Jan 18th, 2023

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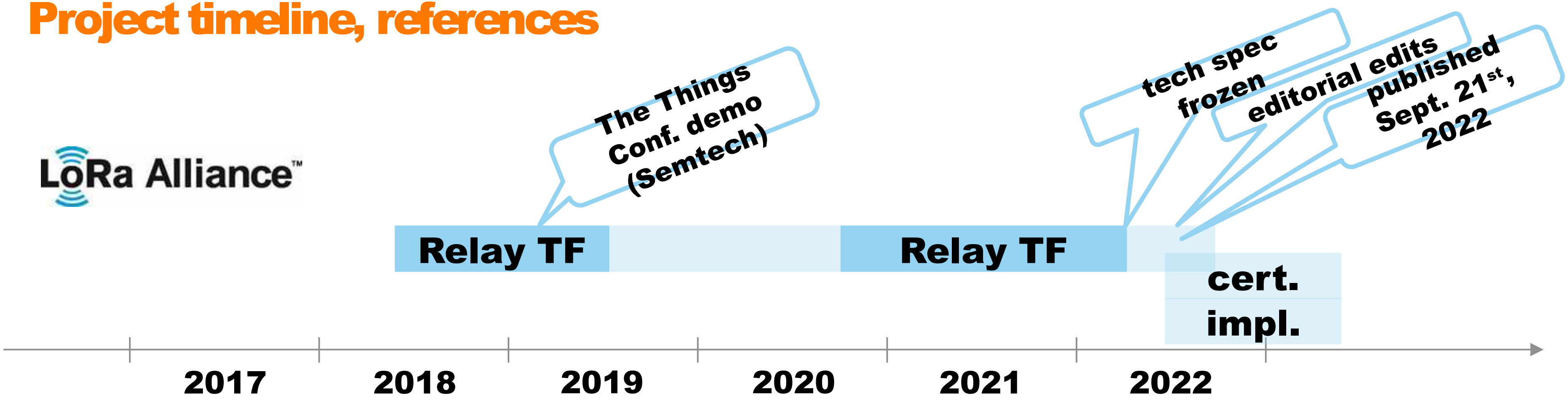
LoRaWAN® Relay
by the LoRa Alliance®

Dominique Barthel

orange™

Project timeline, references



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

Agenda

Uses cases, requirements (1 mn)

Specification (25 mn)

Q&A (x mn)

