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Flexible LPWA Based on Environmental Dynamics

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SUMMARY A low power wide area network (LPWAN) is suitable for the wide area sensor network applications. However, its data rate is limited by the duty cycle (DC) and narrow frequency bandwidth. Thus, the LPWAN may not be able to send the sensing information to the gateway (GW) enough to detect the change of the monitoring environment. This paper firstly defines the change of sensing information as *environmental dynamics*. Based on the environmental dynamics, the selection of sensors for gathering the sensing information is adaptively changed. Secondly, for the enhancement of LPWAN, we propose a *packet-level index modulation (PLIM)*. This paper shows the concept of flexible LPWAN and its future extension.

key words: *LPWA, LoRaWAN, Index Modulation*

1. Introduction

A low power wide area network (LPWAN) can cover up to several km of communication area [1]. LoRaWAN, which is one of LPWA systems, adopts the chirp spread spectrum (CSS) [3] and multiple frequency channels to enable long-distance communication with low transmission power [2]. One of the main applications of LPWA is wireless sensor networks that monitor the physical environment in factories, disaster monitoring, remote watching, etc. In such applications, an end node (EN) periodically transmits data packets to a gateway (GW) or transmits a data packet upon detecting a predefined event. If the physical environment is either static or changing smoothly, the prediction is possible, and hence the update of sensor information brings little additional information. Thus, it may waste a valuable frequency resource. On the other hand, once the physical environment shows sudden change due to event occurrence, it is necessary to have a high resolution in temporal, frequency, and spatial domains. Thus, in the physical environment recognition, the required resolution changes based on the physical dynamics.

Environmental dynamics models the change of the physical environment. Establishing the relation between the various factors determining the physical environment and its change makes it possible to predict how the physical environment will change in the future.

The transmission rate of LPWA is strictly limited by the duty cycle (DC) restriction and the narrow frequency bandwidth (i.e., up to several hundred kHz) to enable frequency sharing with other systems. Furthermore, it may not be possible to implement advanced functionalities to an EN due to its limited function. Thus, it it not easy to increase the transmission rate.

Since consecutive data packets transmitted from one specific EN is sparse in time, it has a significant amount of degrees-of-freedom (DoF) to choose when to transmit a packet as long as DC is satisfied. Furthermore, each EN selects one of the multiple frequency channels for packet transmission to avoid interference. Based on these observations, we propose a packet-level index modulation (PLIM) to overcome the difficulties of LPWA, specifically for LoRaWAN. Unlike the conventional index modulation (IM), the selection of index is made per data packet. Thus, we can treat the data modulation and IM independently. The flexible LPWA with PLIM has two main advantages. The first advantage is that PLIM can increase the transmission rate of LPWA without modification to the standard. The second advantage is that PLIM can shorten the physical packet length by sending some information by the index. The second advantages result in lower packet collision among ENs.

2. LoRaWAN with PLIM

2.1 System Model

This paper considers a LoRaWAN network composed of one GW and a number of ENs. GW receives data packets from ENs. A packet transmitted from an EN is successfully received only when signal-to-noise-ratio (SNR) is higher than the threshold. If multiple ENs transmit packets simultaneously, a packet transmitted from an EN is successfully received if signal-to-interference-ratio (SIR) is higher than the threshold and SNR is higher than its threshold. The other packets are considered to be lost.

2.2 Principle of PLIM

Since the interval of the consecutive data packets is quite long (i.e., up to several tens of minutes), the interval is split into a number of time slots. When an EN transmits a data packet, it selects one of the combinations of the time slot and the frequency channel, i.e., *index*. Let K and M denote the numbers of frequency channels and time slots, then PLIM can increase the data rate per packet by $\lfloor \log_2(K \times M) \rfloor$.

