Karlsruher Institut für Technologie

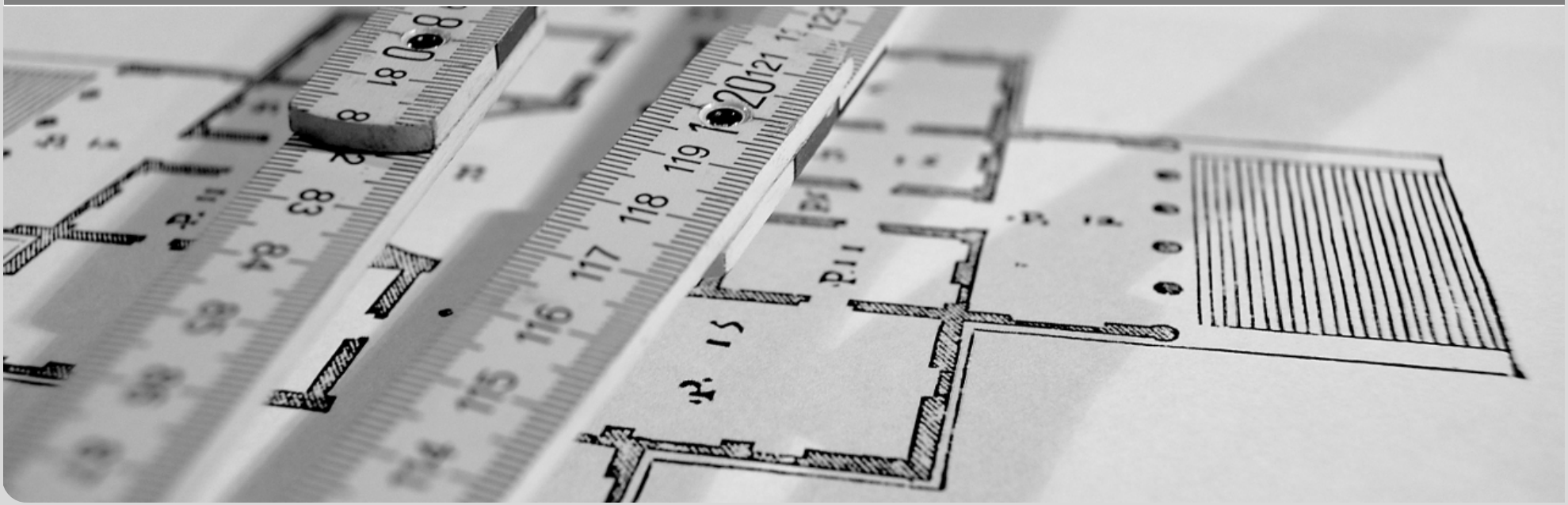
ZÜBLIN

Zuverlässige funkbasierte Bereichsortung im Tunnelbau

Masterarbeit von Marius Wodtke

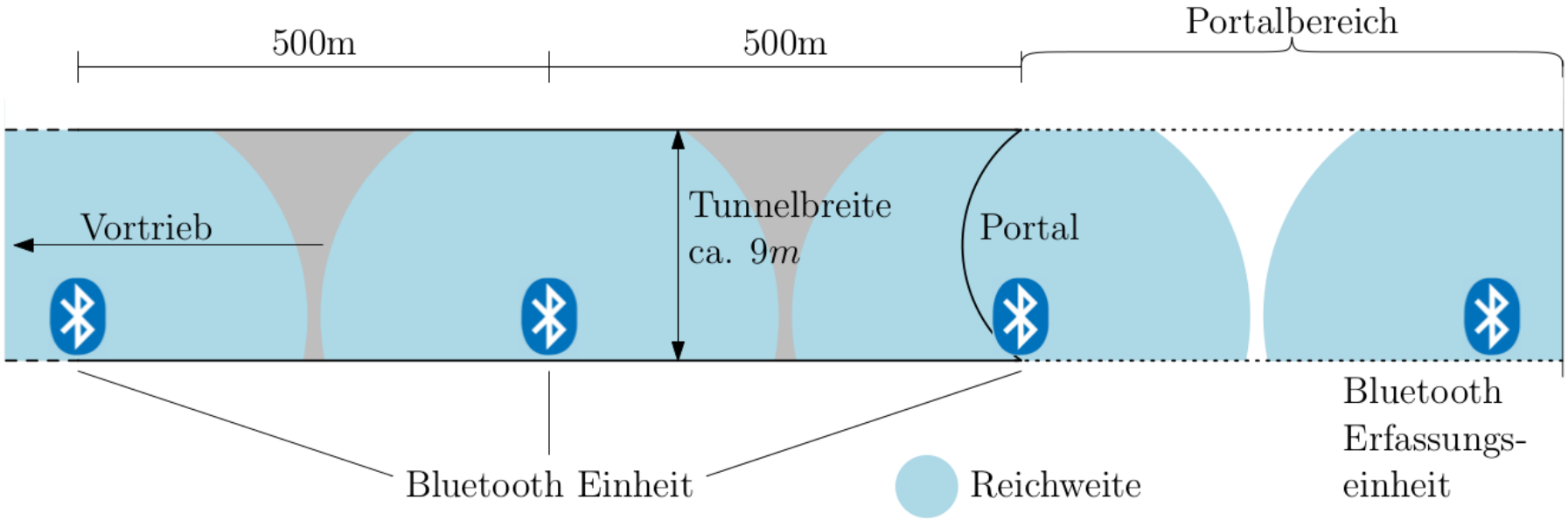
Marius Wodtke | 14. November 2017

INSTITUT FÜR ANGEWANDTE INFORMATIK UND FORMALE BESCHREIBUNGSVERFAHREN



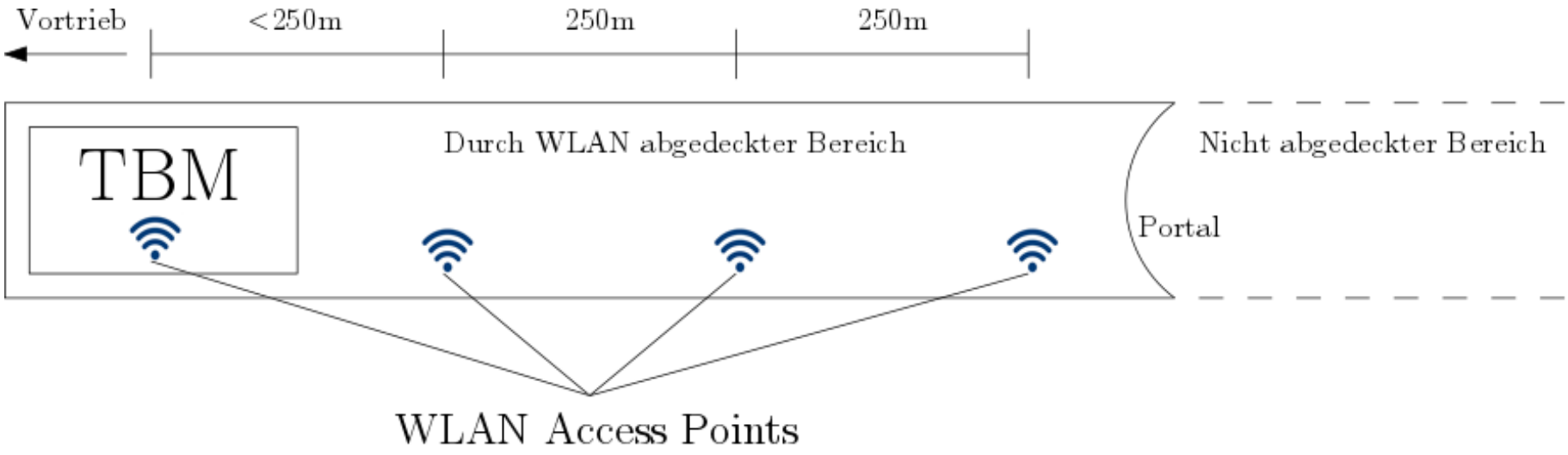
Gliederung

Bisherige Situation



[4]

Zukünftige Situation



Aufgabe

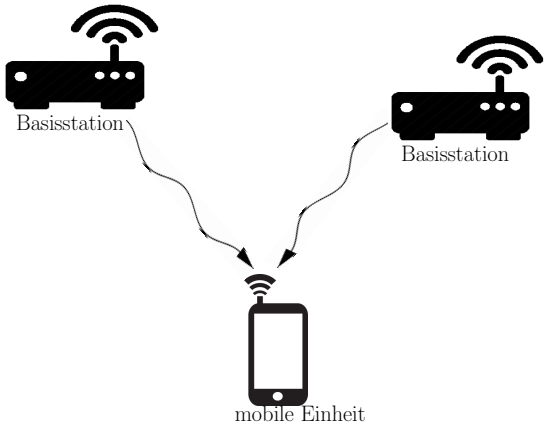
Zielsetzung

- Funkbasiertes Ortungssystem
- Bereichsortung (250m Abschnitte)

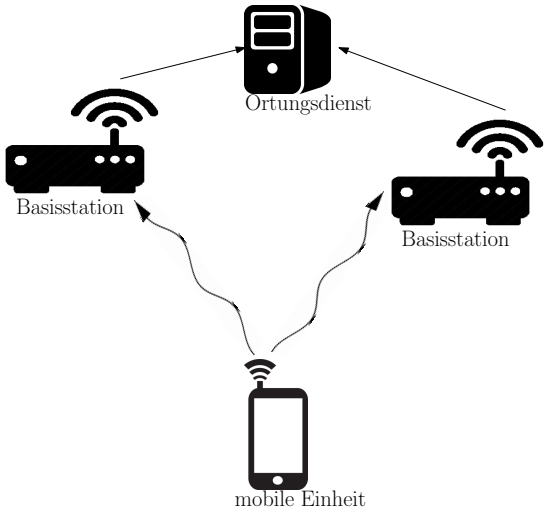
Anforderungen

- Nichtintrusiv (Keine Tore, Schranken, ...)
- Zuverlässige Erkennung von Abschnittswechseln
- Wenig Interaktion mit mobiler Einheit erforderlich

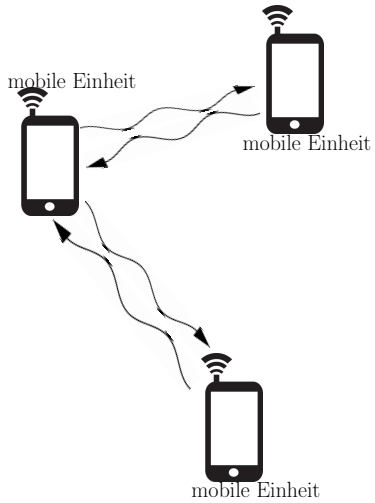
Topologien



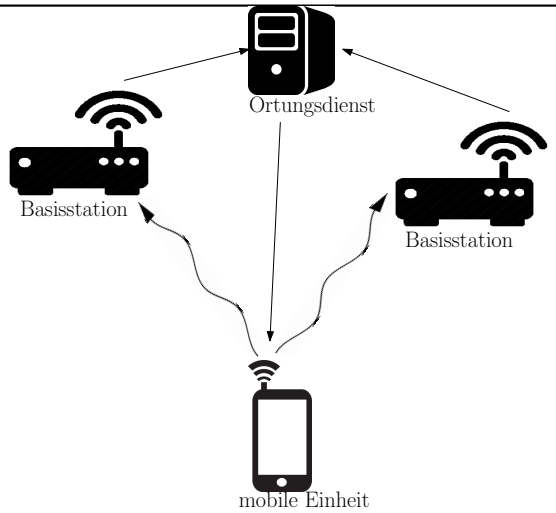
Direkte Selbstlokal.



Direkte Fernlokal.



