Parameter Optimization for BLE Mesh Sensor Networks Using an MQTT Gateway

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Dr. Ulf Witkowski heads the Electronics and Circuit Technology research group at the South Westphalia University of Applied Sciences in Soest, Germany. He has been an active researcher for about 20 years in the area of wireless networking, sensor networks, cognitive systems, and mini- robotics. He has established his research group at the South Westphalia University as a professor in 2009. His research areas include wireless communication involving mobile ad-hoc networking, radio-based node localization, sensor networks, and embedded systems. He received the diploma degree in electrical engineering in 1995 from the Technical University of Hamburg-Harburg, Germany and in 2003 the Dr.-Ing. degree from the University of Paderborn. U. Witkowski has published more than 80 scientific articles.

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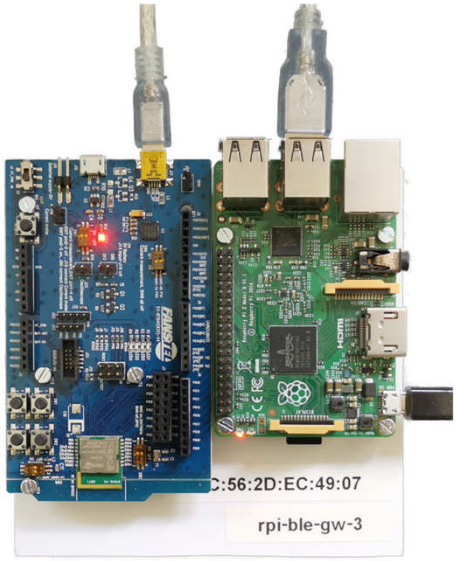
Agenda

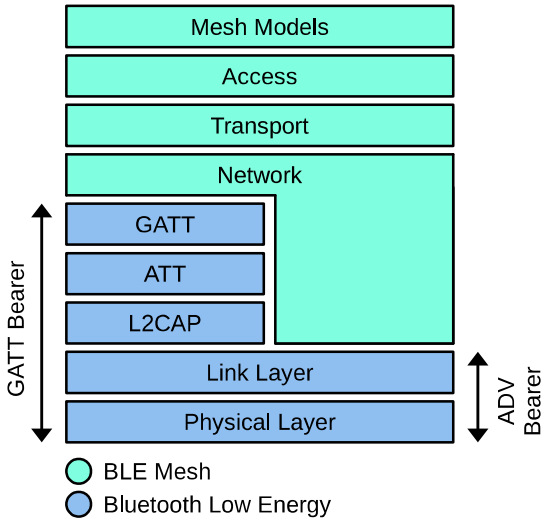
- Bluetooth Low Energy Mesh
- MQTT Gateway Architecture
- Reference Set-up
- Experiments
- Conclusions



