time frame. Here we assume a packet of a node is transmitted only once during the PLIM time frame length, T_{FRM}, which is given by:

$$T_{\mathrm{FRM}} = T_{\mathrm{SLOT}} \cdot S_{\mathrm{T}} = T_{\mathrm{SLOT}} \cdot 2^{B_{\mathrm{T}}}. \tag{5}$$

The PLIM time frame length, T_{FRM}, is finite because the nodes periodically send the packet to the gateway.

Especially, the PLIM time frame length, which is equal to the the number of time slots per PLIM time frame, has a concern with the duty cycle. In the PLIM, the packet length has to be smaller than a slot length and the time frame length has to satisfy the duty cycle considering the packet length which is the period occupying a channel resource. However, when the number of transmitting bits in time domain with PLIM increases, the time frame length has to be expanded to obtain many kind of symbol which depends on the number of time slots, or the length of packet is shortened with dividing the frame length into short slots. Moreover, the time frame length and the number of channel decide the data rate with PLIM.

Fig. 1 shows the image of packet transmission under PLIM. In Fig. 1, the number of channel is 2, and the number of slot within the time frame is 4. Then the total number of additional bits transmitted by PLIM per packet is 3 which are composed of a symbol, $S_{\mathrm{F},x}$, (0 or 1) in frequency dimension and a symbol, $S_{\mathrm{T},y}$, (00, 01, 10 or 11) in time dimension, where x and y are indexes, respectively. A node transmits a packet during one time frame. The time frame length is decided by the packet length and the duty cycle.

III. Packet Collision Avoidance for Packet-Level Index Modulation

In the IoT system with PLIM, the packet collision is high likely to occur at periodic timing because the packets are transmitted after the frequency index and time index are decided and these indexes are based on data with less time variation. If the data modulated by PLIM do not change, the packet collision might continue occurring at a regular intervals. Moreover, one of the causes of packet collisions is the data of the high correlation and the transmission timing of the high correlation between several nodes. Therefore, we propose a method to avoid colliding with different nodes' packets which are periodically transmitted at the same time and with the same frequency.

The periodic packet losses lead to decrease the data rate. Therefore, in order to avoid the packet collision cased by PLIM, the frequency index and time index of transmission packet are shifted at every transmission time irrespective of whether the packet collide or not. However, in the case of PLIM, if the both indexes are shifted randomly, the gateway cannot demodulate the data which are modulated by PLIM. The gateway needs information how to change the indexes to demodulate with PLIM because the PLIM symbol depends on the assigned indexes.

Our proposed method to avoid packets collision, which abbreviates to PCA (Packet Collision Avoidance) in this paper, uses an identification (ID) of each node. We assume that the transmission data transmitted by PLIM does not change. The node's ID and the packet ID, which is equal to the number of transmitted packet before that, are included in the received packet. All the nodes work without synchronization.

1) At first, at a node, the data which is transmitted by PLIM (called PLIM data) are generated. Each node generates PLIM data at a regular interval because IoT system usually gathers the surrounding information periodically. Here, the packet transmission of each node is performed once a PLIM time frame duration.
2) The node decides a time slot index and a frequency channel index for transmitting a packet for the PLIM data The indexes are derived from the data transmitted by PLIM.
   Let D_i be the PLIM data bit sequence, which is composed of bit sequence for channel index and bit sequence for time slot index, where i is the number of packets. Here, let D_i^{H} and D_i^{L} be the high-order bits and the low-order bits of D_i, respectively. The number of bits of D_i^{H} is denoted by B_{F} and the number of bits of D_i^{L} is denoted by B_{T}, as mentioned in Sect. II. The symbol, $S_{\mathrm{F},x}$, in frequency domain is decided according to D_i^{H} and the symbol, $S_{\mathrm{T},y}$, in time domain is decided according to D_i^{L}. For the packet of the first frame, the channel index, x, and the time slot index, y, are given by the following equations, respectively:
   $$x = D_i^{\mathrm{H}} \text{ (in decimal notation)}, \quad (6)$$
   and
   $$y = D_i^{\mathrm{L}} \text{ (in decimal notation)}. \quad (7)$$
3) The packet is transmitted by using the indexes of frequency domain and time domain.
4) After the reception of the packet, the gateway demodulates the node's ID, z, and the packet ID, i, from the received packet.
5) Then, the frequency index and the time index of the transmitted packet are detected.
6) The gateway confirms the data transferred by PLIM according to the node's ID and the packet ID.
   When the first packet is received, the high-order bits and the low-order bits of the transmitted PLIM data are given by the following equations, respectively:
   $$D_i^{\mathrm{H}} = x \text{ converted into a binary number}, \quad (8)$$
   and
   $$D_i^{\mathrm{L}} = y \text{ converted into a binary number}. \quad (9)$$
   Note that, the procedures of the normal PLIM are to repeat from Step 1 to Step 6 regardless of the node's ID and the packet ID.
7) For the next transmission, the node adds 1 to the counter of the packet ID.
8) The PLIM data bit sequence, D_i, which is transmitted at the previous PLIM time frame is shifted by z based on own node ID. The new PLIM data bit sequence is denoted by
   $$D_{i+1} = D_0 + i \cdot z \text{ (in binary notation)}. \quad (10)$$
   When D_{i+1} is over the maximum value, M, that the PLIM data bit sequence can express, a cyclic shift is performed on D_{i+1}. Here, $M = \sum_{m=0}^{B_{\mathrm{PLIM}}-1} 2^m$.
9) The both of indexes are updated according to the new PLIM data bit sequence, D_{i+1}.
10) Then the next packet in which the node ID and the packet ID are included is transmitted with the new frequency index and the new time slot index.
11) The procedure repeats from Step 4.