1. Use cases, Requirements

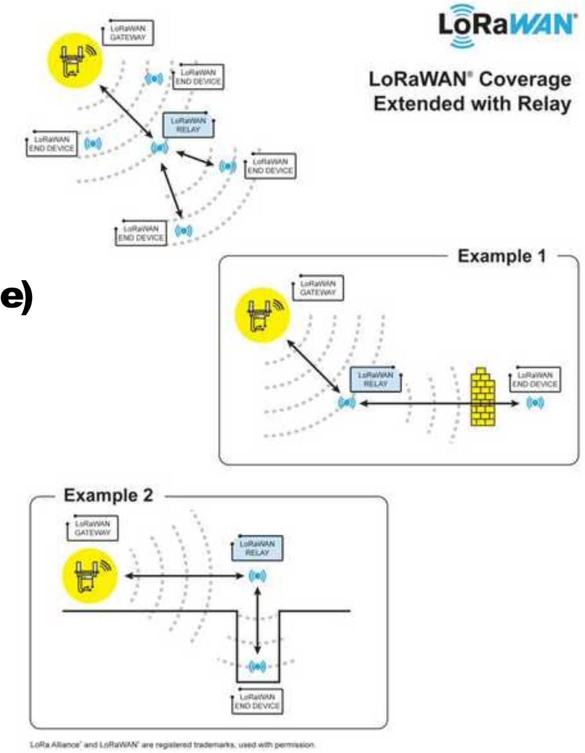
Battery-operable, low-cost relaying

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



LoRaWAN® Coverage Extended with Relay

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2. Specifications

2. Specifications

Overview

Protocol elements

Synchronization

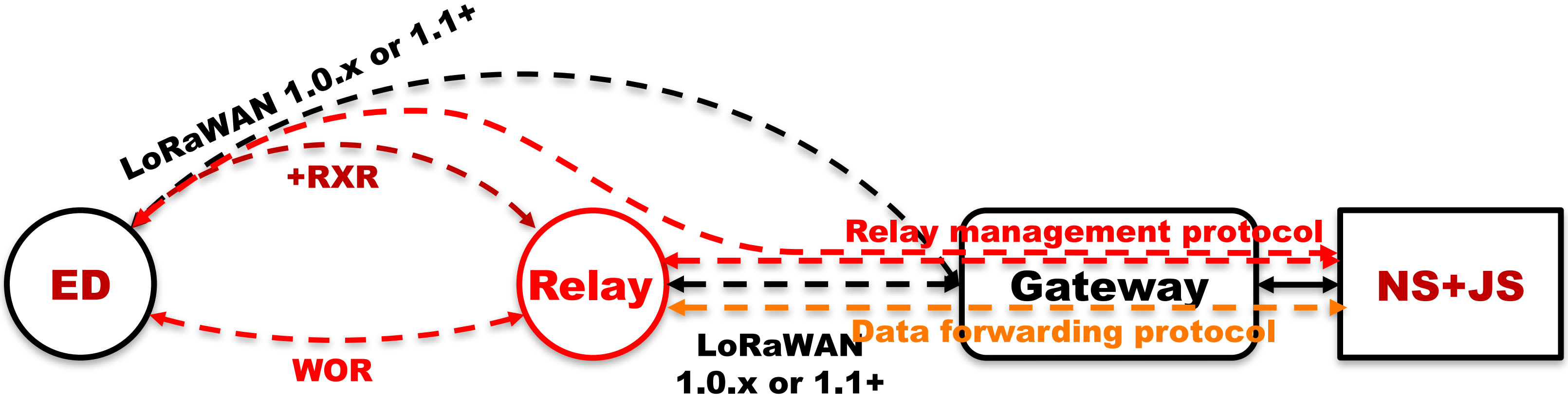
Forwarding

Security

Relayed network architecture

New/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

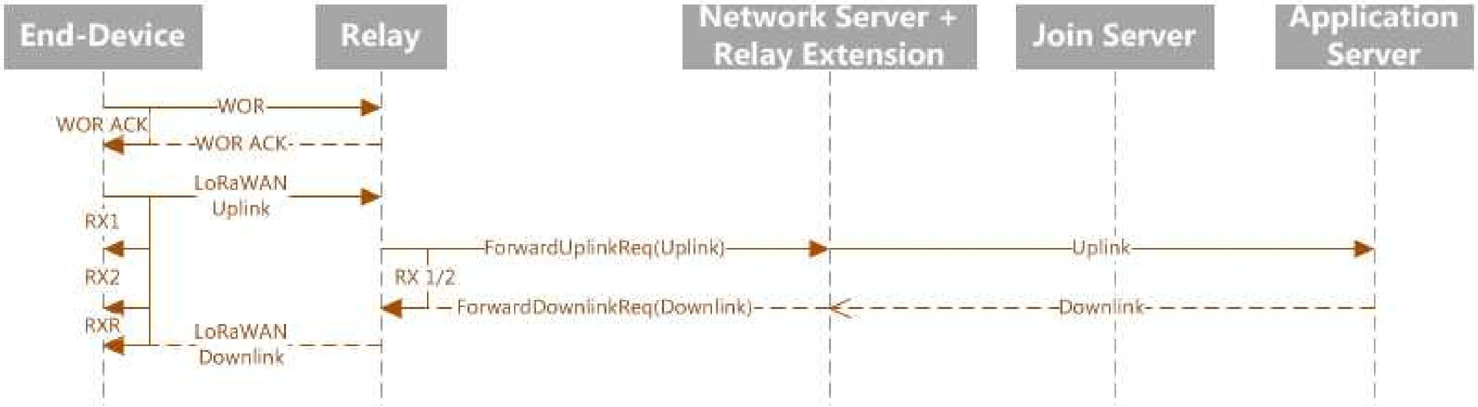
Data forwarding, in a nutshell

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

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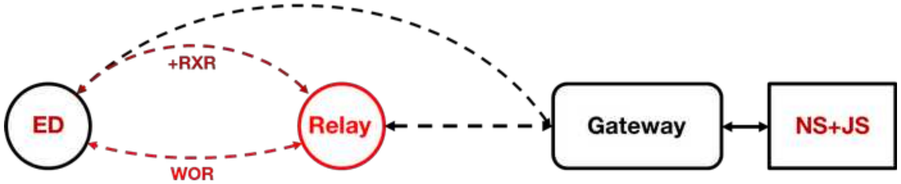
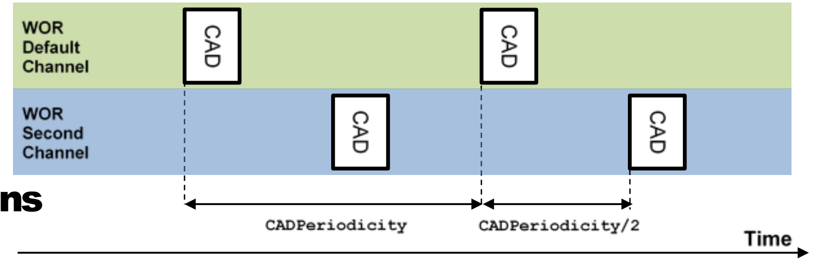
WOR link



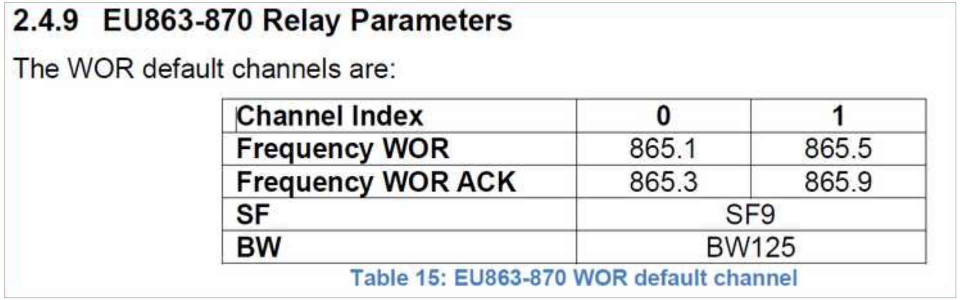
Designed for long preamble

- **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



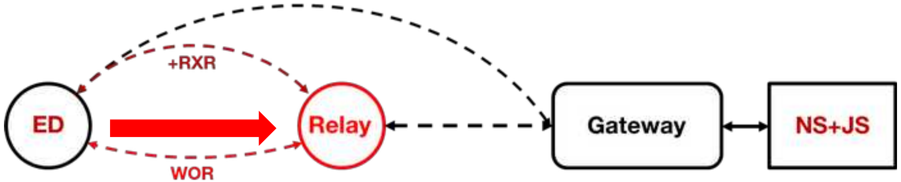
2.4.9 EU863-870 Relay Parameters

The WOR default channels are:

Channel Index	0	1
Frequency WOR	865.1	865.5
Frequency WOR ACK	865.3	865.9
SF	SF9	
BW	BW125	

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

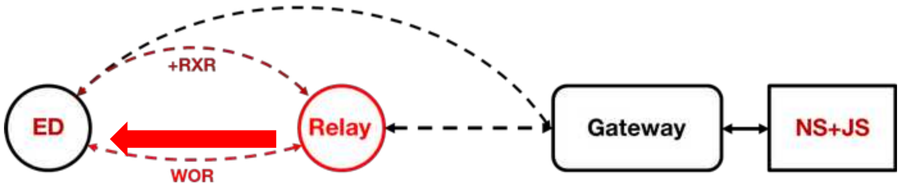
1 byte	1 byte	3 bytes
WOR Type = 0	DR[3:0]	Frequency[23:0]

WOR Class A Uplink

- secured
- authentication mixes in Phy parameters, DevAddr, WFCnt

1 byte	4 bytes	4 bytes	2 bytes	4 bytes
WOR Type = 1	DevAddr	Encrypted {DR| Frequency}	WOR Frame Counter (WFCnt)	MIC

WOR Relay ACK



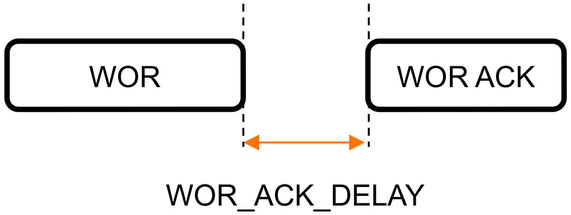
Acknowledges the WOR Relay Class A Uplink

- 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

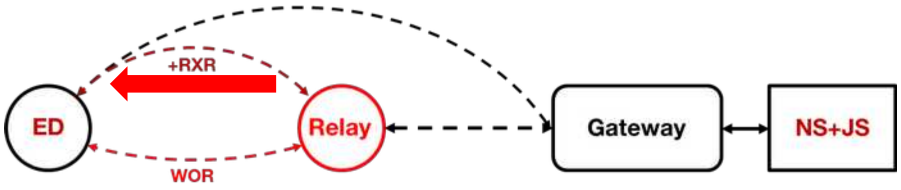
- forwarding data rate
- forwarding limit status
- timing information

3 bytes	4 bytes
Encrypted {Forwarding datarate, forwarding limit status, timing info}	MIC

Secured

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

RXR downlink

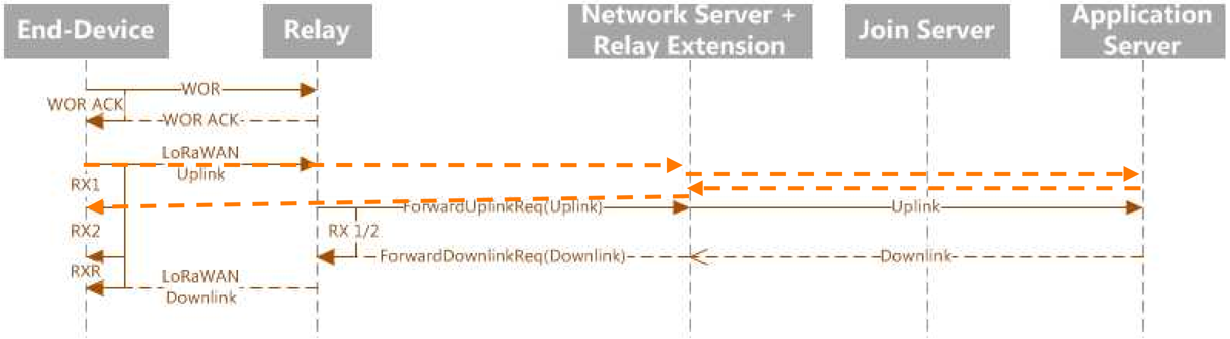


from Relay to End Device

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

timing

- 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



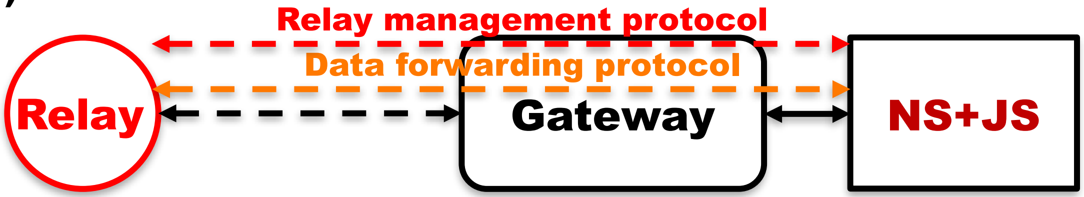
Relay - NS communication (relay protocol related)

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)



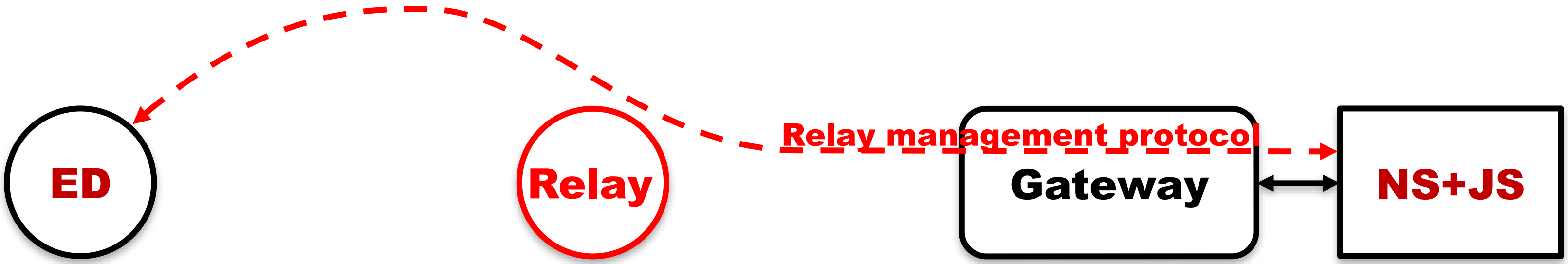
Data plane communication (encapsulated data frames)