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Table 1 Simulation parameters

Parameters	Values
Simulation area	1×1 [km^2]
Number of ENs	1000
Duty cycle	0.01
Transmission power	13 [dBm]
Carrier frequency	923 [MHz]
Number of frequency channels K	16
Bandwidth	125 [kHz]
Packet generation interval	10 [min]
Spreading factor	{7, 8, 9, 10}
Payload size	{170, 85, 34, 5} [byte]
Overhead size	15 [byte]
Number of preamble symbols	12.25
Number of overhead symbols	8
Coding rate	4/7
Dwell time	400 [msec]

Table 2 Performance comparison between LoRaWAN and LoRaWAN with PLIM

SF	LoRaWAN	LoRaWAN with PLIM	Improvement [%]
7	1339.0	1352.8	1.03 %
8	669.1	682.9	2.07 %
9	267.6	281.3	5.15 %
10	39.3	52.3	35.11 %

2.3 Computer Simulation of PLIM

This section provides the computer simulation results showing the average amount of transmission data per packet of the LoRaWAN with PLIM. Table 1 summarizes the simulation parameters. The interval of consecutive data packets is set to 10 [mins]. For each time slot of PLIM, the time duration is set as twice of data packet. Thus, the number of available time slots becomes about $M = 2,000$.

The simulation results are summarized in Table 2. As the table shows that the average amount of bits per packet can be increased by the proposed PLIM. With SF of 10, the average number of data conveyed by one data packet of the proposed PLIM is 35.11% higher than that of the conventional LoRaWAN.

3. Environmental Dynamics

This paper defines a time and spatial modeling of sensing information as an environmental dynamics. If we consider a temperature sensor as sensing information, the change of temperature caused by the heater is at least over the 100msec. It has a time correlation. If we assume a heat propagation through the physical environment, the two or more sensing information has the spatial correlation. In an illuminance sensor and a radio wave sensor, the propagation speed of optical and radio sensors is so high that the change of source is immediately propagated to the sensor. If we assume the change of source as a stochastic process, the sensing information of illuminance and radio wave can be modeled by stochastic process.

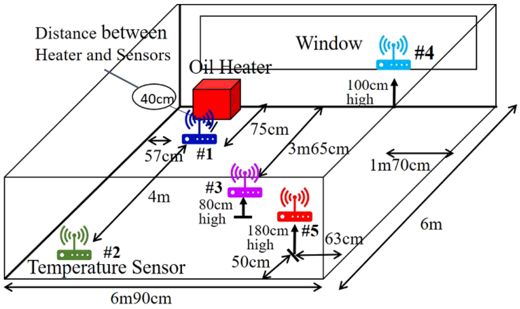


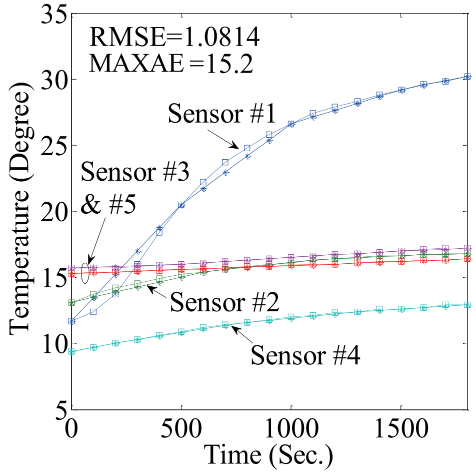
Fig. 1 Monitoring Environment of Temperature Sensors

The time and spatial modeling of sensing information based on environmental models makes the reduction of transmission data and the improvement of the communication quality possible in wireless sensor networks (WSN). If we can assume the spatial correlation model between the two sensing information, the source coding of Slepian-Wolf is available for the compression of sensing information [6].