Ohne Basisstation



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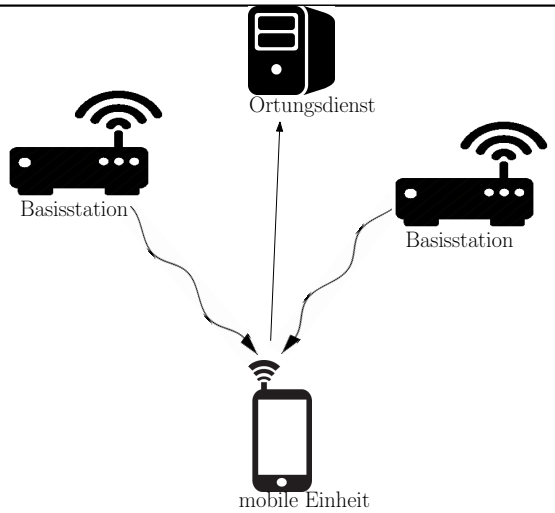
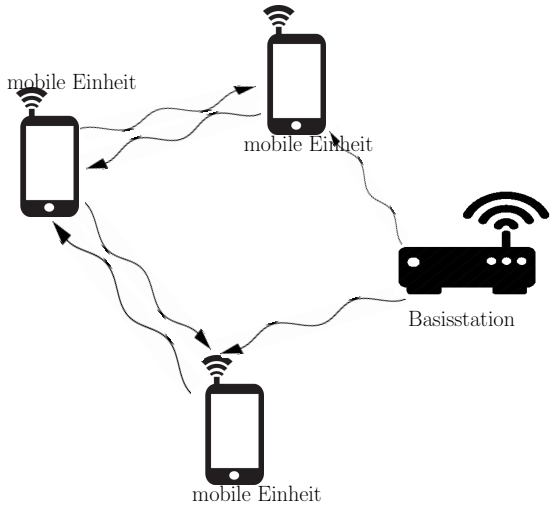
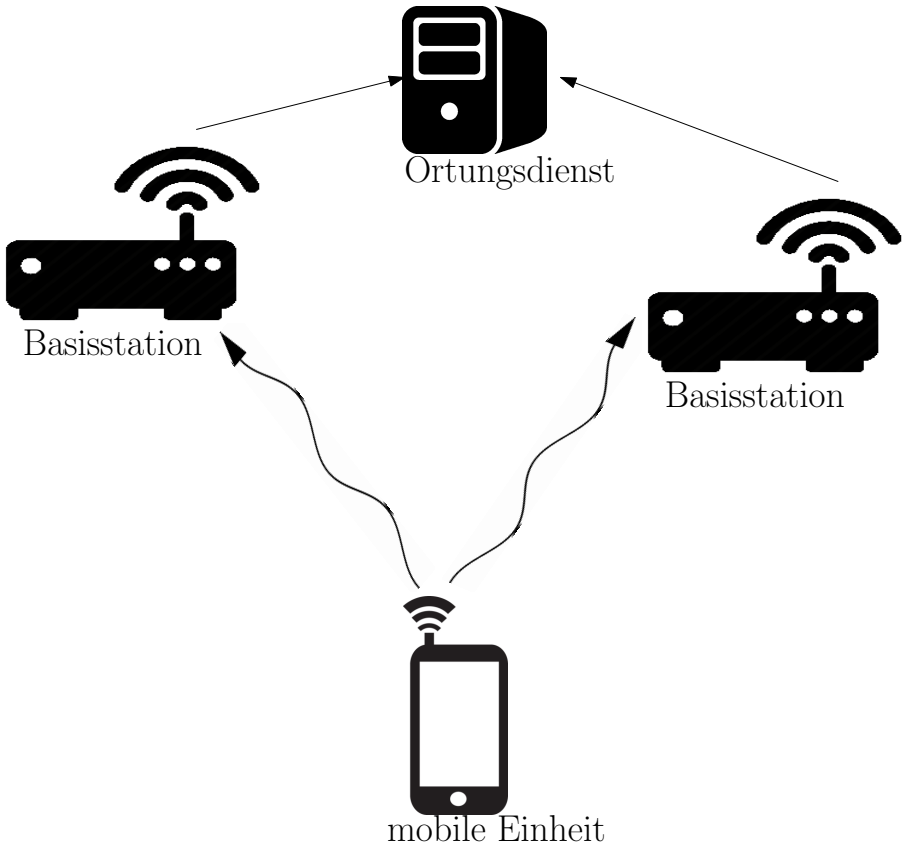


Indirekte Fernlokal.

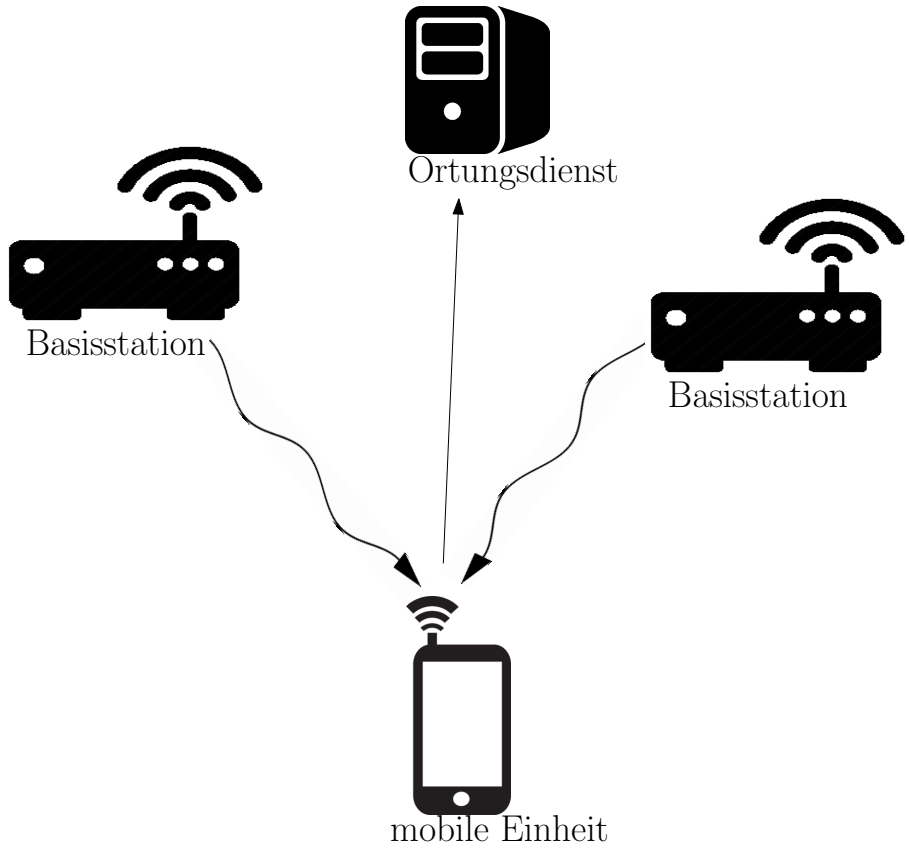


Hybride Topologie

Fernlokalisierung



Direkte Fernlokalisierung



Indirekte Fernlokalisierung

Messgrößen

- Time of Arrival
- Time Difference of Arrival
- (Roundtrip) Time of Flight
- Received Signal Strength (Indicator)
- Heartbeat

