# Secure Update of IoT Devices over Low Data Rate Wireless Networks

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# What we'll cover ...

Why do we need updates for IoT devices?

Requirements for *secure* updates.

Implementations currently available to RIOT users.

Challenges to face for devices connected using low data rate networks.

Solutions to those challenges.

# Why do we need updates for IoT devices?

- Fixing vulnerabilities and bugs
- Adding and improving features of IoT applications
- Adjust on-device configurations and AI models

# Requirements for *Secure* Updates

**Atomic Transactions:** Immune to power and network loss mid-update

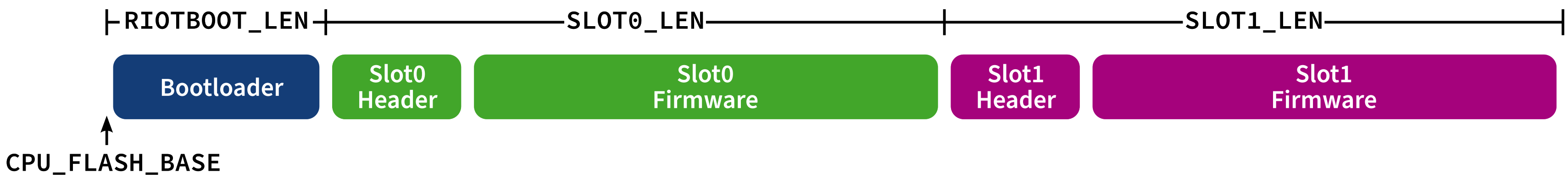
**Ensure Integrity:** Immune to corruption due to manipulation or transmission errors

**Ensure Purpose:** Update is intended for the device

**Prevent Replay:** Immune to downgrades to older versions

# Implementations Currently Available to RIOT Users

# RIOTBOOT[1]: The Small and Powerful Bootloader

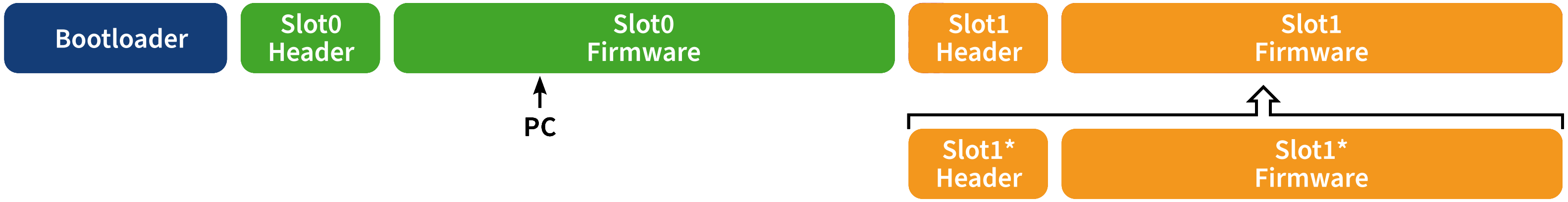



```c
typedef struct {
  uint32_t magic_number; /* Always "RIOT" -> 0x544f4952 */
  uint32_t version;      /* Slot's version number */
  uint32_t start_addr;   /* E.g. Slot0: CPU_FLASH_BASE + RIOTBOOT_LEN + RIOTBOOT_HDR_LEN */
  uint32_t chksum;       /* Checksum from magic_number to start_addr */
} riotboot_hdr_t;
```

## Bootloader algorithm:

```c
uint32_t highest_seen_version = 0;
int slot_to_boot = -1;
for (unsigned i = 0; i < riotboot_slot_numof; i++) {
  const riotboot_hdr_t *header = riotboot_slot_get_hdr(i);
  /* Check magic */
  if (header->magic_number != 0x544f4952) continue;
  /* Check checksum */
  if (riotboot_hdr_checksum(header) != header->chksum) continue;
  /* Highest seen version? */
  if (slot_to_boot == -1 || header->version > highest_seen_version) {
    highest_seen_version = header->version;
    slot_to_boot = i;
  }
}
riotboot_slot_jump(slot_to_boot);
```

