Orange Innovation

LoRaWAN® Relay by the LoRa Alliance®

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LoRa Alliance™

Project timeline, references

Relay TF  Relay TF

2017  2018  2019  2020  2021  2022

The Things Conf. demo (Semtech)
tech spec frozen editorial edits published Sept. 21st, 2022

cert. impl.

Protocol specification, architecture

- TS011-1.0.0, Relay Specification (Sept 21st, 2022)
  https://resources.lora-alliance.org/technical-specifications/ts011-1-0-0-relay

Regional Parameters

- RP002-1.0.4, Regional Parameters (Sept 21st, 2022)
  https://resources.lora-alliance.org/technical-specifications/rp002-1-0-4-regional-parameters

2

Unrestricted
Agenda

Uses cases, requirements (1 mn)

Specification (25 mn)

Q&A (x mn)
1. Use cases, Requirements
Battery-operable, low-cost relaying

Use case
- End-device does not communicate with network well enough (far edge)
- User/operator adds a Relay, commissions it into NS
- If network later densified (Gateway), Relay may be decommissioned
- All transparently to End device

Key features
- about a dozen devices per Relay
- years of Relay operation with typical traffic and typical battery
- Relay uses hardware similar to that of an End Device
- Relay increases coverage/reliability by supplementing communication to network, not replacing
- Relay is an End-device in its own right, can act as a regular sensor/actuator as well
- relaying protocol is an optional extension to regular LoRaWAN protocol
2. Specifications
2. Specifications

Overview

Protocol elements

Synchronization

Forwarding

Security
Relayed network architecture

New compared to existing LoRaWAN
Modified compared to existing LoRaWAN

The LoRaWAN “relay protocol extension” is optional for End Devices to implement or to use.
Relay protocol extension can be added on top of LoRaWAN 1.0.4 or 1.1+
Maximum of 16 ED’s under a Relay
Data forwarding, in a nutshell

New WOR frame/protocol between ED and Relay clues the Relay in on the forthcoming uplink

- Long preamble, few channels: Relay can operate on low duty cycle

New RXR slot allows ED to receive repeated downlink while keeping RX1 and RX2 unchanged

- direct ED-NS communication is unhampered (multiple channels)
2. Specifications

Overview
Protocol elements
Synchronization
Forwarding
Security
**WOR link**

Designed for long preamble
- Relay samples the WOR channel(s) to detect preambles
- sampling period up to 1 second, configurable
- allows Relay to sleep between Channel Activity Detections
- actual ED’s preamble length is dynamically adjusted

Two channels
- **one default channel, mandatory**
  - uses one among two specified frequencies
  - defined in the Regional Parameters document
  - each Relay configured to use choice 0 or 1
- **an optional second channel**
  - fully configurable by the Network Server
  - communicated to End Device through configuration

### 2.4.9 EU863-870 Relay Parameters

The WOR default channels are:

<table>
<thead>
<tr>
<th>Channel Index</th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency WOR</td>
<td>865.1</td>
<td>865.5</td>
</tr>
<tr>
<td>Frequency WOR ACK</td>
<td>865.3</td>
<td>865.9</td>
</tr>
<tr>
<td>SF</td>
<td>SF9</td>
<td></td>
</tr>
<tr>
<td>BW</td>
<td>BW125</td>
<td></td>
</tr>
</tbody>
</table>

*Table 15: EU863-870 WOR default channel*
**WOR Relay Class A uplink, WOR Relay Join Request frames**

WOR frame attracts Relay’s attention to forthcoming LoRaWAN uplink
- because Relay unable to listen to all frequencies, all datarates, at all time

Clues it in on the physical parameters
- time, frequency, datarate

**WOR Relay Join Request**
- no security

**WOR Class A Uplink**
- secured
- authentication mixes in Phy parameters, DevAddr, WFCnt

### WOR Relay Join Request

<table>
<thead>
<tr>
<th>1 byte</th>
<th>1 byte</th>
<th>3 bytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>WOR Type = 0</td>
<td>DR[3:0]</td>
<td>Frequency[23:0]</td>
</tr>
</tbody>
</table>

### WOR Class A Uplink

<table>
<thead>
<tr>
<th>1 byte</th>
<th>4 bytes</th>
<th>4 bytes</th>
<th>2 bytes</th>
<th>4 bytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>WOR Type = 1</td>
<td>DevAddr</td>
<td>Encrypted {DR</td>
<td>Frequency}</td>
<td>WOR Frame Counter (WFCnt)</td>
</tr>
</tbody>
</table>
WOR Relay ACK