- 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



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Synchronization

Forwarding

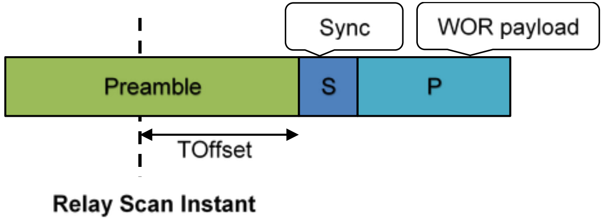
Security

ED synchronizes to Relay wake-ups

Inspired from WiseMAC [1]

- unencombered by IPR

Relay measures timing on WOR Class A Uplink



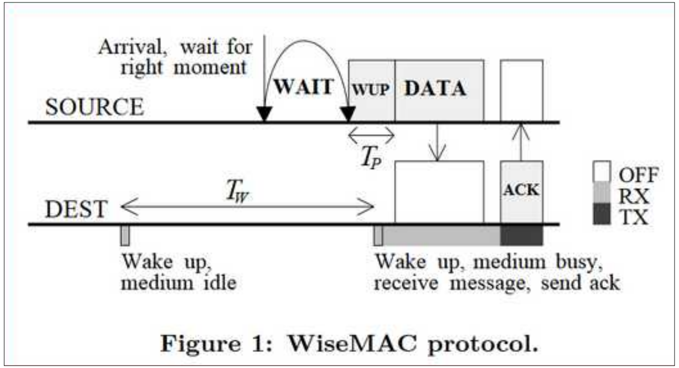

Arrival, wait for right moment
SOURCE
WAIT
WUP
DATA
T_P
DEST
T_W
ACK
OFF
RX
TX
Wake up, medium idle
Wake up, medium busy, receive message, send ack

Figure 1: WiseMAC protocol.

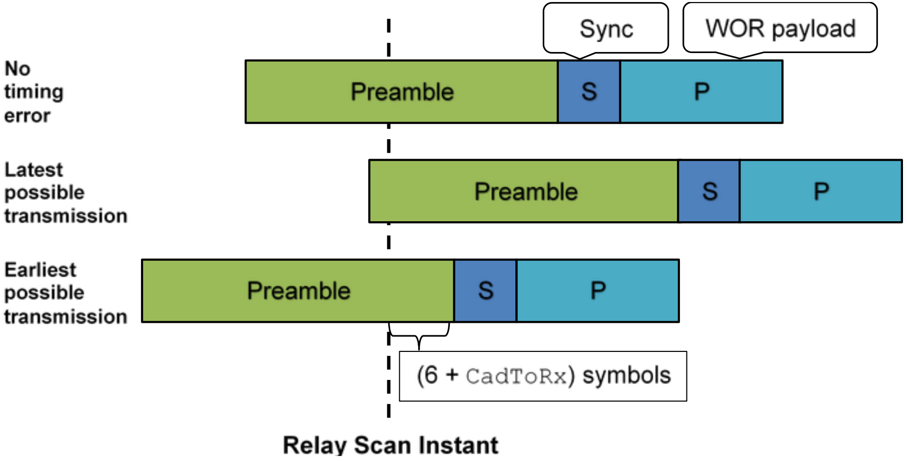
[1] A. El-Hoiydi, J.-D. Decotignie, C. Enz, and E. Le Roux. 2003. Poster abstract: wiseMAC, an ultra low power MAC protocol for the wiseNET wireless sensor network. In Proceedings of the 1st international conference on Embedded networked sensor systems (SenSys '03). Association for Computing Machinery, New York, NY, USA, 302–303. https://doi.org/10.1145/958491.958531

WOR ACK contains timing-related information

Bits	23:22	21:20	19:16	15:14	13:11	10:0
	CadToRx	Forward	Relay DataRate	XTAL Accuracy	CAD Periodicity	TOffset

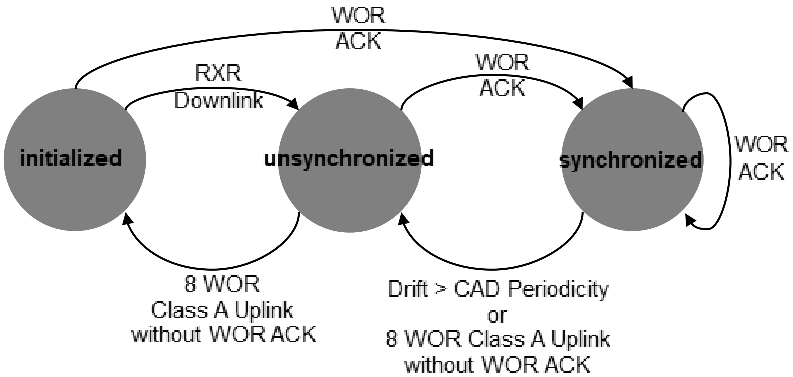
ED synchronizes to Relay wake-ups

ED computes preamble length based on timing info



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

- **assume synchronization is lost**


WOR ACK
RXR Downlink
WOR ACK
initialized
unsynchronized
synchronized
WOR ACK
8 WOR Class A Uplink without WOR ACK
Drift > CAD Periodicity or 8 WOR Class A Uplink without WOR ACK