Bluetooth Low Energy Mesh

Based on Bluetooth Low Energy (BLE) 4.0

- Mesh structure instead of point to point communication

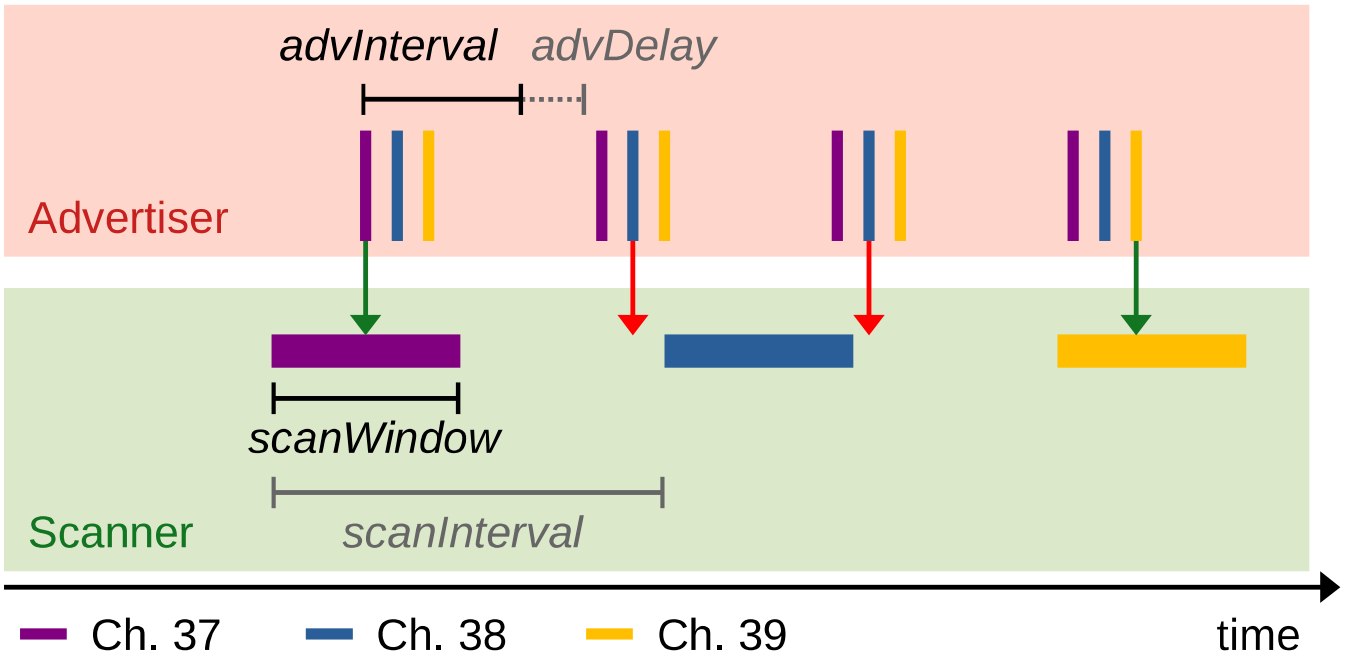


Multiple communication types (bearer)

- Advertisement packets (default)
- GATT profile for compatibility (e.g., communication with a smartphone)

Bluetooth Low Energy Mesh

Communication flow using ADV bearer



- Advertiser (sender) transmits the data multiple times on each of channels 37, 38 and 39
- Scanner (receiver) listens alternately on those channels for incoming data

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Bluetooth Low Energy Mesh

BLE Mesh is using flooding approach

- **Publish Transmission Count (PTC)** and **Publish Transmission Interval (PTI)** how many new messages are queued on (sensor) state change
- **Network Transmission Count (NTC) and Network Transmission Interval (NTI)** define retransmissions of each message
- **Relay Retransmission Count (RRC) and Relay Retransmission Interval (RRI)** specify the retransmission behaviour of a relay node

	PTC	PTI	NTC	NTI	RRC	RRI
Min.	1	50 ms	1	10 ms	1	10 ms
Max.	8	1600 ms	8	320 ms	8	320 ms

Maximum number of total transmissions on state change: $PTC_{max} \bullet NTC_{max} = 64$