# RIOTBOOT[1]: The Small and Powerful Bootloader




```c
int install_update(int target_slot, const uint8_t *new_data, size_t new_data_len,
                   const uint8_t new_data_hash[SHA256_DIGEST_LENGTH]) {
  riotboot_flashwrite_t state;

  /* Prepare context and erase first page -> RIOTBOOT magic gets destroyed */
  riotboot_flashwrite_init(&state, target_slot);
  /* Write image to slot omitting the magic (i.e. first 4 bytes) */
  riotboot_flashwrite_putbytes(&state, new_data + 4, new_data_len - 4, false);
  /* Check written image against provided hash. It will take care of the omitted magic. */
  if (riotboot_flashwrite_verify_sha256(new_data_hash, new_data_len, target_slot) != 0) {
    /* Image is not valid! */
    return RC_INVALID_HASH;
  }
  /* Enable slot by writing the magic */
  riotboot_flashwrite_finish(&state);
  /* Start the written image by rebooting */
  pm_reboot();

  return RC_SUCCESS;
}
```

# RIOTBOOT[1]: The Small and Powerful Bootloader

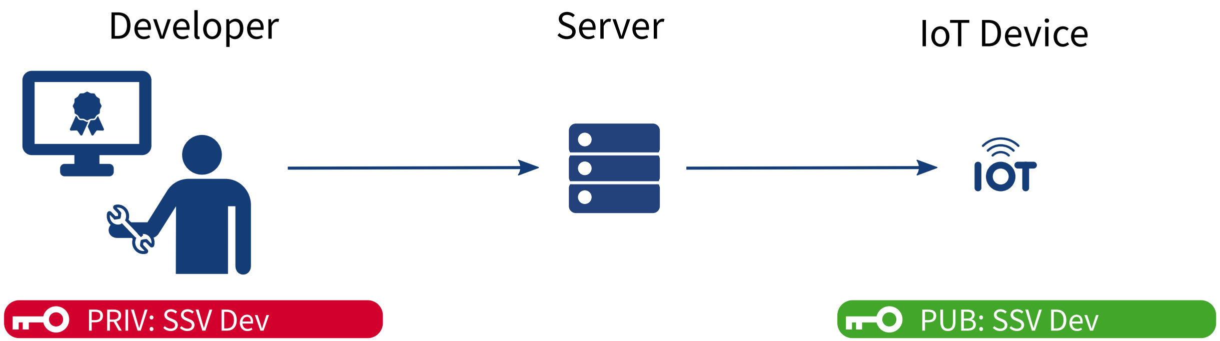
**Atomic Transactions:** Writing the magic is the last step and enables the slot.

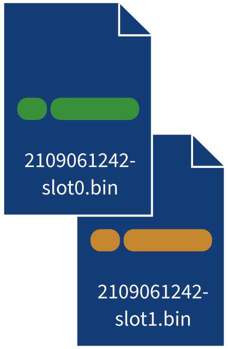
**Ensure Integrity:** Checking against a cryptographic hash.
*But:* The hash must be transferred securely!

**Ensure Purpose:** Magic ensures the image to be a RIOTBOOT image.
*But:* The image may be compiled for another device!

**Prevent Replay:** The bootloader always starts the image with the highest version.

# SUIT[2,3]: Software Updates for Internet of Things




**Manifest**

**Version:** 2109061243
**Components:**
- **VENDOR=**SSV, **CLASS=**MySensor, **SLOT=**0 ?
  => **URL=**coap://server/2109061243-slot0.bin **HASH=**5feceb66ffc...
- **VENDOR=**SSV, **CLASS=**MySensor, **SLOT=**1 ?
  => **URL=**coap://server/2109061243-slot1.bin **HASH=**6b86b273ff...

Signed by **PRIV: SSV Dev**

# SUIT[2,3]: Software Updates for Internet of Things

**Atomic Transactions:** Writing the magic is the last step and enables the slot.

**Ensure Integrity:** Asymmetric keys and digital signature protect information from the developer to the IoT device.

**Ensure Purpose:** The Manifest defines the image's purpose precisely.

**Prevent Replay:** SUIT checks the Manifest's version field.

# Optimizations for Low Data Rate Wireless Networks with High Density of IoT Devices

# Why do we *need* optimizations?

SUIT uses unicast CoAP. Every device downloads updates individually.