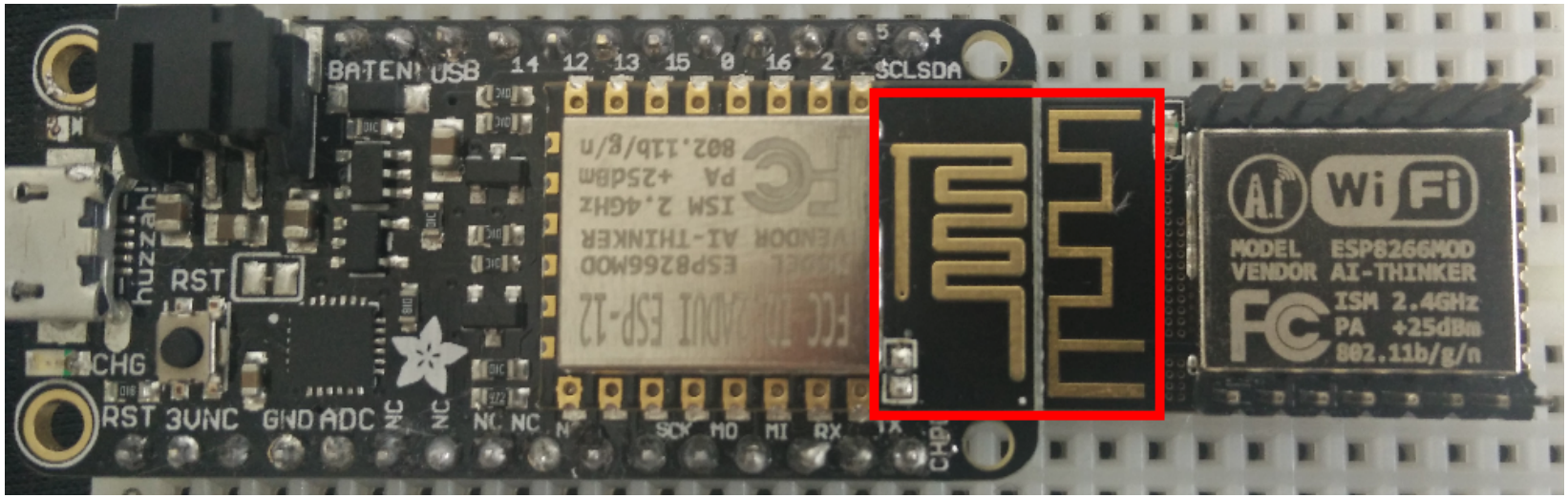
Lokalisierungsprinzip

- Umgebungsprinzip
- Geometrische Bestimmung
- Szenenanalyse

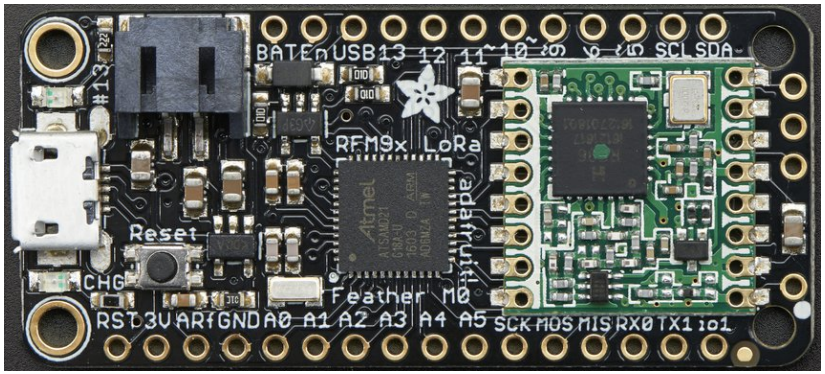
Protokolle

- IEEE 802.11
- Bluetooth (Low Energy)
- Long Range

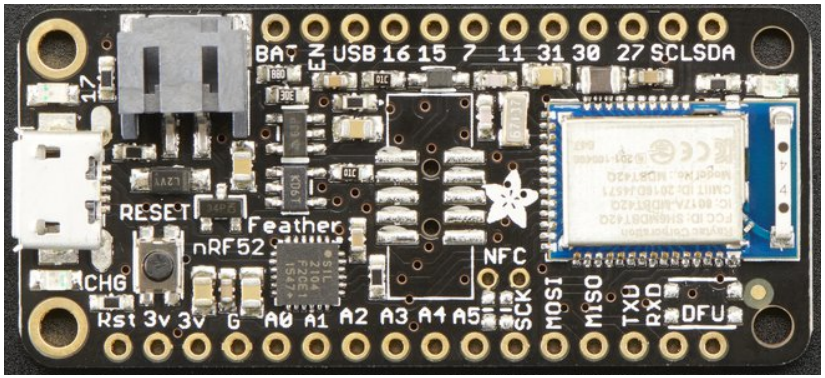
Hardware



Adafruit Feather HUZZAH ESP8266

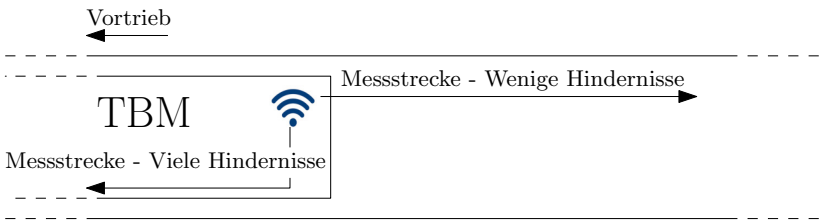


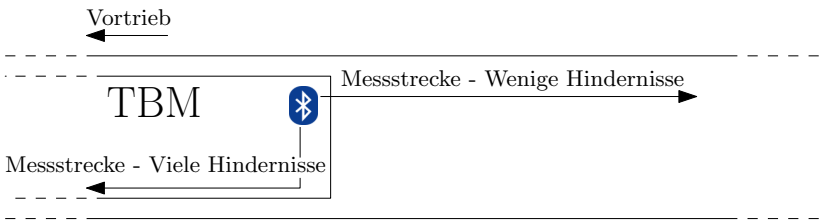
Feather M0 RFM95 LoRa Radio

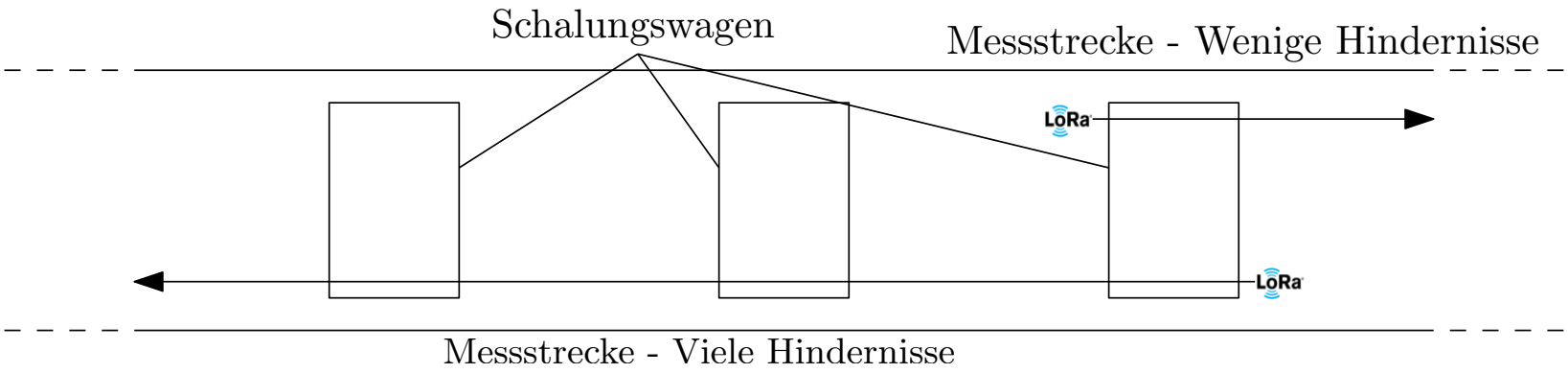


Feather nRF52 Bluefruit

Reichweiten







Reichweiten

Protokoll	Strecke	Reichweite
BLE	Wenige Hindernisse	32 m
802.11b	Wenige Hindernisse	88 m
LoRa 5 dBm	Wenige Hindernisse	250 m
LoRa 23 dBm	Wenige Hindernisse	1250 m
BLE	Viele Hindernisse	14 m
802.11b	Viele Hindernisse	32 m
LoRa 5 dBm	Viele Hindernisse	100 m
LoRa 23 dBm	Viele Hindernisse	>350 m

Reichweiten

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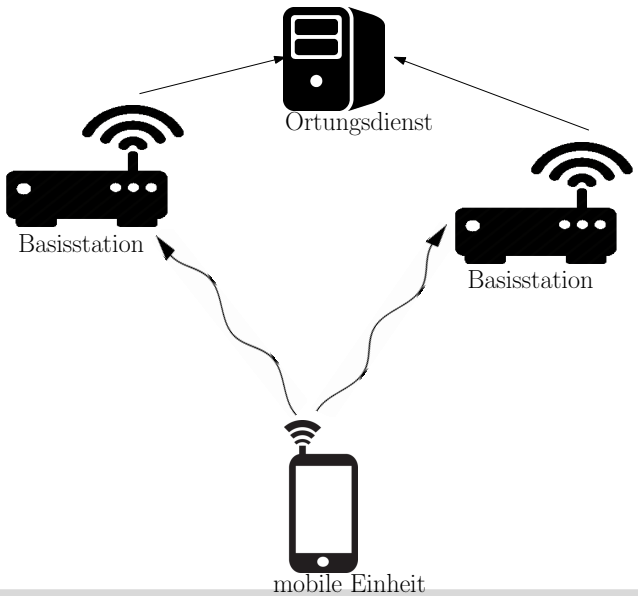
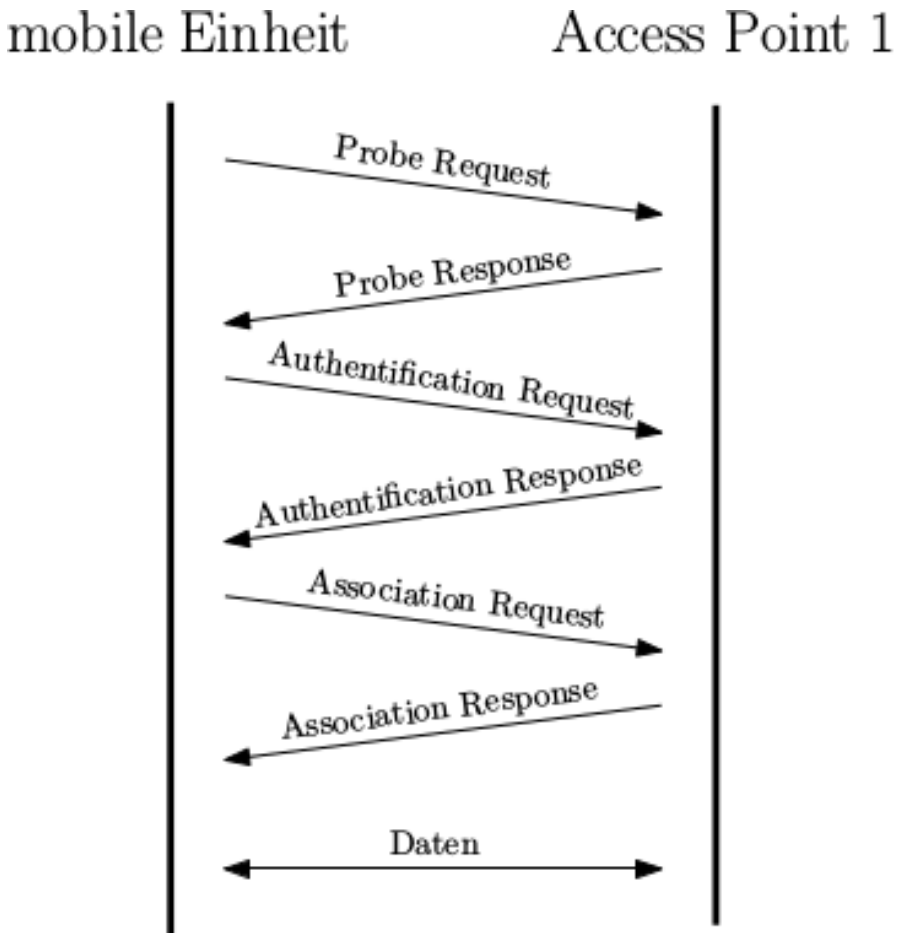
BLE	Viele Hindernisse	14 m
802.11b	Viele Hindernisse	32 m
LoRa 5 dBm	Viele Hindernisse	100 m
LoRa 23 dBm	Viele Hindernisse	>350 m