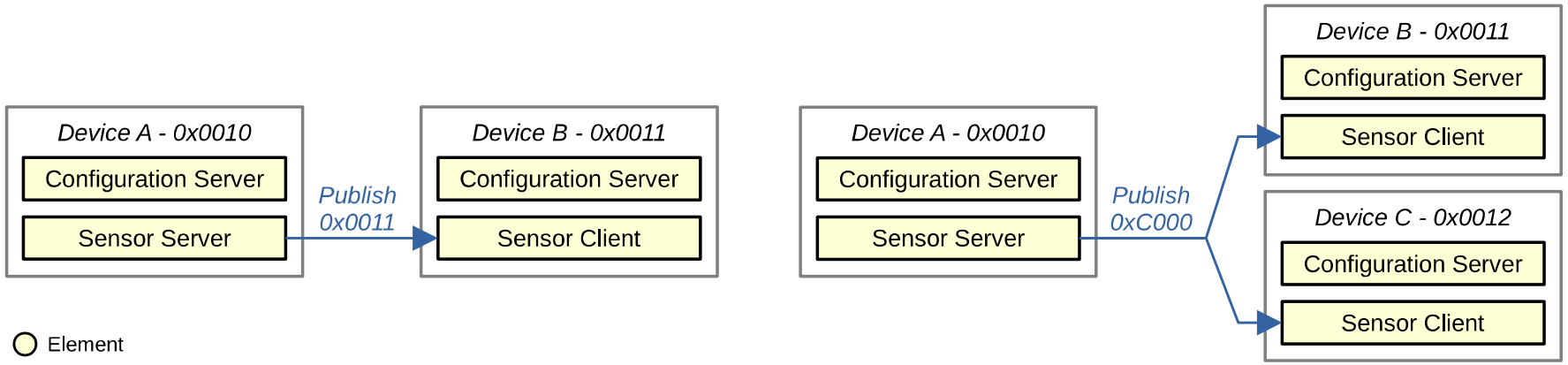
Bluetooth Low Energy Mesh

Addressing

- Each device has a unicast address (0x0001-0x7FFF)
- Virtual addresses for vendor specific purposes (0x8000-0xBFFF)
- Group addresses for multicast (0xC000-0xFFFC)

Unicast transmission

Multicast transmission

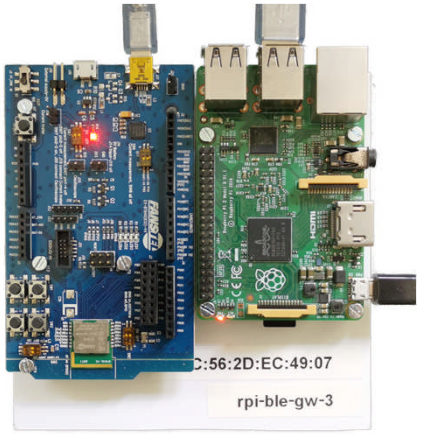


- Published messages with unicast address will be parsed automatically by receiver
- Device needs to subscribe to a group address to receive corresponding messages

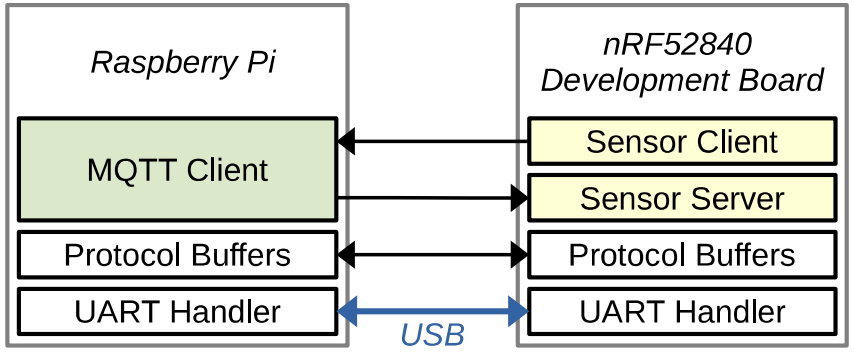
BLE Mesh to MQTT Gateway Architecture

MQTT

- Widely used protocol in Internet of Things (IoT)
- Based on TCP/IP protocol stack
- Publish/subscribe pattern



