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Brief Communication

Analysis of energy consumption on deferred transmission of LoRaWAN down-link frame for IoT in a ship

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Abstract: As the data-driven management of ships is required, the demand for Internet of Things (IoT) technology to acquire and stably exchange in-ship data is increasing. When considering a wireless sensor network for IoT in a ship, a technology that reduces the energy consumption of distributed IoT devices and ensures stable communication coverage is important to acquire various in-ship data and guarantee the accuracy of the collected data. The long-range wide area network (LoRaWAN) protocol is a promising solution for IoT because it has a long communication range and supports a suitable bit rate for IoT applications. Energy-efficient operations must be confirmed for the LoRaWAN protocol to be applied to in-vessel IoT networking. Although the LoRaWAN protocol generally does not consume considerable energy, the energy-efficient operation of the end device is limited because of the low-complexity communication scheme adopted in the LoRaWAN protocol. Therefore, this study analyzes the energy loss of a LoRaWAN end device owing to the operation of a LoRaWAN network server and discusses an alternative that complies with the LoRaWAN standard.

Keywords: Long-range wide area network (LoRaWAN), Energy consumption, Internet of Things (IoT)

1. Introduction

With the enhancement of Internet of Things (IoT) technologies, the scale of applications and markets has grown in various areas. To ensure stable network connectivity among IoT devices, many methods and strategies are proposed to improve power consumption performance and increase the lifetime of each node **[1]**. In IoT applications, a large number of nodes with communication and sensing capabilities require access to the Internet and wide communication coverage with limited battery power **[2]**.

To improve the efficiency and safety of vessels, data-driven management is required, for which a networking solution satisfying the requirements of a ship is required. For example, voyage data recorders (VDRs) must be carried in passenger and non-passenger ships of 3000 gross tonnages and upwards constructed on or after July 1, 2002, to assist in the investigation of accidents **[3]**. The VDR is a data recording system to collect in-ship data using distributed sensors onboard a vessel that is designed for the requirements to comply with the IMO's International Convention Safety of Life at Sea (SOLAS) Requirements (IMO Res. A. 861 (20)) **[4]**.

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

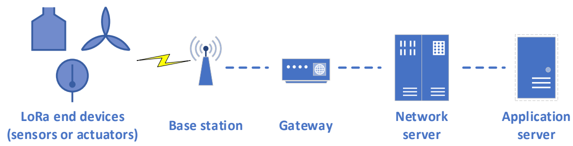

Figure 1: LoRaWAN architecture **[2]**

LoRaWAN **[5]-[7]** is an IoT technology that can be used in many applications in ships. **Figure 1** shows an example of a LoRaWAN implementation. Uplink packets are sent by end devices to a network server relayed by one or many gateways **[5]**. Downlink packets are sent by a network server to only one end device and are transmitted by a network server through one or more gateways **[5]**. This study analyzes the energy wastage problems of the LoRaWAN standard presented as an IoT solution for the data-centric management of ships and briefly proposes improvement strategies.

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The remainder of this paper is organized as follows: Section 2 explains the LoRaWAN data frame exchanges defined in the corresponding specification. In Section 3, the problem of energy consumption in LoRaWAN is analyzed. In Section 4, energy wastage in LoRaWAN is evaluated, and an alternative that complies with the LoRaWAN standard is discussed. Finally, concluding remarks are presented in Section 5.

2. Data exchanges of LoRaWAN protocol

After sending the uplink frame, the end device listens to one or two receive windows (RX1 and RX2) to receive the downlink frame. The receive window is opened after a specific time from the end of the uplink transmission **[5]**. The end device must not transmit another uplink packet unless a downlink packet exists in the RX1 or RX2 window associated with the previous uplink transmission or the second receive window associated with the previous transmission has expired **[5]**.

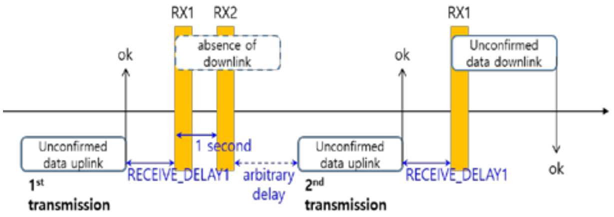

Figure 2: An example of LoRaWAN data frames exchange (*NbTrans* = 3)

Figure 2 shows an example timing diagram for an unconfirmed data frame exchange, where *NbTrans* represents the maximum allowed number of transmissions of uplink confirmed and unconfirmed frames. The network server correctly receives the first transmission. No downlink transmission occurs in the corresponding two receive windows (RX1 and RX2) because the network server may not have data or MAC commands to send to the end device or downlink transmissions to other end devices may be active **[5]**. If no downlink transmission occurs, the end device waits for a random delay after the RX2 window closes.