**RF Network:** IEEE802.15.4 - 868.3MHz

Data rate[4] $DR = 200\frac{\text{kBit}}{\text{s}}$

Duty cycle[5] $DC = 1\%$

$DR_{eff} = DR \cdot DC = 2\frac{\text{kBit}}{\text{s}}$

Protocol overhead $OH = 25\%$

**Update:**

File size $L = 128\text{kByte} = 1\text{MBit}$

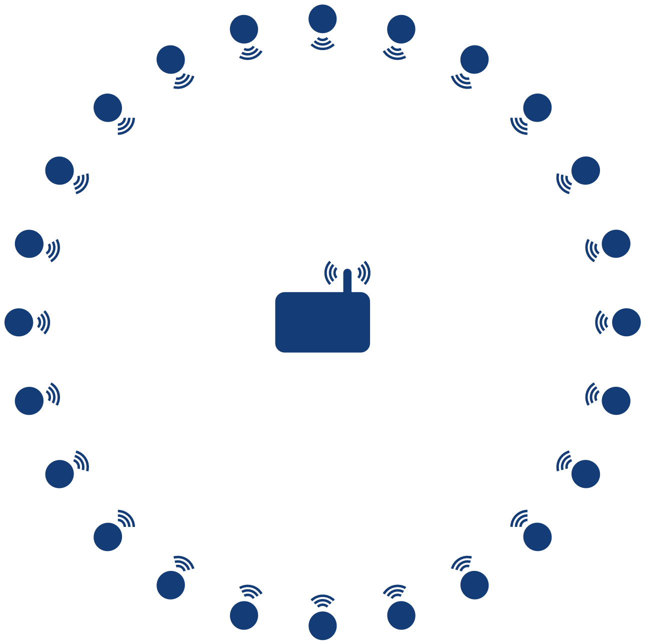
$L_{eff} = L \cdot (1 + OH) = 1.25\text{MBit}$

**Transmission of 1 update:**

$$t_1 = \frac{L_{eff}}{DR_{eff}} = 625\text{s} = 10.4\text{min}$$

**Transmission of 24 updates:**

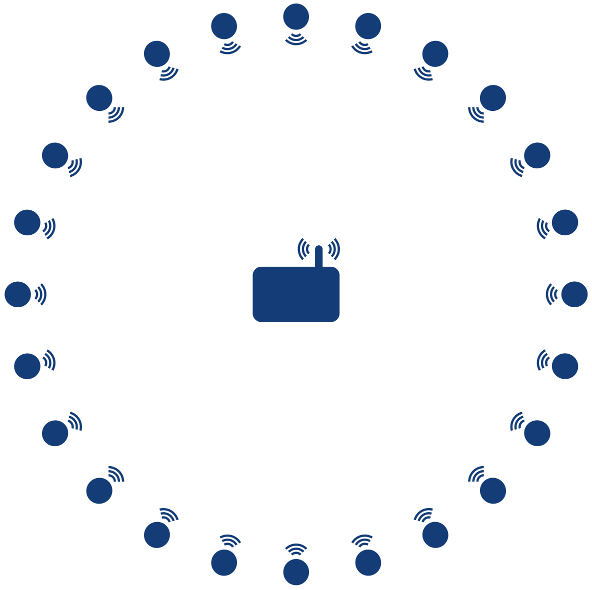
$$t_{24} = 24 \cdot t_1 = 4.17\text{h}$$



# How to optimize?

1. Sync all devices to be awake at the same time.
2. Transfer the update once using multicast.
3. If a device missed a chunk:
   Request it using unicast.