Gateway is composed of 2 parts



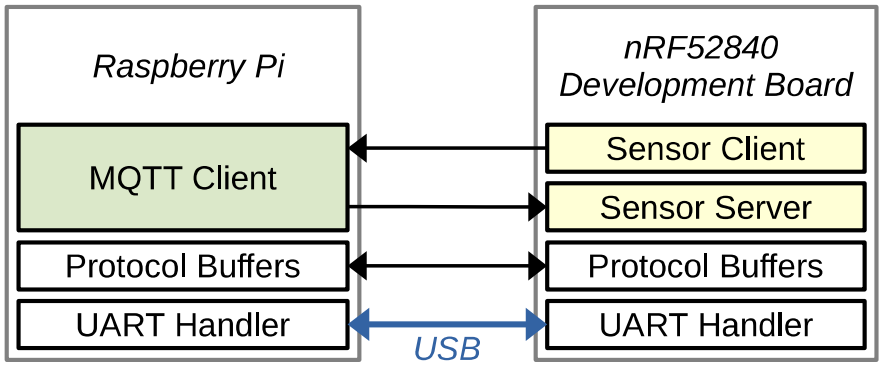
nRF52840 development board

- BLE Mesh endpoint
- Integrates a BLE Mesh interface
- C program based on nRF Connect SDK

Raspberry Pi (RPi) miniature computer

- MQTT endpoint
- Integrates a TCP/IP interface
- Python program with MQTT client

BLE Mesh to MQTT Gateway Architecture



MQTT Payload Example

```
{
  "seq": 236,
  "timestamp": 29470814,
  "addr": 31,
  "recvRssi": -86,
  "recvTtl": 6,
  "ambientHumidity": {
    "ambientHumidity": 33.91
  }
}
```

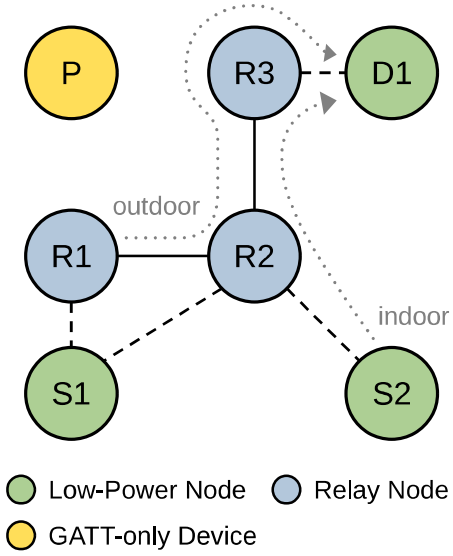
- Incoming BLE Mesh messages are transferred from nRF52840 to RPi
- Incoming MQTT messages are sent from RPi to nRF52840
- Communication between RPi and nRF52840 using USB-UART interface
- Efficient payload coding using Google Protocol Buffers (protobuf)

Implemented BLE Mesh sensor types:

- Present ambient humidity
- Precise present ambient temperature
- Present input voltage

Reference Set-up

The proposed GW architecture is used to track messages inside the mesh network



Relay nodes

- R1, R2, R3 are acting as MQTT GWs
- All incoming messages are redirected via MQTT
- Buffering of messages for sleeping nodes

Low Power Nodes (LPN)

- Sleep between active intervals
- Two sensor nodes S1, S2 are collecting temperature and humidity measurements
- Display node (D1) shows indoor data (S1) and externally injected outdoor data from OpenWeather via R1

Provisioning

- A smartphone (P) is used to configure the mesh network

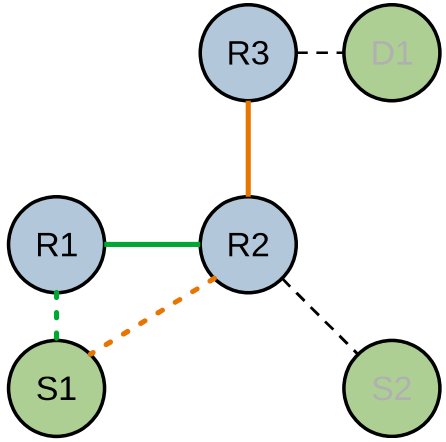
Experiments

Do higher retransmission counts reduce packet loss?