Acknowledges the WOR Relay Class A Uplink
- End Device knows Relay is listening
WOR Join Requests are not acknowledged

Physical parameters
- same frequency/datarate as WOR Relay Class A Uplink
- also inverted IQ, fixed timing

Provides information about Relay
- forwarding data rate
- forwarding limit status
- timing information

Secured
- encrypted, authenticated, mixing in info from WOR Relay Class A Uplink

<table>
<thead>
<tr>
<th>3 bytes</th>
<th>4 bytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encrypted {Forwarding datarate, forwarding limit status, timing info}</td>
<td>MIC</td>
</tr>
</tbody>
</table>

WOR_ACK_DELAY
from Relay to End Device

- same freq as WOR that triggered the relaying
- same datarate as LoRaWAN uplink (Join Request or data uplink)
- inverted IQ (as regular downlinks)

**timings**

- 18 seconds after end of LoRaWAN uplink (Join Request or data uplink)
- allows time for Relay to forward uplink and receive downlink
- allows End Device to hear early response from network
Relay - NS communication (relay protocol related)

Takes place over regular LoRaWAN connection
- Relay is an End Device in its own right

Control plane communication (management of Relay, notification of new devices)
- uses new “MAC commands”
- regular FPort 0, new Command IDs (CID)

Data plane communication (encapsulated data frames)
- dedicated FPort (226), used for both directions
- allocated from the “reserved” range in TS008 (LoRa Alliance Assigned Value Registries) v1.0.5
End Device - NS communication (relay protocol related)

Control plane communication (management of relay protocol on End Device)
- uses one new “MAC command”
- regular FPort 0, new CID
2. Specifications

Overview
Protocol elements
Synchronization
Forwarding
Security
ED synchronizes to Relay wake-ups

Inspired from WiseMAC [1]

- unencumbered by IPR

Relay measures timing on WOR Class A Uplink

WOR ACK contains timing-related information

ED synchronizes to Relay wake-ups

ED computes preamble length based on timing info

If computed preamble length > CAD Period or Relay no longer responding

- **assume synchronization is lost**
2. Specifications

Overview
Protocol elements
Synchronization
Forwarding
Security
Forwarding uplink frames (Join Request, data uplink)

ED sends uplink
- with fixed delay
- after sending WOR (Join Request) or receiving WOR ACK (data)

Relay encapsulates uplink frame i.e., sends uplink
- on its own LoRaWAN link, with FPort 226 (to NS Relay Server)
- the received \text{PHYPayload} and associated metadata (RSSI, SNR, freq., DR of the LoRaWAN uplink; WOR channel index),
- secured with network session keys,
- after fixed delay after ED’s uplink (Join Request or data uplink)

ED is responsible to make payload small enough so that it can be encapsulated
No cryptographic link between WOR frame and ensuing uplink frame
Forwarding downlink frames (Join Accept, data downlink)

Relay decapsulates message received on its own RX1 or RX2 timeslots from NS on FPort 226

- and sends it verbatim to End Device (PHYPayload, no metadata)
- at time RXR after end of ED’s uplink transmission
- with RXR physical parameters (WOR frame freq, uplink frame datarate)
- at default power

NS is responsible to make payload small enough

In 1.1+, NS shall MIC with RXR physical parameters
Forwarding (misc.)

New End-Device notification
- WOR Class A Uplink not MIC’ed ok (whether DevAddr absent from trusted list or present)

Join Request forwarding/filtering mechanism
- Join Requests not authenticated, need to be selective
- Longest Prefix Match on N leftmost bytes of JoinEUI|DevEUI, action to filter (i.e. block) or forward
- MUST support 16 entries

Forwarding limitation

Token bucket algorithm
- Reload rate: X tokens/hour
- Bucket size: max number of tokens

<table>
<thead>
<tr>
<th>Limiting Bucket / Default parameters</th>
<th>Reload Rate</th>
<th>Bucket Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Join-Request</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>“New device” detected</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Class A Uplink (per trusted end-device)</td>
<td>No default value</td>
<td></td>
</tr>
<tr>
<td>Class A Uplink (for all trusted end-devices)</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>Global uplink</td>
<td>8</td>
<td>16</td>
</tr>
</tbody>
</table>
2. Specifications

Overview
Protocol elements
Synchronization
Forwarding
Security
Link layer security

Communication between Relay and NS-RelayServer

- secured by Relay’s own session keys ($\text{NwkSKey in 1.0.x, NwkSEncKey and F/SNwkSIntKey in 1.1+}$)
- not just MAC commands: forwarded payloads are also secured with network session keys!
- Relay can also be an End Device in its own right, with regular App server