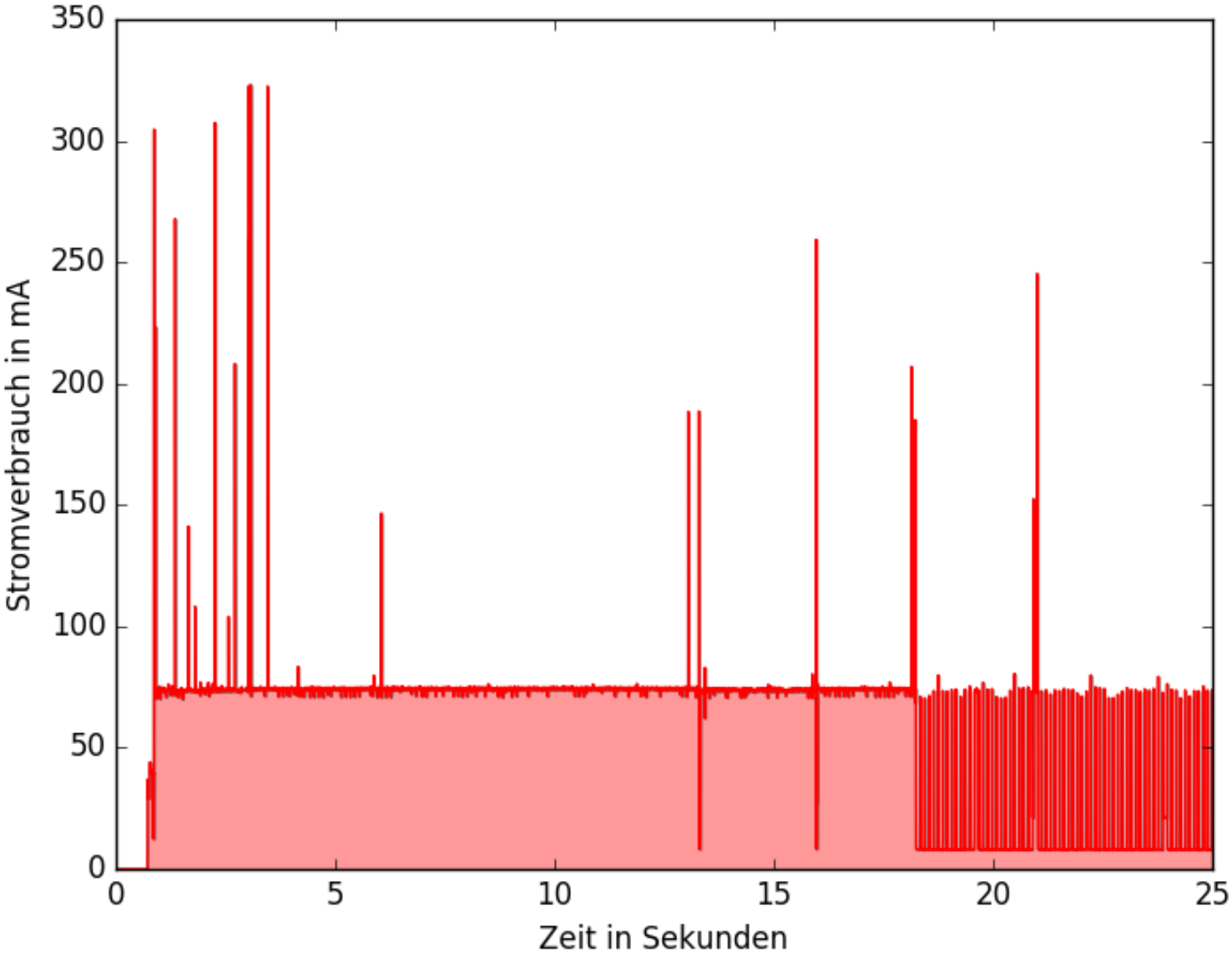
RADAR

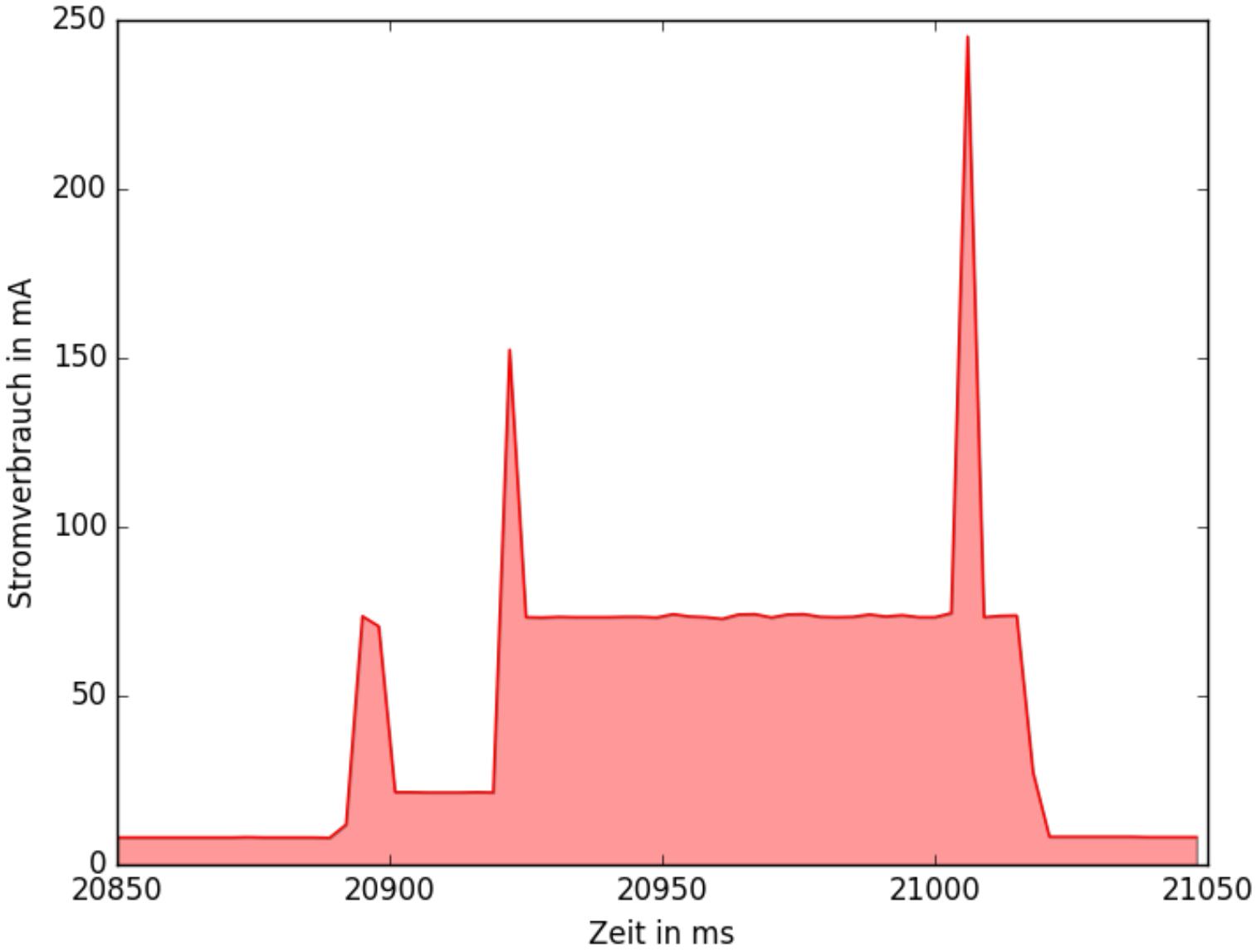
RADAR

- Bahl et al. [1]
- Direkte Fernlokalisierung
- 6 Byte mit UDP
- RSSI an Basisstation messen
- Szenenanalyse





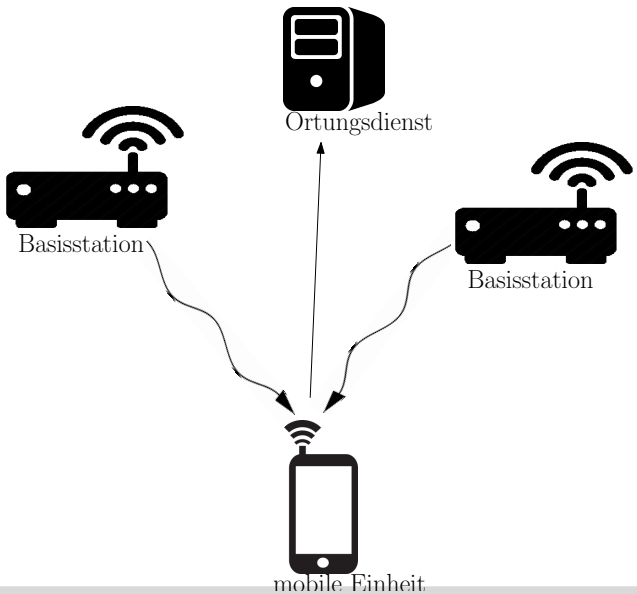

Stromverbrauch in mA
Zeit in Sekunden
0
50
100
150
200
250
300
350
0
5
10
15
20
25

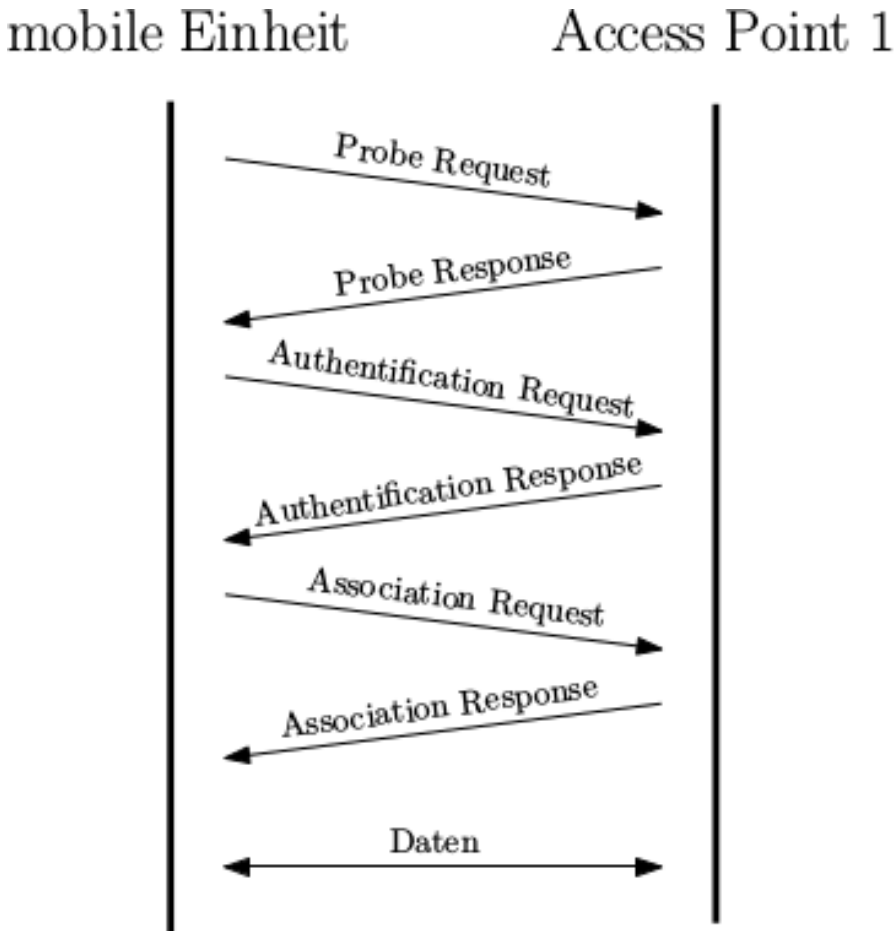

250
200
150
100
50
0
Stromverbrauch in mA
20850
20900
20950
21000
21050
Zeit in ms