In this study, it is assumed that the gateway can know the beginning of a PLIM time frame of each node.

TABLE I
SIMULATION PARAMETERS

Parameter	
Time slot length	T_{SLOT}
Transmission packet length	1 (slot)
Duty cycle of each node	$\frac{1}{T_{\mathrm{FRM}}}$
The number of channels ($= S_{\mathrm{F}}$)	4 (channel)
The number of packet transmissions of each node	100
The first transmission slot number for each node	Random decision every trial
PLIM data bit sequence, D_i, even in any node's ID	0 (in decimal notation)
The number of trial	1000

IV. SIMULATION EVALUATIONS

A. Simulation Setup

Each IoT node has an oscillator, and there are many kinds of oscillator because the material is different. As is well known, the material of the oscillator of node decides an accuracy of time. In the case that some data are assigned to the time index such as PLIM, the accuracy of the transmission time depends on transmission rate because the shifted transmission time leads to demodulation errors in PLIM. Ideally, every nodes must be equipped by an expensive oscillator in which amount of time shift is small. In general, the component cost of IoT nodes has to be low to obtain the high cost-effectiveness because the IoT system consists of a number of sensor. Therefore, it is better that the time slot length is slightly longer than a packet length. However, in this paper, we don't care the time shift caused by the oscillator. We assume that the transmitted packets under PLIM can be received at the gateway without demodulation errors by PLIM.

Table I shows the simulation parameters. At first, the simulation environment is explained.

The impact of the packet collision is larger as the number of IoT nodes is larger, because competitions between many IoT nodes occur on the limited frequency resources. In Japan, the carrier sense is applied to confirm whether the frequency resource can use or not by the regulation rule that is different from other countries. However, the effectiveness of the carrier sense might be low under the situation where there are many buildings with long communication range.

Moreover, it is difficult to propagate the signal of IoT system far away. The strength of the signals assigned to IoT system becomes weak due to shields such as buildings when it is father than around 1km [8]. Therefore, the reception of the IoT signal outside of a radius of around 1km from a gateway under the non line of sight is fault with high probability. On the other hand, the signals can be received at a gateway within a 1km radius of the node regardless of wether the environment is the line of sight or not. However, in this simulation, it is assumed that the node doesn't carry out the carrier sense as the worst case scenario.

In addition, in this simulation, all nodes are not synchronized. Each node decides the first packet transmission timing within the time frame length from a beginning of the simulation as an initialization. The first packet transmission timing indicates its own beginning of operation and the starting point of the time slot of the node. Subsequent packets are transmitted at a regular time frame length, which is composed of the time slot length, without the proposed PCA. However each node works by following own starting point of the time slot. Here, the time slot length, T_{SLOT}, is common for every node in this simulation.

TABLE II
EVALUATION PARAMETERS

Parameter	(A)	(B)
The number of nodes	1 to 300	300
The number of time slot indexes (S_{T})	128	32 to 4096

This simulation assumes that the packet length is equal to the time slot length for simplicity. Moreover, when at least a part of the packets transmitted from different nodes overlap temporally, we regard the packet transmission as the packet loss. On the other hand, as previously mentioned, in real system with PLIM, in order to decrease the demodulation error caused by a poor oscillator, it is better that the time slot length is longer than packet length. In addition, in this simulation, there is no interference from out of the system with PLIM. This study does not consider nodes' location and propagation model. The transmitted packets from nodes can arrive at the gateway with enough power for the packet reception.