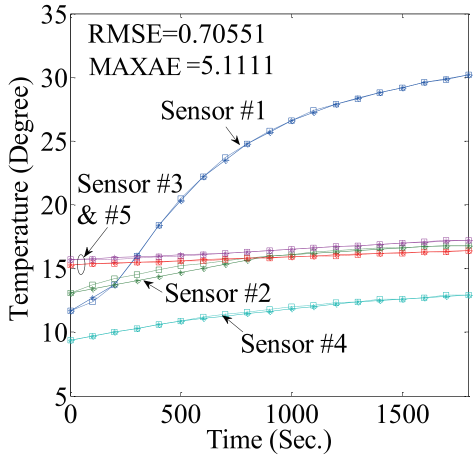
This paper shows the example of high-quality data gathering of WSN based on environmental dynamics. Figure 1 shows the temperature monitor. There are five temperature sensors and each sensor detects the temperature every 100 sec. A heater is set and it starts working after 5 minutes from the start of monitoring. In the assumption of WSN, a sensor can access a data center every 100 sec. The sensor can send the sensing information to the data center without error. If the sensing information is missed by no access from the sensor, it is estimated by the linear compensation between the before and after sensing information. Figure 2 shows the performance between the time and the temperature. In this figure, the circle plot with the solid line and the asterisk plot with the dashed line are the grand truth of data gathering from all the sensors and the gathering results from informed sensing information, respectively.

Figure 2 (a), (b), and (c) are the uniform access of each sensor, the larger access opportunities of #1 than the others, and the larger access opportunities of #1 and #2 than the others, respectively. We assume the selector of the sensor node knows that sensors #1 and #2 take the significant change of temperature. RMSE and MAXAE are the root mean square error and the maximal absolute error between the gathered sensing information and the true one, respectively. The two values are normalized by the minimum resolution of temperature, which is 0.1 degrees.

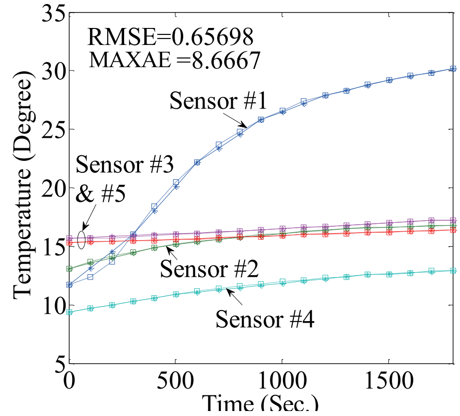
From this figure, the RMSE of Fig. 2 (a) is 1.08 and the largest. This is because the difference between the gathered information and the true one in sensor #1 is large from 0 sec to 1000 sec. The RMSE of Fig. 2 (b) is 0.7 because this difference is mitigated by the large access opportunity of sensor #1. We can see the error of sensor #2 from 0 sec to 1000 sec. This is because the access opportunity of sensor #2 is reduced due to the enlargement of the access opportunity of sensor #1. The RMSE of Fig. 2 (c) is 0.65 and the smallest. Since the access opportunity is assigned to the sensor taking the significant change of sensing information, the RMSE is



(a) Uniform Data Collection



(b) Collecting More Data from Sensor #1



(c) Collecting More Data from Sensor #1 &#2

Fig. 2 Gathered results of temperature sensors.

improved. Suppose the environmental model of each sensor information is given. In that case, the suitable assignment of access opportunities improves gathered sensing information under the limitation of resources of WSN possible.

The MAXAE of Fig. 2 (c) is larger than that of Fig. 2 (b) because the large error of sensor #1 is observed around 100 sec in Fig. 2 (c). Therefore, the adaptation of assigning the access opportunities to the criterion of evaluating the quality of sensing information is important.

4. Conclusion

This paper showed the concept of flexible low power wide area (LPWA) networks based on environmental dynamics. The environmental dynamics is defined as a time and spatial modeling of sensing information. When the time and spatial model of sensing information is known, the transmission control for highly accurate data gathering is available. A packet level index modulation (PLIM) is proposed for achieving the flexible data rate of LPWA. In PLIM, as a packet format is maintained, the accessing channel or timing of the packet is assigned to the information data label and thus the additional data can be transmitted. A matching between the required data rate estimated from the environmental dynamics and the supplied data rate of the LPWA with PLIM is an important future work.

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