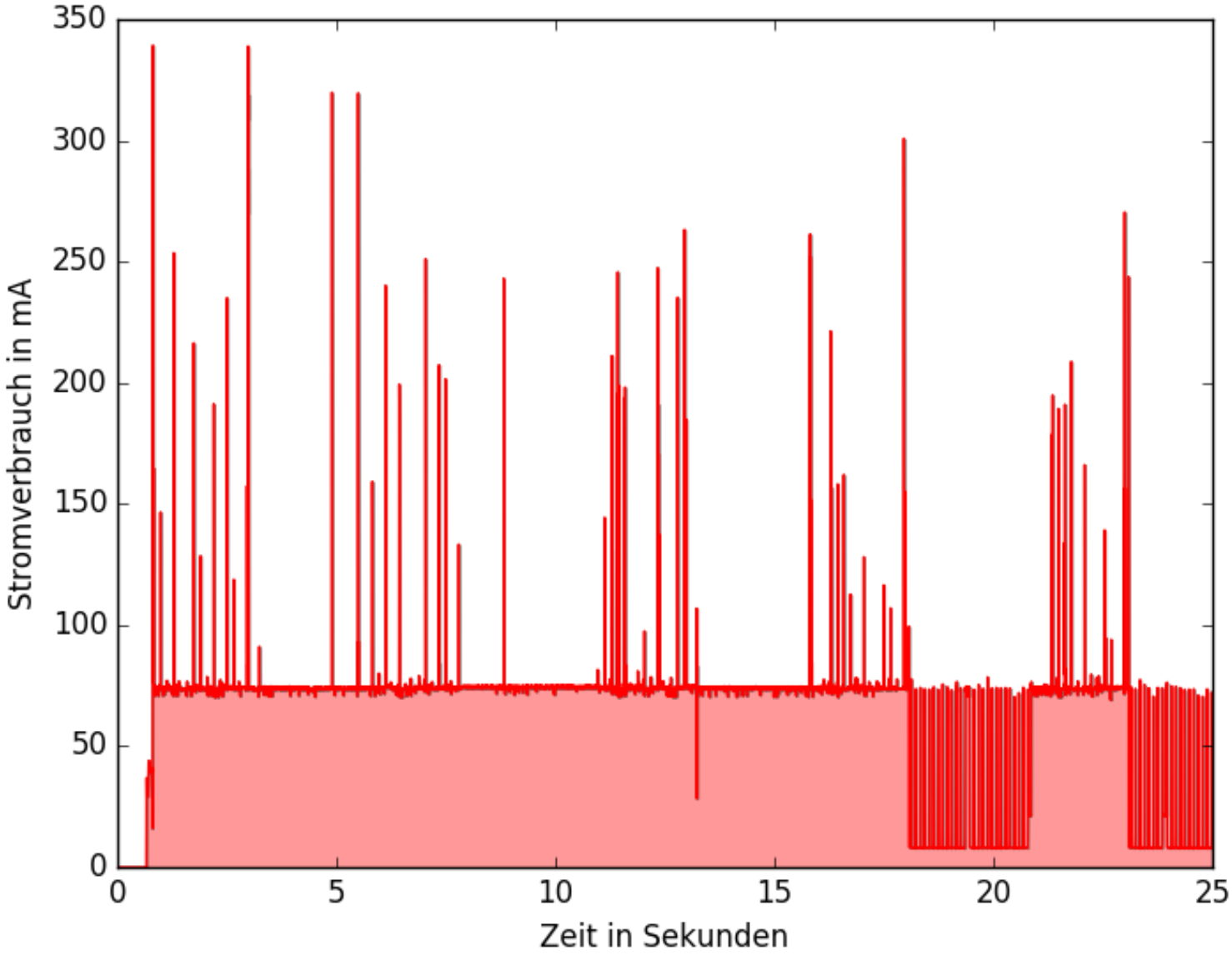
WiFi-LLS

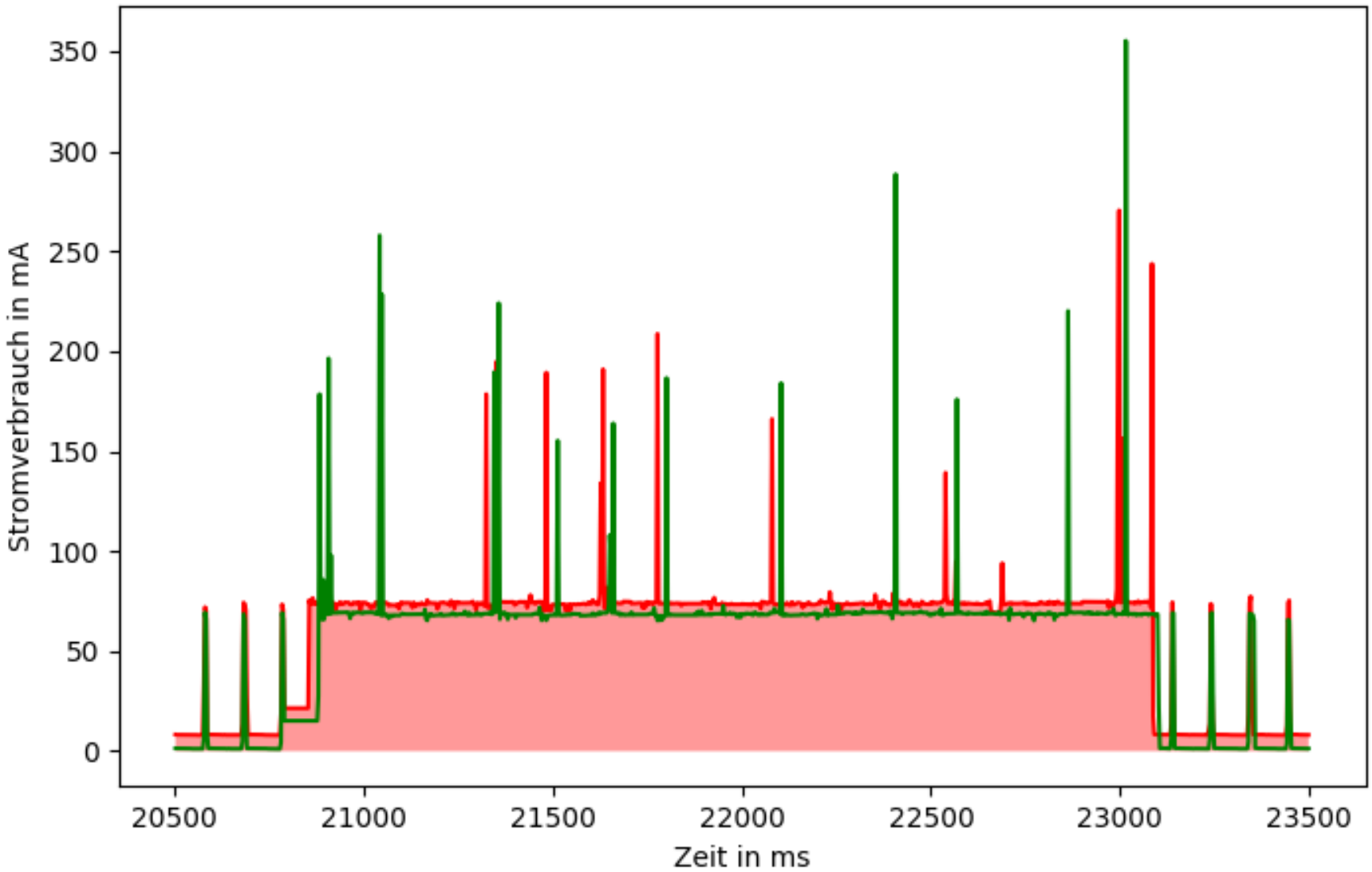
WiFi-LLS

- Chen et al. [2]
- Indirekte Fernlokalisierung
- RSSI der Probe Responses
- An mobiler Einheit gemessen
- Geometrische Bestimmung



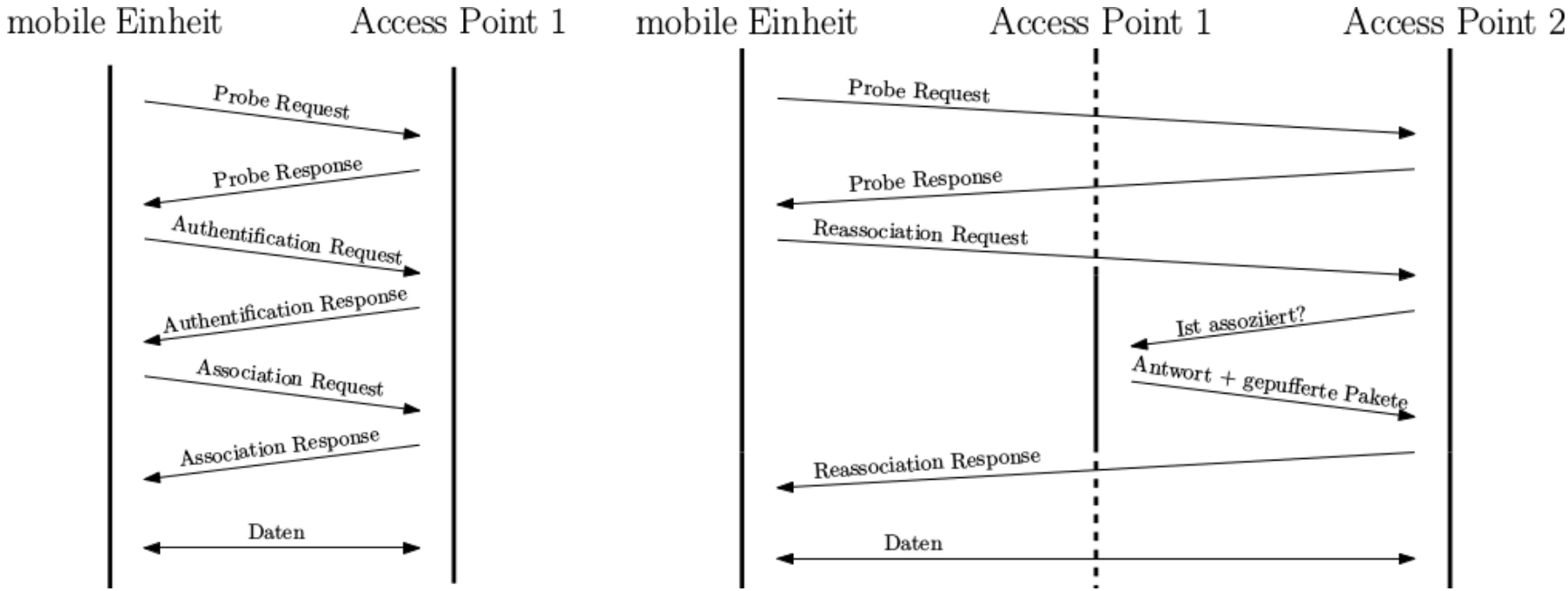



Stromverbrauch in mA
Zeit in Sekunden
0
50
100
150
200
250
300
350
0
5
10
15
20
25


Stromverbrauch in mA
350
300
250
200
150
100
50
0
20500
21000
21500
22000
22500
23000
23500
Zeit in ms

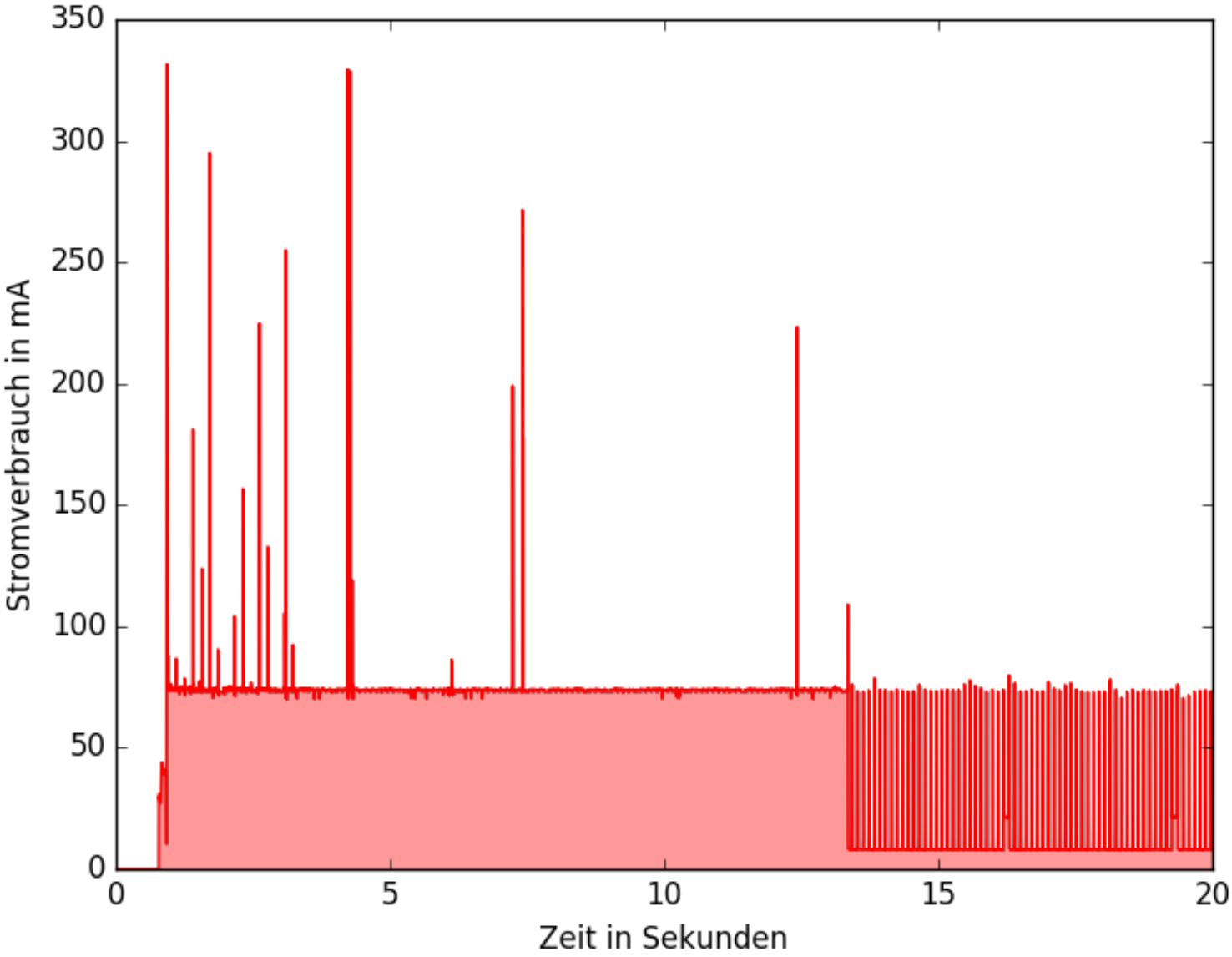
Protokoll	Modul	Programm	∅ Verbrauch (normalisiert)
IEEE 802.11	*ESP8266* Feather	*RADAR*	16,70 (8,60)
IEEE 802.11	*ESP-12F*	*RADAR*	10,10 (8,80)
IEEE 802.11	*ESP8266* Feather	*WiFi-LLS*	42,20 (34,10)
IEEE 802.11	*ESP-12F*	*WiFi-LLS*	36,50 (35,20)