Communication between End-Device and Relay

WOR Class A Uplink, WOR ACK:

- secured by dedicated session key pair: $\text{WorSEncKey and WorSIntKey}$
- mutually authenticated, encrypted, replay protected ($\text{WFCnt}$)

Relay not trusted with the End Device’s session keys ($\text{NwkSEncKey or F/SNwkSIntKey}$)

WOR Relay Join-Request not authenticated, not encrypted, not replay protected

RXR downlink is secured by NS

- Relay forwards at RXR the exact $\text{PHYPayload received from NS (i.e., MHDR, MACPayload, and MIC)}$
- be it a Join Accept or a data downlink
On Join Request

- JS derives and sends to NS network session keys as usual
- whether Relay involved or not

NS configures Relay

- NS derives relay “root” session key, RootWorSKey
- sends to Relay
- “application” protected

Relay

- derives WorSEncKey and WorSIntKey
Wrap-up
Wrap-up

Specifications

- publicly available on the LoRa Alliance website
- RP002-1.0.4, Regional Parameters (Sept 21st, 2022) https://resources.lora-alliance.org/technical-specifications/rp002-1-0-4-regional-parameters

Tutorial

- 1 hour webinar by the LoRa Alliance, Oct 4th, 2022

Certification

- on-going work

Implementations (as of Jan 2023)

- Actility working on relay-enabled Network Server
- other companies working on it, without public statement yet
Thanks
Attic
2. Specifications

Overview
Protocol elements
Synchronization
Forwarding
Security
Management
Unrestricted Relay Gateway NS+JS

LoRaWAN 1.0.x or 1.1+

+RXR

WOR

Relay management protocol
References

Use-cases, requirements

- LoRaWAN_Relay_Requirement_FINAL (May 27th, 2021)
  https://members.lora-alliance.org/wg/Relay-D2D-tf/document/5435

Protocol specification, architecture

- TS011-1.0.0, Relay Specification (Sept 21st, 2022)
  https://resources.lora-alliance.org/technical-specifications/ts011-1-0-0-relay

Regional Parameters

- RP002-1.0.4, Regional Parameters (Sept 21st, 2022)
  https://resources.lora-alliance.org/technical-specifications/rp002-1-0-4-regional-parameters

Assigned Values Registry

- TS008-1.0.5, LoRa Alliance Assigned Value Registries (Apr 6th, 2022)
  https://members.lora-alliance.org/wg/Technical/document/7113
Use Cases

End-device in a hard-to-reach place, cannot communicate well enough with network

Customer buys relay, may require commissioning into network, may require configuration.

- OR -

Operator installs relay transparently to user; if network later densified, operator may remove relay transparently to user.
Requirements

Mandatory features

1. A relay SHALL be able to handle context for at least 10 end-devices at the same time.
2. The relay SHALL support the LoRaWAN L2 specification as an end-device, to connect to a LoRaWAN network.
3. A relay SHALL only support end-devices that are compliant with LoRaWAN L2 specification.
4. In order to be relayed, the end-devices SHALL implement the L1R/L2R Relay Protocol Extension.
5. The L1R/L2R Relay Protocol Extension SHALL NOT preclude operation in Class B and Class C of the end-devices and the relay.
6. A relay SHALL NOT relay any message between two end-devices. (i.e., no mesh networking of end-devices)
7. End-devices SHALL be able to join/re-join a LoRaWAN network under a relay.
8. End-devices SHALL be capable to revert back to normal operation from relay mode.
9. The L1R/L2R Relay Protocol Extension SHALL be as secure and private as standard LoRaWAN® communications.
10. The end-device LoRaWAN root key SHALL NOT be exposed to the relay.
11. The relay mechanism SHALL support OTAA end-devices.
# Desired features

1. A relay **SHOULD** be able to be powered from batteries for 5 years without any battery changes, in useful scenarios. An energy amount in the 30-300 kJ range **SHOULD** be considered.

