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Brief Communication

Effective signal detection in a LoRa-networked ship for data-driven ship management

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Abstract: Recently, as the data-based management of ships using in-ship data has been required, the demand for networking technology to acquire and stably transmit the data is increasing. However, maintaining stable connections in a ship for IoT-based data-driven management is technically challenging owing to the various communication environments and application scenarios in ships. IoT wireless sensor networks on a ship must adopt techniques to reduce the energy consumption of distributed devices and to extend communication coverage to accurately collect various data. Among commercially available IoT networking services such as long-range wide area network (LoRaWAN), Sigfox, narrowband Internet of Things (NB-IoT), and long-term evolution (LTE) machine-to-machine (M2M) (LTE-M), LoRaWAN is one of the most promising technologies because it is a data link layer with a long range, low power consumption, and suitable bit rate for IoT applications. However, for life- and safety-related applications, the detection performance of related information may be a more important criterion that must be guaranteed. Therefore, this study discusses effective signal detection in a LoRa-networked ship for data-driven ship management.

Keywords: Internet of Things (IoT), Long-range wide area network (LoRaWAN), Data-driven management, Signal detection

1. Introduction

With advancements in Internet of Things (IoT) technology, the market demand for various IoT technologies has increased. For achieving better network connectivity, many studies have been conducted to determine optimal power consumption strategies to increase the lifetime of each node **[1]**. In an IoT application, a large number of nodes equipped with communication devices and sensors requires access to the Internet and long-distance communication with limited energy **[2]**.

Recently, data-based ship management with in-ship data is increasingly being used to improve efficiency and safety. Networking solutions that enable data-driven management in a ship should satisfy the requirements of a ship **[3]**. Passenger and non-passenger ships with a gross tonnage of 3000 or more that are constructed on or after July 1, 2002, must carry voyage data recorders (VDRs) to assist in accident investigations under regulations adopted in 2000 **[3]**. The VDR is a data recording system that collects data from various sensors onboard a vessel; it is designed for all vessels required to comply with the International Maritime Organization's (IMO's) International Convention for the Safety of Life at Sea (SOLAS) Requirements (IMO Res. A. 861 (20)) **[4]**.

An IoT wireless sensor network on a ship must adopt techniques to reduce the energy consumption of distributed devices and to extend communication coverage to accurately collect various data. One study **[2]** noted that a long-range wide area network (LoRaWAN) **[5]-[6]** is one of the most promising technologies among various commercially available IoT networking services because it is a data link layer with a long range, low power consumption, and suitable bit rate for IoT applications.

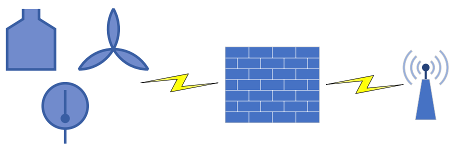

Figure 1: LoRaWAN communication environment in a ship

In ships, it is difficult to guarantee a line-of-sight (LOS) communication environment because of the presence of shielding and obstacles in narrow spaces, as depicted in **Figure 1**. To ensure stable connectivity in such an environment, more relay nodes or

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gateways need to be deployed. However, this directly increases the installation and maintenance costs. Therefore, effective signal detection is essential to ensure a stable connection at a minimum cost, especially in life- and safety-related applications. In this light, this study develops an effective signal detection method for data-driven management in the communication environment of a ship.

This paper is organized as follows: Section 2 proposes an applicable solution for effective signal detection in a LoRa-networked ship. Finally, concluding remarks are presented in Section 3.

2. Applicable solutions for effective signal detection in a LoRa-networked ship

The first part of a LoRa packet is the preamble. It consists of a variable number N_{pr} of upchirps, thus enabling effective preamble detection for a very large range of effective signal-to-noise ratios (SNRs) **[7]**. If the received signal strength indicator (RSSI) is below the noise floor, it is impossible to demodulate the signal **[8]**. However, LoRa can demodulate signals that are below the noise floor with dynamic spreading factors (SFs) informed by the *RegModulationCfg* parameter. The minimum SNR required for demodulation is shown in **Table 1 [9]**.

Table 1: Minimum SNR for demodulation with different SFs **[9]**

RegModulationCfg (SF)	SF [chips/symbol]	LoRa demodulator SNR
6	64	-5 dB
7	128	-7.5 dB
8	256	-10 dB
9	512	-12.5 dB
10	1024	-15 dB
11	2048	-17.5 dB
12	4096	-20 dB

As shown in this table, LoRa signals with an SNR of up to -20 dB can be demodulated by adjusting the SF. Beyond the range of the minimum required SNR, it is necessary to increase the transmission (Tx) power, increase N_{pr}, or use a combination of these methods for signal detection. However, because adjusting the Tx power, SF, or preamble length causes the loss of transmission or processing power, the usage of these methods might be limited in the energy-restricted IoT environment.