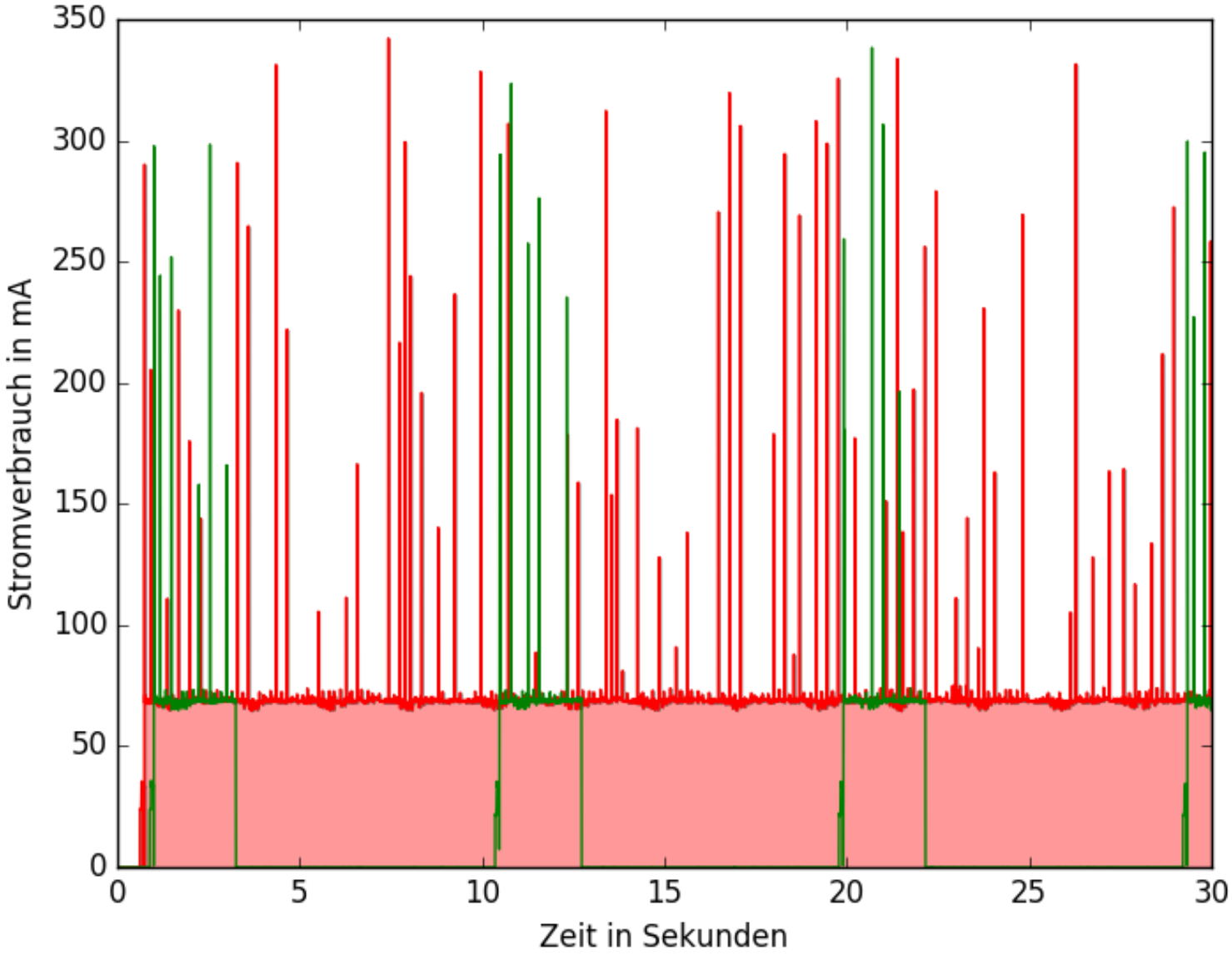
Assoziations-Lokalisierung



Assoziations-Lokalisierung

- Indirekte Fernlokalisierung
- Erfolgreiche (Re-)Assoziation, implizit RSSI der Probe Responses
- Umgebungsprinzip
- Für Bereichsortung geeignet


Stromverbrauch in mA
Zeit in Sekunden
0
50
100
150
200
250
300
350
0
5
10
15
20

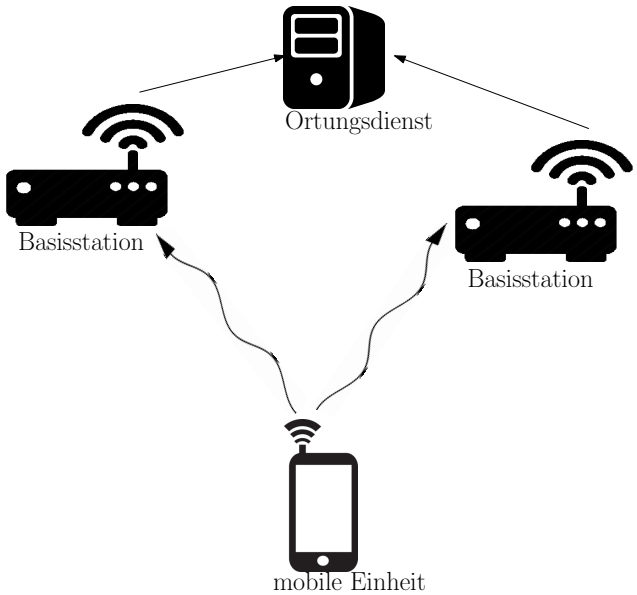

Stromverbrauch in mA
Zeit in Sekunden
0
50
100
150
200
250
300
350
0
5
10
15
20
25
30

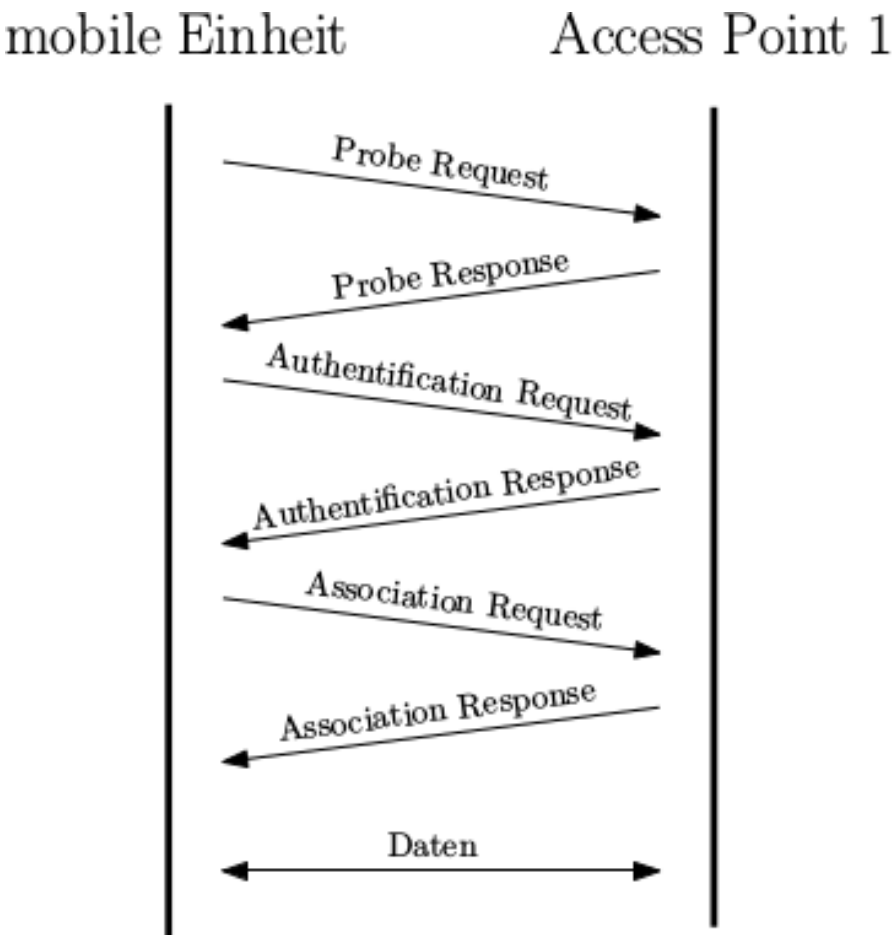
Protokoll	Modul	Programm	∅ Verbrauch (normalisiert)
IEEE 802.11	*ESP8266* Feather	*RADAR*	16,70 (8,60)
IEEE 802.11	*ESP-12F*	*RADAR*	10,10 (8,80)
IEEE 802.11	*ESP8266* Feather	*WiFi-LLS*	42,20 (34,10)
IEEE 802.11	*ESP-12F*	*WiFi-LLS*	36,50 (35,20)
IEEE 802.11	*ESP-12F*	*Assoziations-Lokalisierung*	8,80 (7,50)
IEEE 802.11	*ESP-12F*	*Assoziations-Lokalisierung* (kein *Access Point*)	17,10 (17,10)