ED synchronization states

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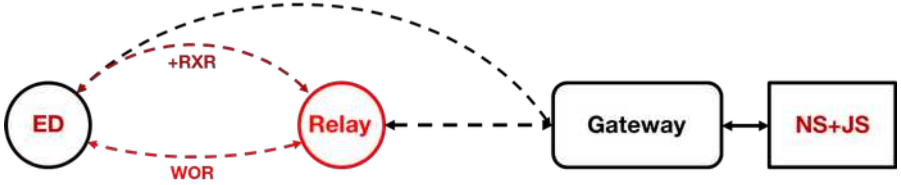
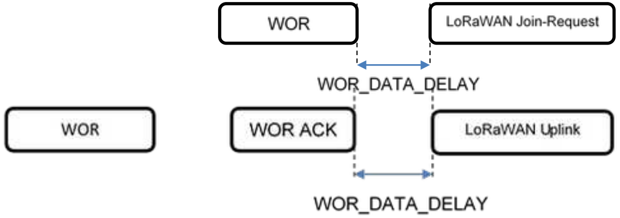
Forwarding uplink frames (Join Request, data uplink)



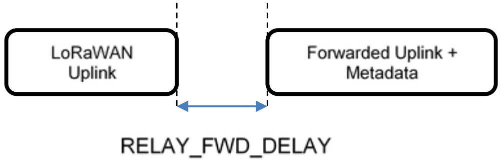
ED sends uplink

- **with fixed delay**
- **after sending WOR (Join Request) or receiving WOR ACK (data)**



Relay encapsulates uplink frame i.e., sends uplink

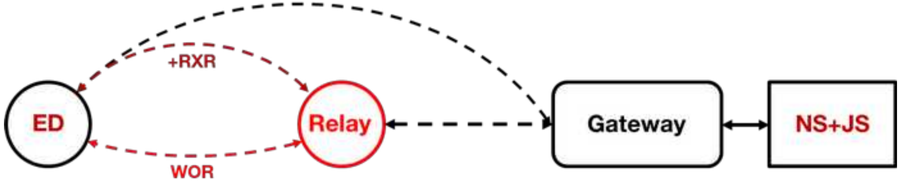
- **on its own LoRaWAN link, with FPort 226 (to NS Relay Server)**
- **the received** `PHYPayload` **and associated metadata (RSSI, SNR, freq., DR of the LoRaWAN uplink; WOR channel index),**
- **secured with *network* session keys,**
- **after fixed delay after ED's uplink (Join Request or data uplink)**



ED is responsible to make payload small enough so that it can be encapsulated

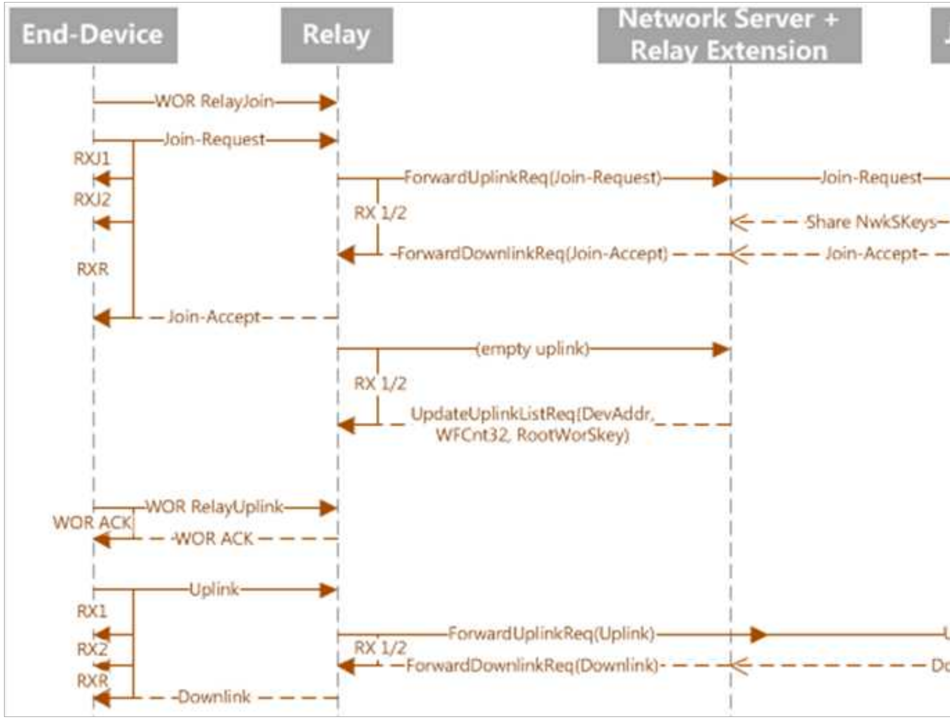
No cryptographic link between WOR frame and ensuing uplink frame

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**

Limiting Bucket / Default parameters	Reload Rate	Bucket Size
Join-Request	4	8
"New device" detected	4	8
Class A Uplink (per trusted end-device)	No default value	
Class A Uplink (for all trusted end-devices)	8	16
Global uplink	8	16