Because LoRaWAN end devices are power limited, energy-efficient operation is crucial. In the example shown in **Figure 2**, if no downlink frame transmission occurs after successful uplink frame reception at the network server, it will result in waste of energy of the end device owing to the additional transmission and reception operations. If no downlink data or MAC command exists to be transmitted, an acknowledgement frame (possibly empty) can be transmitted to the end device. In addition, because normal network servers can accommodate multiple end devices when responding to another active end device, at least an acknowledgement frame transmission is possible. Therefore, Section 3 analyzes the energy consumption of the end device owing to the intentionally delayed transmission depicted in **Figure 2**.

3. Analysis of energy consumption

When a network server intentionally defers the transmission of downlink frames, additional energy is wasted because of redundant transmission and reception operations, as shown in **Figure 2**. Assuming that an end device receives a downlink frame after n uplink frames are transmitted, the expected power consumption E[P] is as follows:

$$\begin{aligned}\mathrm{E}[P] = {} & P_{tx} \times T_{tx} \times n + P_{rx} \times T_{rx} \times 1 \\ & + P_{IDLE,1} \times RECEIVE\_DELAY1 \times n \\ & + P_{IDLE,2} \times E[arbitrary\ delay] \times (n-1) \\ & + P_{detect} \times (T_{RX1} + T_{RX2}) \times (n-1) \\ & + P_{detect} \times T_{RX1} \times 1/2 \end{aligned} \tag{1}$$

where P_{tx}, P_{rx}, and P_{detect} denote the power consumptions for frame transmission, reception, and preamble detection, respectively. $P_{IDLE,i}$ denotes the consumed power in the IDLE state, where i = 1 represents the duration of RECEIVE_DELAY1 and i = 2 is that of the arbitrary delay. T_{tx} and T_{rx} represent the uplink and downlink dwell times, respectively, that are configured using the *TxParamSetupReq* MAC command.

The energy dissipated owing to the intentionally deferred transmission of the downlink frame, E[$P_{deferred}$], is described by **Equation (2)**.

$$\begin{aligned}\mathrm{E}[P_{deferred}] = {} & P_{tx} \times T_{tx} \times (n-1) \\ & + P_{IDLE,1} \times RECEIVE\_DELAY1 \times (n-1) \\ & + P_{IDLE,2} \times E[arbitrary\ delay] \times (n-1) \\ & + P_{detect} \times (T_{RX1} + T_{RX2}) \times (n-1) \end{aligned} \tag{2}$$

4. Numerical result

According to the number of uplink frame transmissions (n), the dissipated-to-total energy consumption ratio for each power element (P_{tx}, $P_{IDLE,1}$, $P_{IDLE,2}$, and P_{detect}) is shown in **Figure 3**. As the number of transmissions increased, the unnecessarily wasted energy out of the total energy consumption increased rapidly. Based on the LoRaWAN specification **[5]**, n could be increased up to 15 (that is, *NbTrans*), in which case the P_{tx}- and $P_{IDLE,1}$-

elements wasted 93.3% of the energy. The $P_{IDLE,2}$- and P_{detect}-elements were totally dissipated energies (assuming that the downlink frame was received in RX1).

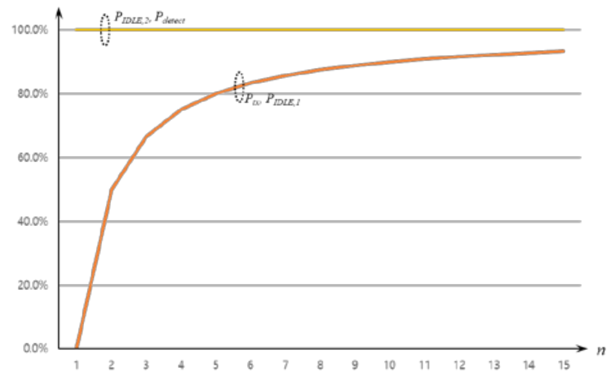

Figure 3: Dissipated-to-total energy consumption ratio with respect to each power element

As shown in **Figure 3**, intentionally delayed transmission of downlink frames wasted a significant portion of energy consumption unnecessarily and thus reduced the energy efficiency of LoRaWAN. In addition, guaranteeing the quality of service (QoS) was difficult owing to the increased redundancy of repeated uplink transmissions.

Therefore, to reduce unnecessary energy consumption by the end device and guarantee QoS, intentionally deferred downlink transmission should be avoided and an acknowledgment frame (possibly empty) should be transmitted immediately.

5. Conclusion

This study analyzed the energy loss of a LoRaWAN end device in the case of an intentionally deferred downlink transmission of the LoRaWAN network server. The intentionally delayed transmission of downlink frames wasted a significant portion of the energy of the end devices, thus hindering the energy-efficient operation of the LoRaWAN. In addition, increased redundancy in repeated uplink transmissions degraded the QoS. Hence, the immediate acknowledgement policy of the network server could minimize energy wastage and ensure the QoS level.

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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