**Update time can be reduced drastically!**



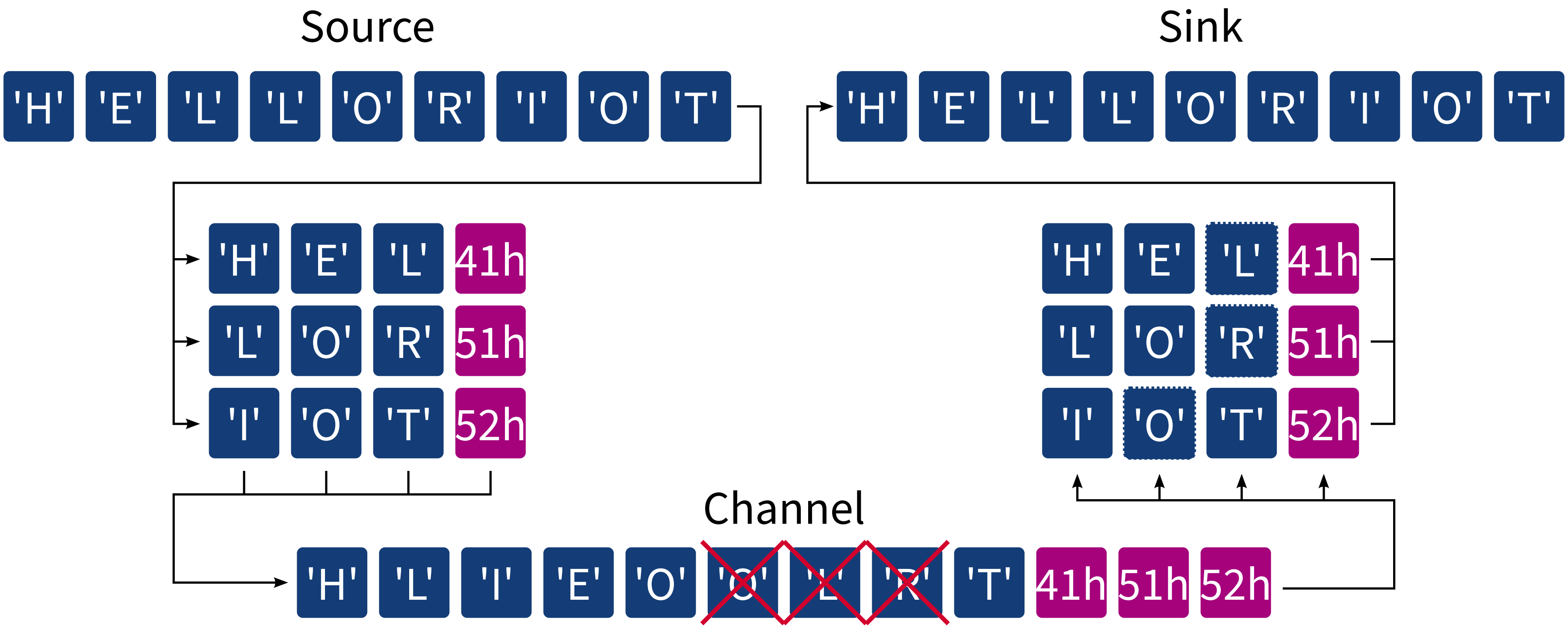
# Introduce redundancy to reduce retransmissions

'H' ⊗ ~~'E'~~ ⊗ 'Y' = 54h

'H' ⊗ 54h ⊗ 'Y' = 'E'

**If only 1 of the 4 blocks is missing, it can be reconstructed!**

# Introduce redundancy to reduce retransmissions




**Interleaving converts burst errors to random errors and improves XOR erasure coding.**

# Current state of multicast updates in RIOT

Already in production but without SUIT integration.

Example code will be released during the next days:
https://github.com/ssv-embedded/RIOTSummit2021

# Optimizations for *Very Low* Data Rate Wireless Networks like LoRaWAN

# Why do we *need* optimizations?

**RF Network:**

LoRa: EU863 · SF8 · 250kHz Bandwidth

The Things Network · Fair Use Policy[6]: $10\,\frac{\text{msg}}{\text{day}}$

Max payload size (excl. overhead): ~$200\,\frac{\text{Byte}}{\text{msg}}$

$$DR_{eff} = 10\,\frac{\text{msg}}{\text{day}} \cdot 200\,\frac{\text{Byte}}{\text{msg}} = 2000\,\frac{\text{Byte}}{\text{day}}$$

**Update:**

Filesize $L = 128\text{kByte}$

**Transmission of 1 update:**

$$t_1 = \frac{L}{DR_{eff}} = 64\text{days}$$

# Remove redundancy!

Small modification to the `gnrc_lorawan` example:

```
diff --git a/examples/gnrc_lorawan/main.c b/examples/gnrc_lorawan/main.c
index 0308de4bda..9d5bf3af46 100644
--- a/examples/gnrc_lorawan/main.c
+++ b/examples/gnrc_lorawan/main.c
@@ -38,7 +38,7 @@
int main(void)
{
  /* start the shell */
- puts("Initialization successful - starting the shell now");
+ puts("Initialization successful - connecting to the net!");
```