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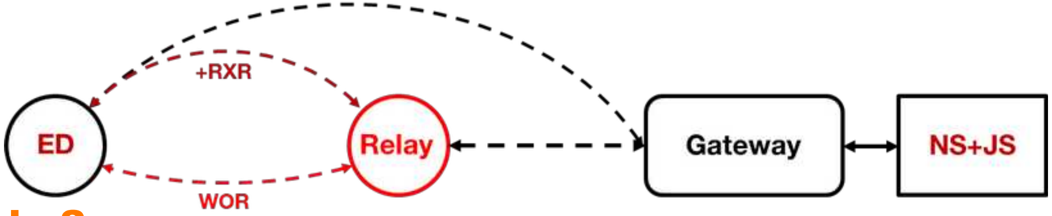
Link layer security



Communication between Relay and NS-RelayServer

- **secured by Relay's own session keys (**`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:** `WorSEncKey` **and** `WorSIntKey`
- **mutually authenticated, encrypted, replay protected (**`WFCnt`**)**

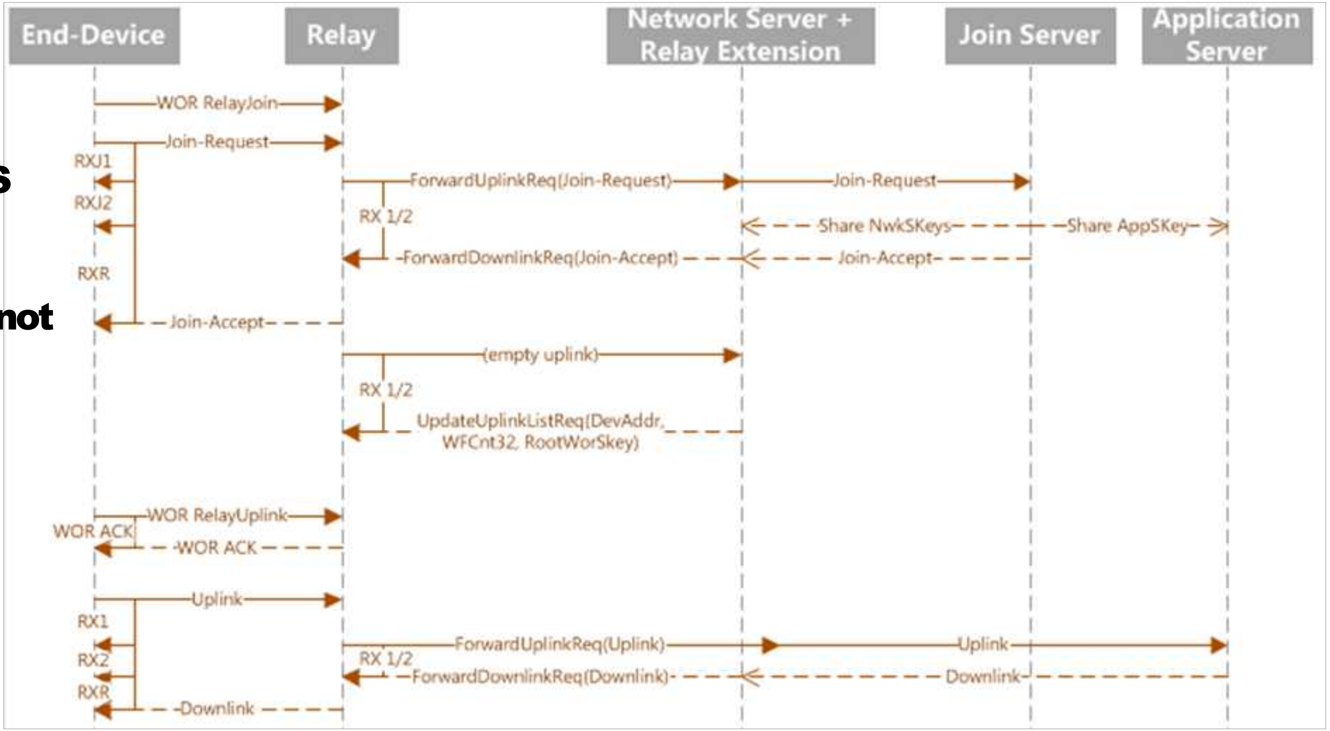
Relay not trusted with the End Device's session keys (`NwkSEncKey` **or** `F/SNwkSIntKey`**)**

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

RXR downlink is secured by NS

- **Relay forwards at RXR the exact** `PHYPayload` **received from NS (i.e.,** `MHDR`, `MACPayload`, **and** `MIC`**)**
- **be it a Join Accept or a data downlink**

WOR keys derivation, ED join



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
- TS011-1.0.0, Relay Specification (Sept 21st, 2022) https://resources.lora-alliance.org/technical-specifications/ts011-1-0-0-relay
- 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
  https://gateway.on24.com/wcc/eh/2820560/lp/3932248/lorawan-standard-expands-to-include-relay-specification

Certification

- on-going work

Implementations (as of Jan 2023)

- Tektelic blog https://www.tektelic.com/expertise/relay-mode-of-operation-extending-lorawan-coverage/
- Actility working on relay-enabled Network Server
- other companies working on it, without public statement yet