Among various IoT application scenarios in a ship, life- or safety-related applications require effective preamble detection even in a harsh communication environment. In most communication systems, misdetection errors (P_m) and false alarms are assumed to be of equal importance. However, in such applications, the detection probability (P_D) must be maximized for a given false alarm probability. Therefore, an effective signal detection solution in a LoRa-networked ship subject to the false alarm constraint is proposed as follows.

The Neyman–Pearson (NP) criterion is used to maximize $P(D_1|H_1)$ subject to the constraint $P(D_1|H_0)$, where $P(D_1|H_1)$ and $P(D_1|H_0)$ are the probability that D_1 (signal is detected ('1')) is true when H_1 (hypothesis '1': with signal) is true and H_0 (hypothesis '0': without signal) is true, respectively **[10]**. In this criterion, the threshold has to be chosen to satisfy the false alarm constraint. As shown in **Figure 2**, the decision threshold (th_{LoRa}) to detect a signal is determined when the measured SNR is less than -20 dB and the applied SF is 12 according to the minimum SNR in **Table 1**.

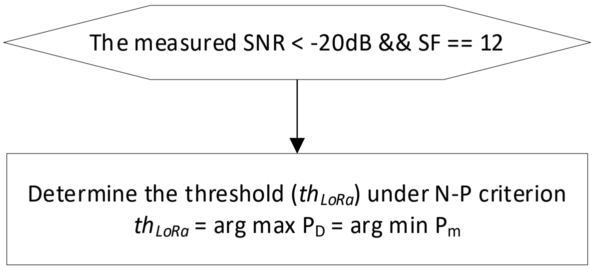

Figure 2: Proposed method for effective signal detection in a LoRa-networked ship

The false alarm probability (P_f), $P(D_1|H_0)$ can be given by **Equation (1)**, where $p_0(y)$ is a probability density function with no signal present and R_1 is the region that results in H1 being chosen.

$$P_f = \int_{R_1} p_0(y)\, dy \tag{1}$$

Assuming Gaussian noise, the probability density function $p_0(y)$ is given by **Equation (2)**.

$$p_0(y) = \frac{1}{\sqrt{2\pi}} e^{-y^2/2} \tag{2}$$

Accordingly, if the tolerable false alarm probability (i.e., constraint) is set, the decision threshold th_{LoRa} can be chosen for effective signal detection in a LoRa-networked ship.

Figure 3 shows the false alarm probability with varying threshold values when the random variable y is defined as a signal with noise, where the noise is a Gaussian random variable having a mean of 0 and variance of 2. In this figure, the false alarm probability is seen to increase as the decision threshold decreases. However, by adjusting th_{LoRa}, the detection probability can be maximized by minimizing the misdetection probability according to the N-P criterion. The decision threshold can be adjusted through the P_f constraint shown in **Figure 3**.

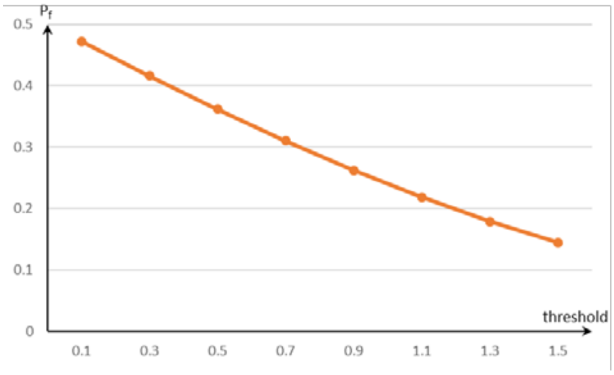

Figure 3: False alarm probability (P_f) with varying threshold (th_{LoRa}) values

3. Conclusion

This study proposes an effective signal detection method in a LoRa-networked ship for data-driven ship management. For life- and safety-related applications, the detection performance is a more important criterion. Because the LoRaWAN protocol has been applied in various areas and meets the requirements for safety and efficiency, the proposed scheme improves its signal detection performance for ship applications and facilitates its easy adoption in an onboard IoT application.

Author Contributions

Conceptualization, Y. -I. Joo; Methodology, Y. -I. Joo; Writing-Original Draft Preparation, Y. -I. Joo; Validation, Y. -I. Joo; Writing-Review & Editing, Y. -I. Joo.

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