B. Simulation Results

This section shows the simulation results as shown in Figs. 2 and 3. These figures display the packet collision ratio whether the proposed PCA is used or not. In our simulation, we compare the performance of the proposed method with PCA with that of the conventional method which does not use PCA. Table II shows the variable parameters for the simulation evaluations. In these simulations, all nodes transmit the same data bit sequence, D_i. Here, we set D_i even in any node's ID to 0.

Fig. 2 shows the influence of the packet collision depending on the number of nodes. The performance without the proposed PCA rapidly increases as the number of nodes increases. In this simulation, the packet transmission of each node is independent and all the nodes do not work by the common slot. Therefore, the influence of packet loss is large because every nodes use the same channel with PLIM. In contrast, the proposed PCA can keep the decrease of the performance comparing with the performance without the proposed PCA in any number of node as shown in Fig. 2. Especially, when the number of nodes is 250, the performance without the proposed PCA cannot avoid the packet collision since the packet collision ratio is almost 100%. By using the proposed method, each node can use the different indexes every packet transmission. The results show that the proposed PCA method can decrease the probability that packets collide periodically due to the continuous transmission of the same data with PLIM.

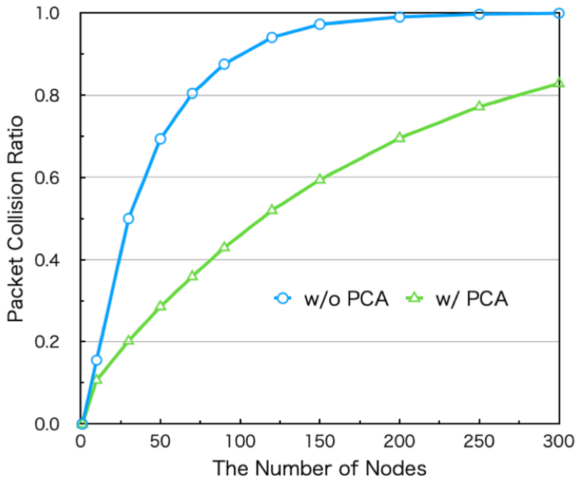

Fig. 2. Packet collision ratio v.s. the number of nodes.

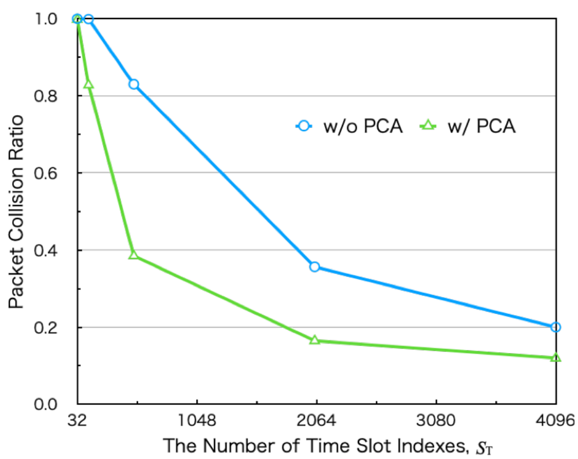

Fig. 3. Packet collision ratio v.s. the number of time slot indexes.

Fig. 3 shows the packet collision ratio with the proposed PCA and without the proposed PCA based on the number of time slot indexes. In our scenario, the nodes select the beginning of the PLIM time frame for the first packet transmission at random. Therefore, the probability that different nodes use the same time slot index decreases as the number of time slot indexes increases regardless of the number of cannel indexes. Then, the packet collision ratio decreases as the number of time slot indexes increases. However, as shown in Fig. 3, the effect that the packet collision ratio is kept down is high by using the proposed PCA. Especially, when the number of time slot indexes is 512, Fig. 3 shows the packet collision ratio with the proposed PCA is roughly half of that without the proposed PCA. Moreover, as compared with the number of the time slot indexes in case of more or less the same number of the packet collision ratio. Therefore the proposed method can obtain these good performances by shifting the indexes based on the node ID and the the packet ID of the transmission packet.

V. Conclusions

The packet-level index modulation (PLIM) has been proposed as the efficient method to increase additional several bits except for data transmitted by packet. The time and frequency indexes are utilized to transfer symbols. This paper focuses on a periodic packet collision caused by PLIM in the transmission of the same data and proposes the packet collision avoidance method based on node ID and packet ID. From the simulation results, we show that the proposed method can dramatically decrease the number of packet collision between the nodes with PLIM.

Acknowledgment

This research and development work was supported by the MIC/SCOPE #JP205004001.

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