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Thanks

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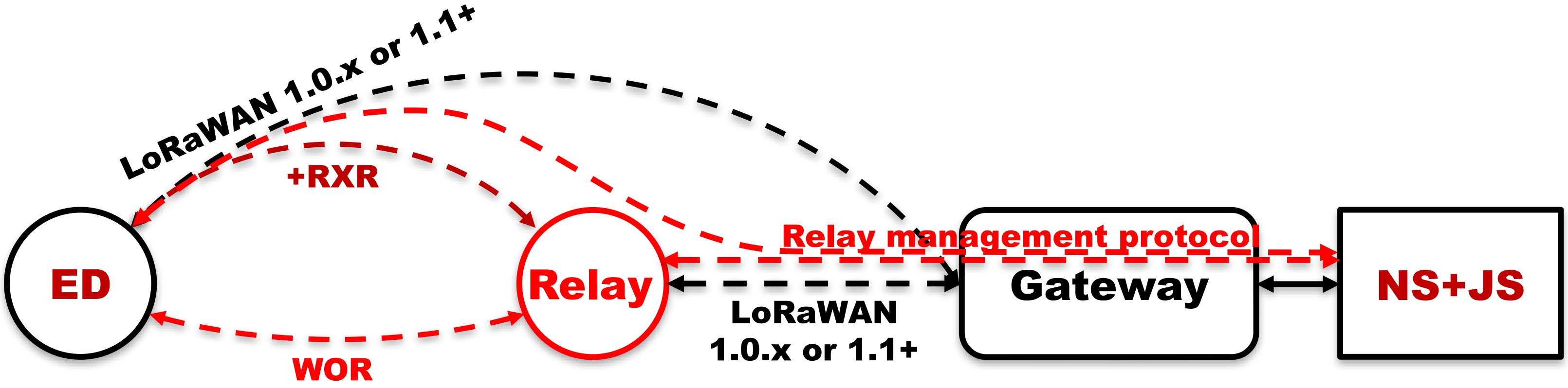
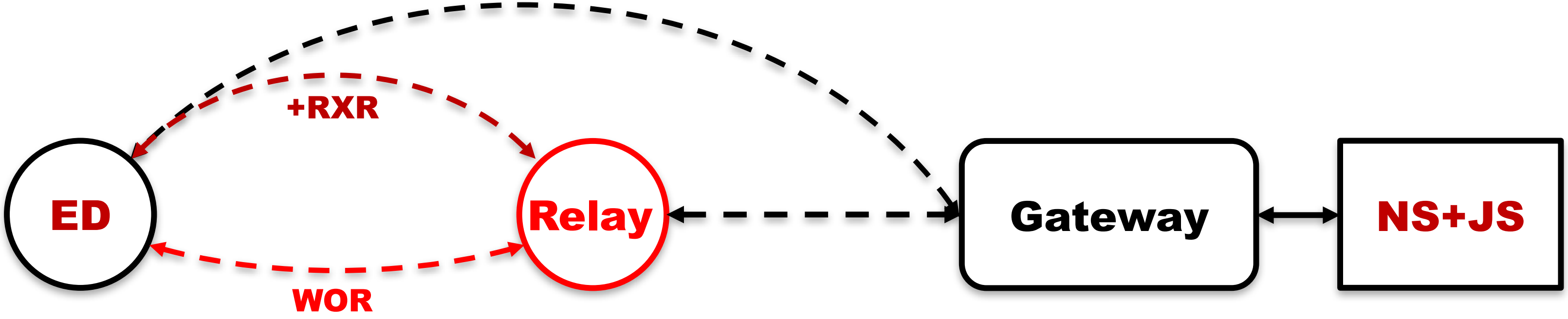
Management


LoRaWAN 1.0.x or 1.1+
+RXR
ED
Relay
Relay management protocol
Gateway
NS+JS
LoRaWAN
1.0.x or 1.1+
WOR


+RXR
ED
Relay
Gateway
NS+JS
WOR

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

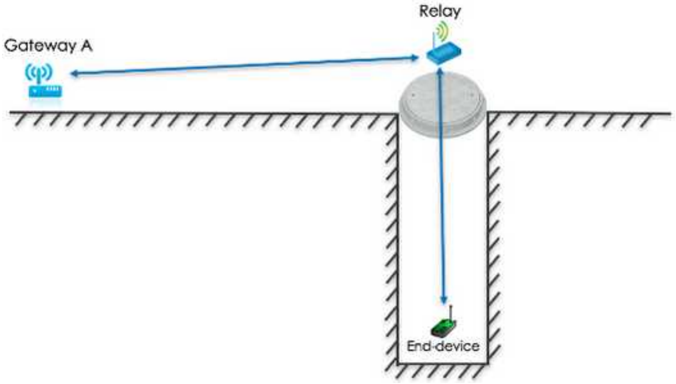
Regional Parameters

- 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

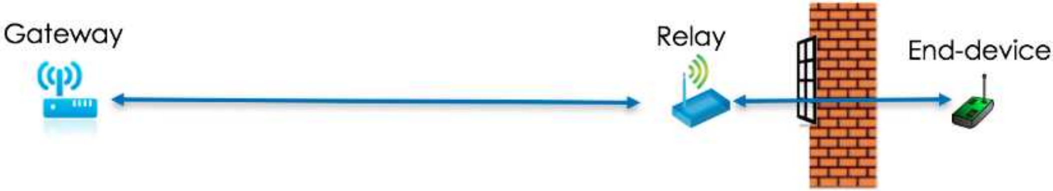


End-device in a hard-to-reach place, cannot communicate well enough with network

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.

Requirements

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

Downlink per uplink	10%
Downlink size	20 Bytes
Uplink size	50 Bytes
SF/BW for Relay-Gtw	SF9 BW125
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)

	SF/BW for ED-Relay	End Device	Uplinks per day per ED	Total forward uplink TOA [s]	Total forward downlink TOA [s]	Average current [µA]	Battery life [year]
Scenario 1	SF9 BW125	10	4	13,8	0,8	220	9,7
Scenario 2			24	82,8	4,8	262	8,2
Scenario 3		20	4	27,6	1,6	231	9,3
Scenario 4			24	165,6	9,6	313	6,9
Scenario 5			144	993,6	57,6	808	2,7
Scenario 6	SF7 BW125	10	4	13,8	0,2	124	17,3
Scenario 7			24	82,8	1,4	152	14,1
Scenario 8		20	4	27,6	0,5	131	16,4
Scenario 9			24	165,6	2,9	188	11,4
Scenario 10			144	993,6	17,3	529	4,1

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?