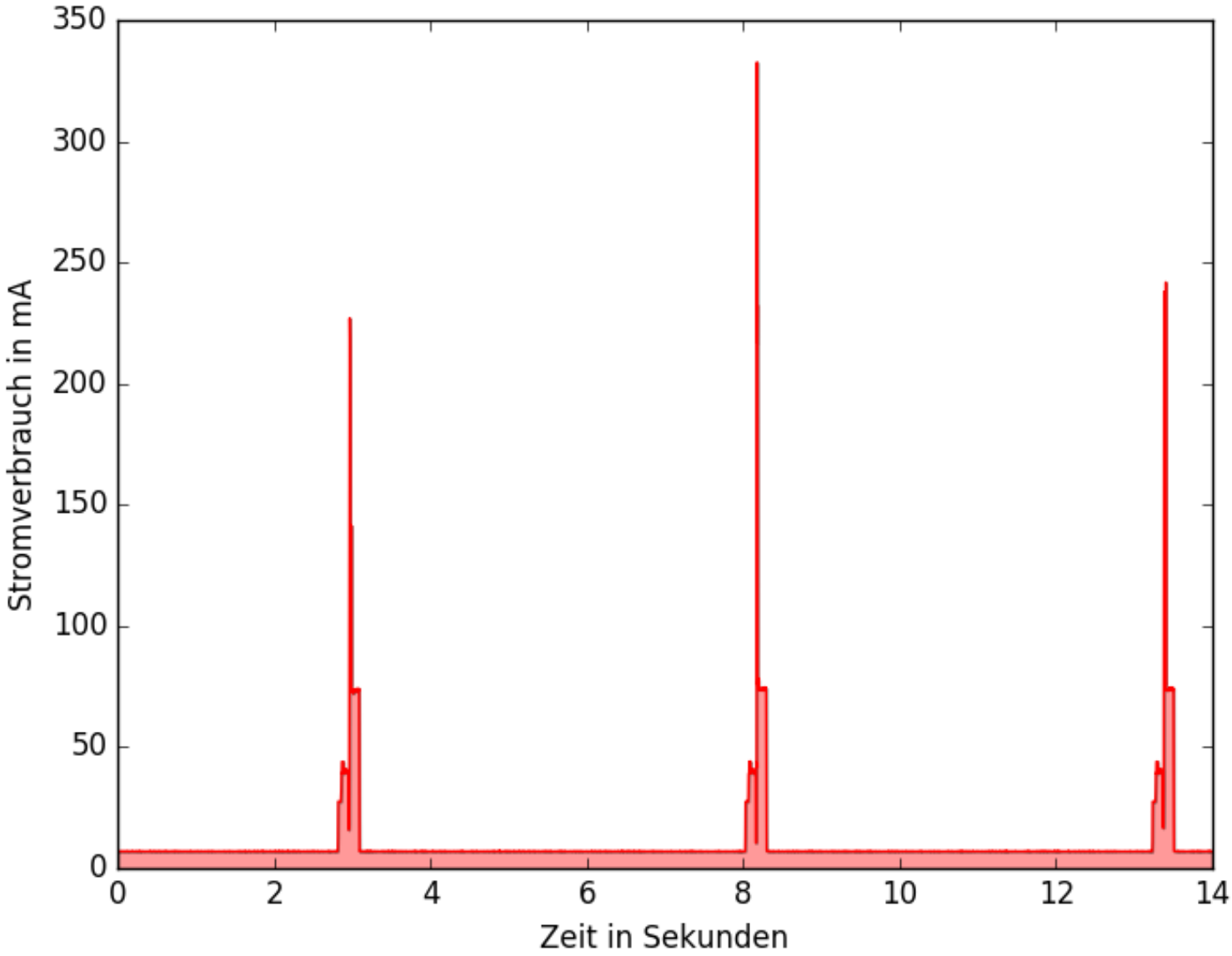
Probe-Request-Lokalisierung

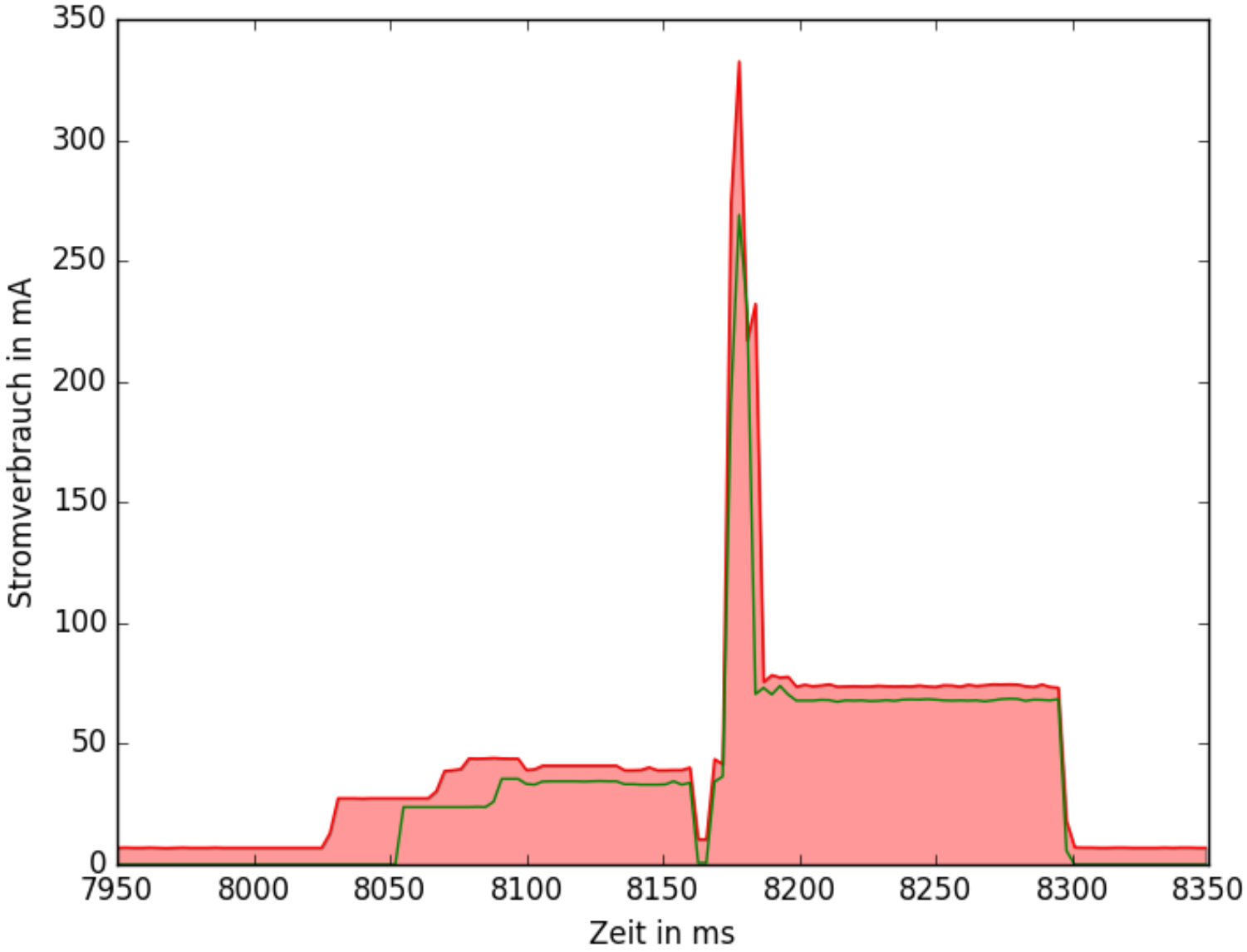
Probe-Request-Lokalisierung

- Direkte Fernlokalisierung
- RSSI der Probe Requests
- An Access Point gemessen
- Umgebungsprinzip






Stromverbrauch in mA
Zeit in Sekunden
0
50
100
150
200
250
300
350
0
2
4
6
8
10
12
14

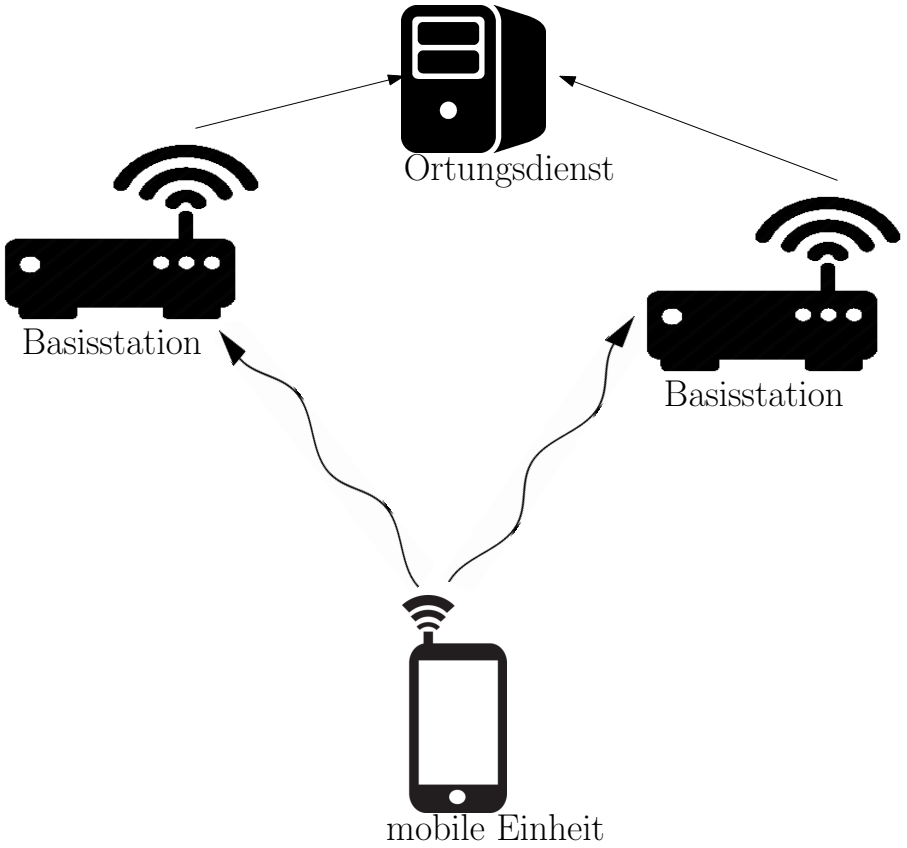

Stromverbrauch in mA
Zeit in ms
0
50
100
150
200
250
300
350
7950
8000
8050
8100
8150
8200
8250
8300
8350

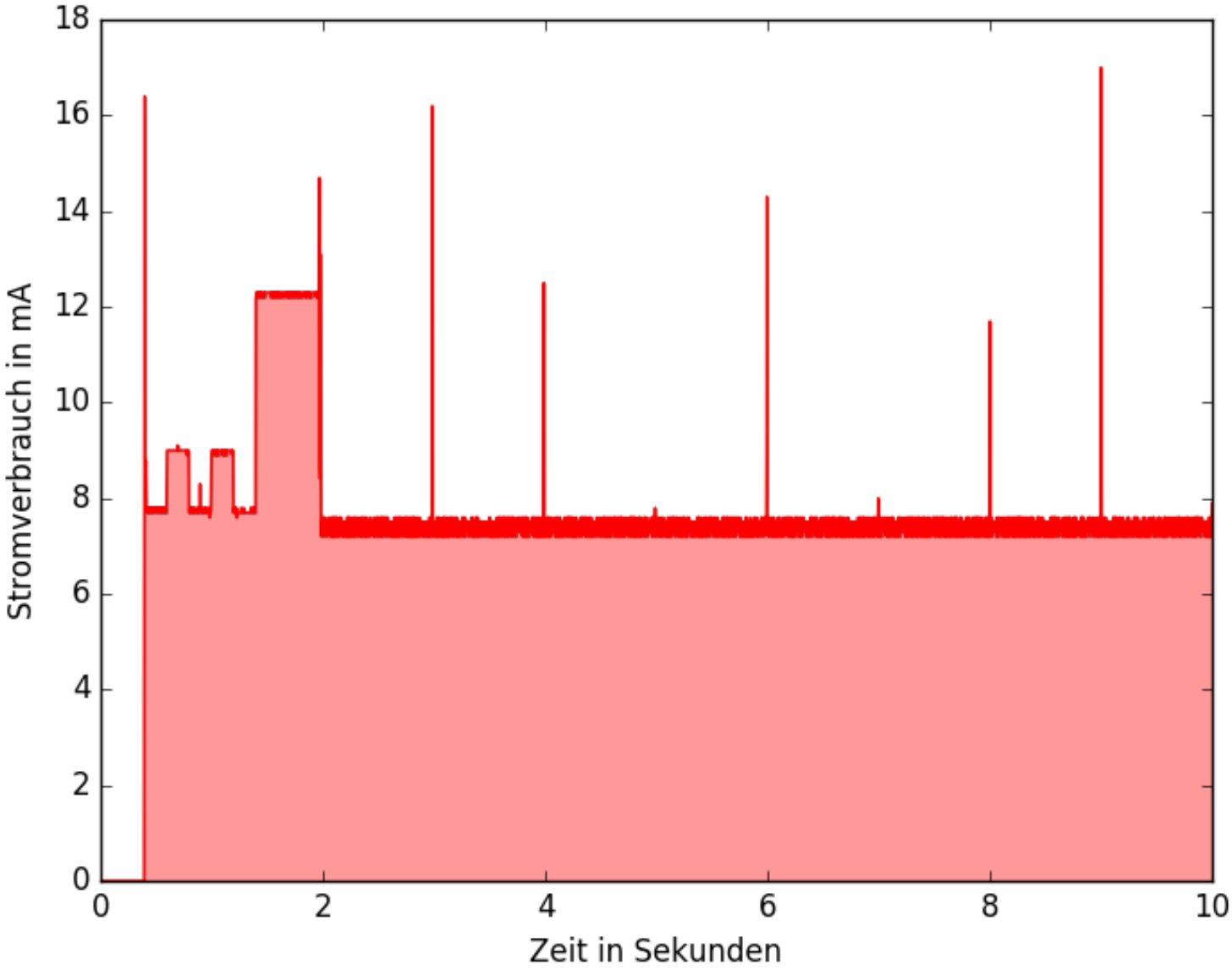
Protokoll	Modul	Programm	∅ Verbrauch (normalisiert)
IEEE 802.11	*ESP-12F*	*Assoziations-Lokalisierung*	8,80 (7,50)
IEEE 802.11	*ESP-12F*	*Assoziations-Lokalisierung* (kein *Access Point*)	17,10 (17,10)
IEEE 802.11	*ESP8266* Feather	*Probe-Request-Lokalisierung*	9,70 (2,70)
IEEE 802.11	*ESP-12F*	*Probe-Request-Lokalisierung*	1,80 (1,80)