- Large number of retransmissions lead to high medium utilization

Transmission of packets from sensor node S1

- Sensor node S1 has good connection to R1 and poor connection to R2
- Relay node R1 has good connection to R1
- Poor connection between R2 and R3



Retransmission settings

	Experiment 1	Experiment 2	Experiment 3
PTC	1	1	-
PTI [ms]	250	500	-
NTC	3	6	2
NTI [ms]	50	50	50
RRC *	3	6	2
RRI * [ms]	60	60	60

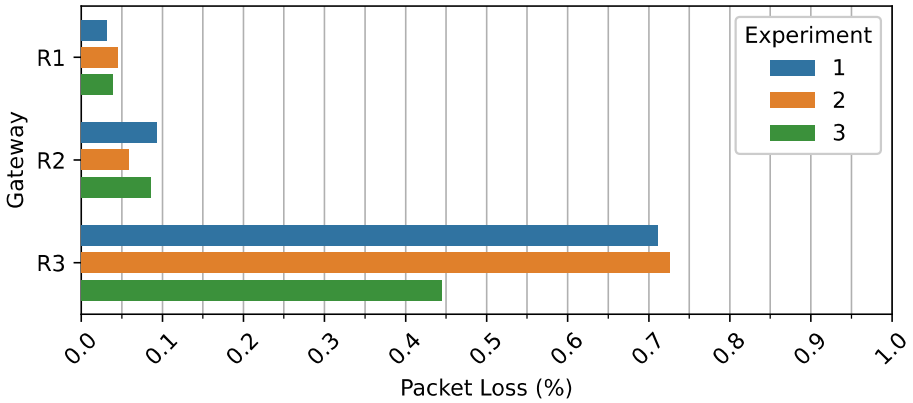
* only for relay nodes

Experiments

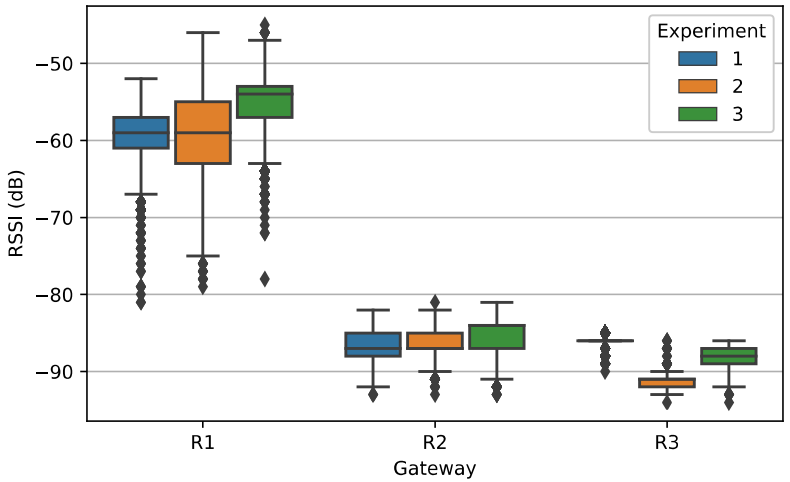
Results for packets sent by sensor node S1

- Experiment time: 7 days (1008 messages per experiment)

Packet loss



RSSI distribution



Experiment 1: Medium number of repetitions

Experiment 2: High number of repetitions

Experiment 3: Low number of repetitions

- Reliable transmission even close to sensitivity limit (-95 dB for nRF52840)
- Increased number of repetition does not improve packet loss if close to sensitivity limit

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Conclusions

- The proposed gateway provides connectivity between BLE Mesh and MQTT
- Easy provisioning of the mesh network using a smartphone
- Integration of existing BLE Mesh networks into the Internet
- Meta data can be used to perform experiments
- BLE Mesh works very reliable even close at the end of link margin
- Packet loss increases significantly shortly before sensitivity limit of the receiver
- Interferer cause a temporary drop in RSSI
- Presence of interferer results in a high packet loss when operating near sensitivity limit
- High repetition rates do not significantly improve packet loss in such cases

Future work

- Retransmission of lost packets between two relay nodes over MQTT