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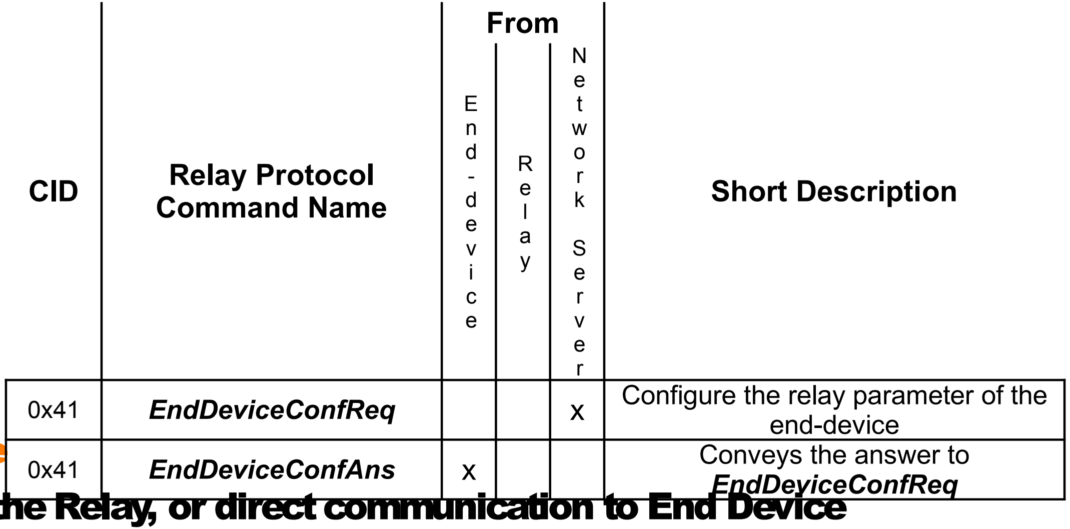
End-Device management



CID	Relay Protocol Command Name	From			Short Description
		End-device	Relay	Network Server	
0x41	*EndDeviceConfReq*			x	Configure the relay parameter of the end-device
0x41	*EndDeviceConfAns*	x			Conveys the answer to *EndDeviceConfReq*

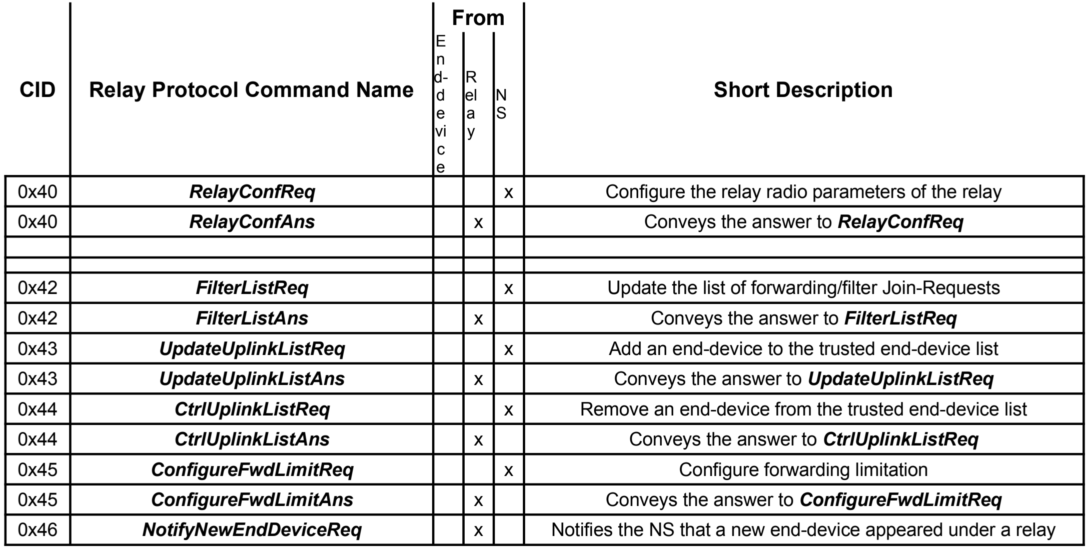
Just a MAC command to the End Device

- **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**

Relay management



CID	Relay Protocol Command Name	From			Short Description
		End-device	Relay	NS	
0x40	***RelayConfReq***			x	Configure the relay radio parameters of the relay
0x40	***RelayConfAns***		x		Conveys the answer to ***RelayConfReq***
0x42	***FilterListReq***			x	Update the list of forwarding/filter Join-Requests
0x42	***FilterListAns***		x		Conveys the answer to ***FilterListReq***
0x43	***UpdateUplinkListReq***			x	Add an end-device to the trusted end-device list
0x43	***UpdateUplinkListAns***		x		Conveys the answer to ***UpdateUplinkListReq***
0x44	***CtrlUplinkListReq***			x	Remove an end-device from the trusted end-device list
0x44	***CtrlUplinkListAns***		x		Conveys the answer to ***CtrlUplinkListReq***
0x45	***ConfigureFwdLimitReq***			x	Configure forwarding limitation
0x45	***ConfigureFwdLimitAns***		x		Conveys the answer to ***ConfigureFwdLimitReq***
0x46	***NotifyNewEndDeviceReq***		x		Notifies the NS that a new end-device appeared under a relay

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**