# Remove redundancy!

Leads to a binary with the same size and small modifications inside the binary:

| File | Size |
|---|---|
| gnrc_lorawan_a.bin | 55344B |
| gnrc_lorawan_b.bin | 55344B |

```
--- gnrc_lorawan_a.asm
+++ gnrc_lorawan_b.asm
@@ -21404,12 +21404,12 @@
    ada8: 75 63 63 65 .word 0x65636375
    adac: 73 73 66 75 .word 0x75667373
    adb0: 6c 20 2d 20 .word 0x202d206c
-   adb4: 73 74 61 72 .word 0x72617473
-   adb8: 74 69 6e 67 .word 0x676e6974
-   adbc: 20 74 68 65 .word 0x65687420
-   adc0: 20 73 68 65 .word 0x65687320
-   adc4: 6c 6c 20 6e .word 0x6e206c6c
-   adc8: 6f 77    .short  0x776f
+   adb4: 63 6f 6e 6e .word 0x6e6e6f63
+   adb8: 65 63 74 69 .word 0x69746365
+   adbc: 6e 67 20 74 .word 0x7420676e
+   adc0: 6f 20 74 68 .word 0x6874206f
+   adc4: 65 20 6e 65 .word 0x656e2065
+   adc8: 74 21    .short  0x2174
    adca: 00      .byte 0x00
```

# The VCDIFF standard[7] creates binary diffs

```
$ vcdiff encode -interleaved -dictionary gnrc_lorawan_a.bin -target gnrc_lorawan_b.bin >a-b.vcdiff
$ ls -l
total 140
-rw-r--r-- 1 jue jue    53  8. Sep 15:14 a-b.vcdiff
-rw-r--r-- 1 jue jue 55344  8. Sep 15:13 gnrc_lorawan_a.bin
-rw-r--r-- 1 jue jue 55344  8. Sep 15:13 gnrc_lorawan_b.bin
$ vcdiff-decode -i gnrc_lorawan_a.bin <a-b.vcdiff >gnrc_lorawan_b-reconstructed.bin
WIN VCD_SOURCE [0x0+55344] => [0x0+55344]
  COPY from SEGMENT [0x0+44468] => [0x0+44468]
  ADD => [0xadb4+22]
  COPY from SEGMENT [0xadca+10854] => [0xadca+10854]
$ md5sum gnrc_lorawan_b*
7ae6a0dcacbc616ed19ad74430333eef  gnrc_lorawan_b-reconstructed.bin
7ae6a0dcacbc616ed19ad74430333eef  gnrc_lorawan_b.bin
```

Encoding: google/open-vcdiff
Decoding: jue89/tiny-vcdiff

# The VCDIFF standard[7] creates binary diffs

More use cases:

| Use Case | Old Bin Size | New Bin Size | Diff Size | Compression | Download Time |
|---|---|---|---|---|---|
| Changing constant value | 55344B | 55344B | 53B | 99.9% | < 1hour |
| Changing small code section | 55344B | 55316B | 2810B | 94.9% | 1.4 days |
| Update from 2021.04 to 2021.07 | 56056B | 55344B | 17374B | 68.6% | 8.7 days |

Still not fast, but OTA updates become achievable!

# Current state of binary diff-based updates

SSV is utilizing VCDIFF in non-RIOT environments:
Updates of Linux filesystem images at compression ratios better than 99.5%.

The decoder implementation is compatible with the RIOT/pkg. A PR bringing the decoder to the RIOT is already prepared. Stay tuned!

A novel approach with a lot to be discovered!

# Your Takeaways

RIOTBOOT is a great foundation for implementing OTA updates.

SUIT might be a good fit if network bandwidth is plentiful.

Multicast updates reduce OTA update duration in high-density environments.

VCDIFF can be the door-opener for OTA updates over LoRaWAN.

# References


1. RIOTBOOT Documentation
2. SUIT: IETF Working Group Documents
3. SUIT: RIOT Impementation
4. IEEE 802.15.4-2020 Standard
5. ETSI EN 300 220-2 V3.2.1 (2018-06): Short Range Devices (SRD) operating in the frequency range 25 MHz to 1 000 MHz; Part 2: Harmonised Standard for access to radio spectrum for non specific radio equipment
6. The Things Network: Duty Cycle
7. VCDIFF: RFC3294