2. The relay mechanism **SHOULD** minimize unwanted wake up of other relays.

## Appendix

### Requirements

<table>
<thead>
<tr>
<th>SF/BW for ED-Relay</th>
<th>SF9 BW125</th>
<th>SF9 BW125</th>
<th>End Device</th>
<th>Uplinks per day per ED</th>
<th>Total forward uplink TOA [s]</th>
<th>Total forward downlink TOA [s]</th>
<th>Average current [µA]</th>
<th>Battery life [year]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scenario 1</strong></td>
<td>SF9 BW125</td>
<td>SF9 BW125</td>
<td>10</td>
<td>4</td>
<td>13,8</td>
<td>0,8</td>
<td>220</td>
<td>9,7</td>
</tr>
<tr>
<td><strong>Scenario 2</strong></td>
<td>SF9 BW125</td>
<td>SF9 BW125</td>
<td>24</td>
<td>4</td>
<td>82,8</td>
<td>4,8</td>
<td>262</td>
<td>8,2</td>
</tr>
<tr>
<td><strong>Scenario 3</strong></td>
<td>SF9 BW125</td>
<td>SF9 BW125</td>
<td>24</td>
<td>4</td>
<td>27,6</td>
<td>1,6</td>
<td>231</td>
<td>9,3</td>
</tr>
<tr>
<td><strong>Scenario 4</strong></td>
<td>SF9 BW125</td>
<td>SF9 BW125</td>
<td>24</td>
<td>4</td>
<td>165,6</td>
<td>9,6</td>
<td>313</td>
<td>6,9</td>
</tr>
<tr>
<td><strong>Scenario 5</strong></td>
<td>SF9 BW125</td>
<td>SF9 BW125</td>
<td>144</td>
<td>4</td>
<td>993,6</td>
<td>57,6</td>
<td>808</td>
<td>2,7</td>
</tr>
<tr>
<td><strong>Scenario 6</strong></td>
<td>SF7 BW125</td>
<td>SF7 BW125</td>
<td>10</td>
<td>4</td>
<td>13,8</td>
<td>0,2</td>
<td>124</td>
<td>17,3</td>
</tr>
<tr>
<td><strong>Scenario 7</strong></td>
<td>SF7 BW125</td>
<td>SF7 BW125</td>
<td>24</td>
<td>4</td>
<td>82,8</td>
<td>1,4</td>
<td>152</td>
<td>14,1</td>
</tr>
<tr>
<td><strong>Scenario 8</strong></td>
<td>SF7 BW125</td>
<td>SF7 BW125</td>
<td>24</td>
<td>4</td>
<td>27,6</td>
<td>0,5</td>
<td>131</td>
<td>16,4</td>
</tr>
<tr>
<td><strong>Scenario 9</strong></td>
<td>SF7 BW125</td>
<td>SF7 BW125</td>
<td>24</td>
<td>4</td>
<td>165,6</td>
<td>2,9</td>
<td>188</td>
<td>11,4</td>
</tr>
<tr>
<td><strong>Scenario 10</strong></td>
<td>SF7 BW125</td>
<td>SF7 BW125</td>
<td>144</td>
<td>4</td>
<td>993,6</td>
<td>17,3</td>
<td>529</td>
<td>4,1</td>
</tr>
</tbody>
</table>

(Uplink size 50 Bytes, Downlink size 20 Bytes, CAD period 500 ms, CAD duration 2 symbols, Battery SAFT LS 33600 (17Ah - 3.6V), PPM drift 20 ppm)

(Excel file available to play with)
Un-asked questions

LoRaWAN 1.0.x and 1.1+ compatible? Or just 1.1+?

Physical forwarding (impersonation) or encapsulation?

Can relay only work with relay-enabled NS, or also with Relay Server on the top of regular NS?
2. Specifications

Overview
Protocol elements
Synchronization
Forwarding
Security
Management
End-Device management

- Just a MAC command to the End Device
- can happen to be forwarded through the Relay, or direct communication to End Device
- Configures the “relaying protocol” part of the End-Device
  - Use of relaying protocol: forced on, forced off, smart on/off (trigger threshold), at ED’s discretion
  - Second WOR channel: enabled/disabled, frequency, DR, ACK freq offset
  - Attempt direct comm. on no WOR ACK after X attempts

<table>
<thead>
<tr>
<th>CID</th>
<th>Relay Protocol Command Name</th>
<th>From</th>
<th>Short Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x41</td>
<td>EndDeviceConfReq</td>
<td>X</td>
<td>Configure the relay parameter of the end-device</td>
</tr>
<tr>
<td>0x41</td>
<td>EndDeviceConfAns</td>
<td>X</td>
<td>Conveys the answer to EndDeviceConfReq</td>
</tr>
</tbody>
</table>
Relay management

Relay Conf
- Relay on/off
- first WOR channel setting
- second WOR channel

Join filter/forward list configuration
- each entry contains N leftmost bytes of JoinEUI|DevEUI and associated Join Request filter/forward decision

Relayed list configuration
- add entry: DevAddr, forwarding limit params, WFCnt, RootWorSKey
- Remove entry, read back WFCnt

Forwarding limit configuration
- non ED-specific: Join Requests, notifications, all data uplinks, global uplinks

Notification of WOR Class A Uplink heard by the Relay
- DevAddr, WOR RSSI, WOR SNR