Bluetooth Low Energy

BLE-Advertising

- Jianyong et al. [3]
- Direkte Fernlokalisierung
- RSSI von Advertising Paketen
- An Basisstation gemessen
- Umgebungsprinzip



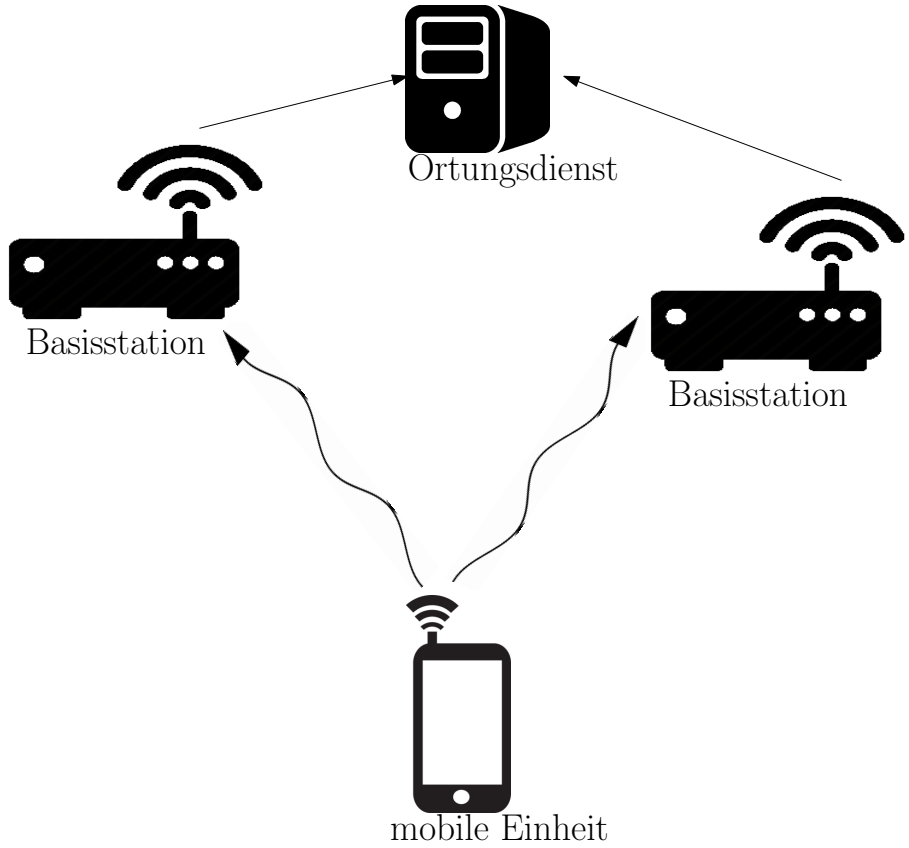

Stromverbrauch in mA
Zeit in Sekunden
0
2
4
6
8
10
12
14
16
18

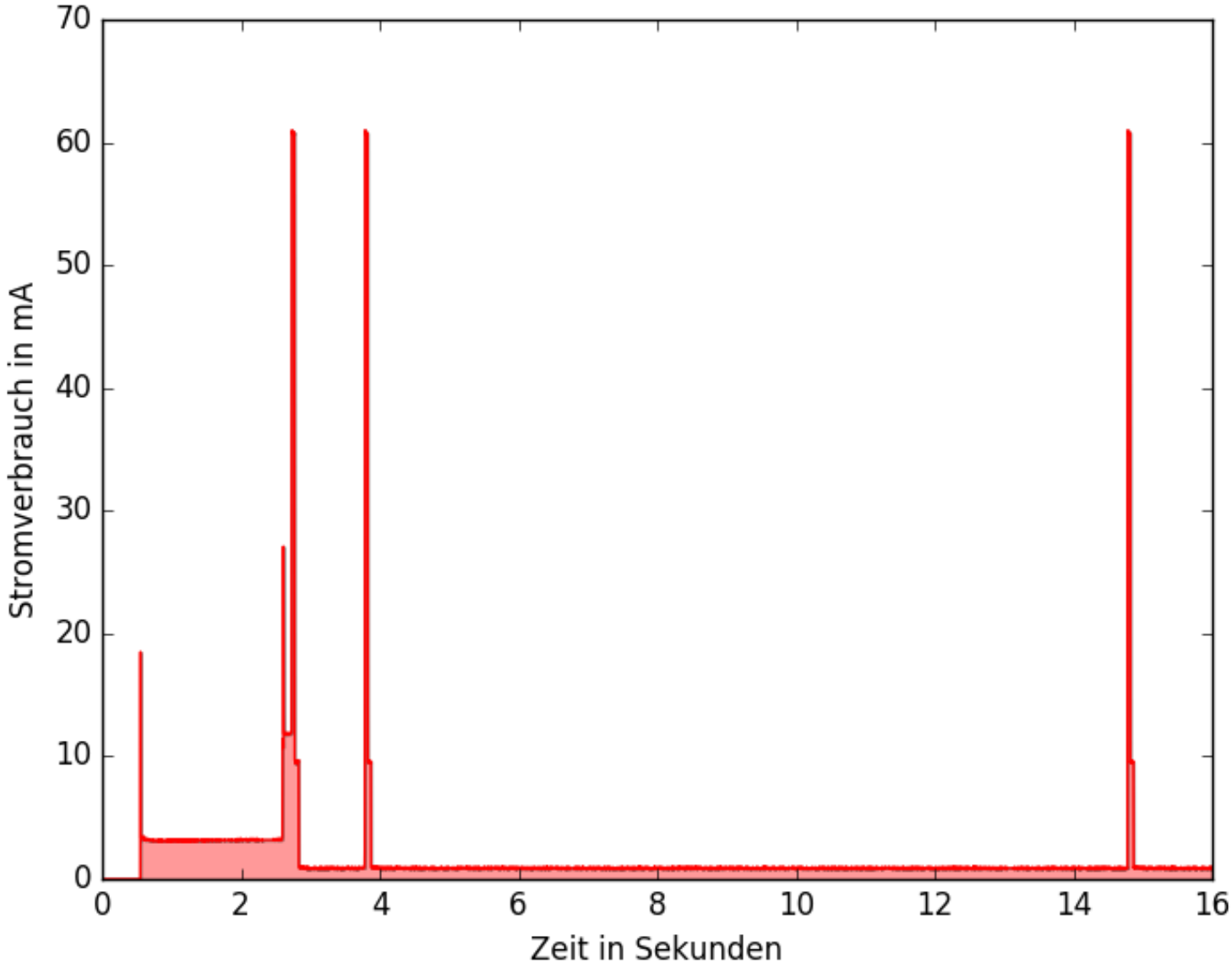
Protokoll	Modul	Programm	∅ Verbrauch (normalisiert)
IEEE 802.11	*ESP8266* Feather	*Probe-Request-Lokalisierung*	9,70 (2,70)
IEEE 802.11	*ESP-12F*	*Probe-Request-Lokalisierung*	1,80 (1,80)
BLE	*nRF52* Feather	Ortung mit *BLE-Advertising*	7,37 (0,04)

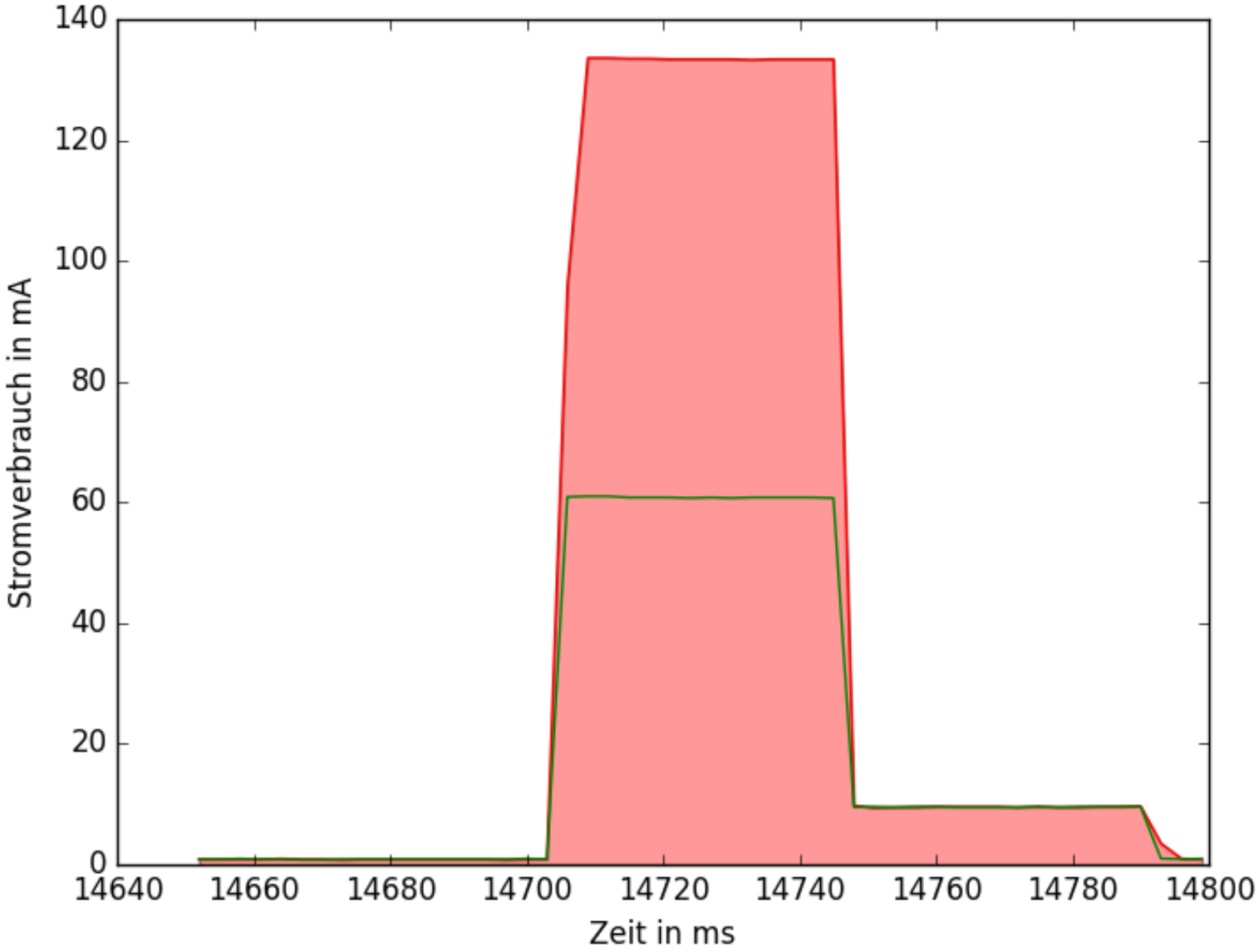
Lokalisierung mit LoRa

Lokalisierung mit LoRa

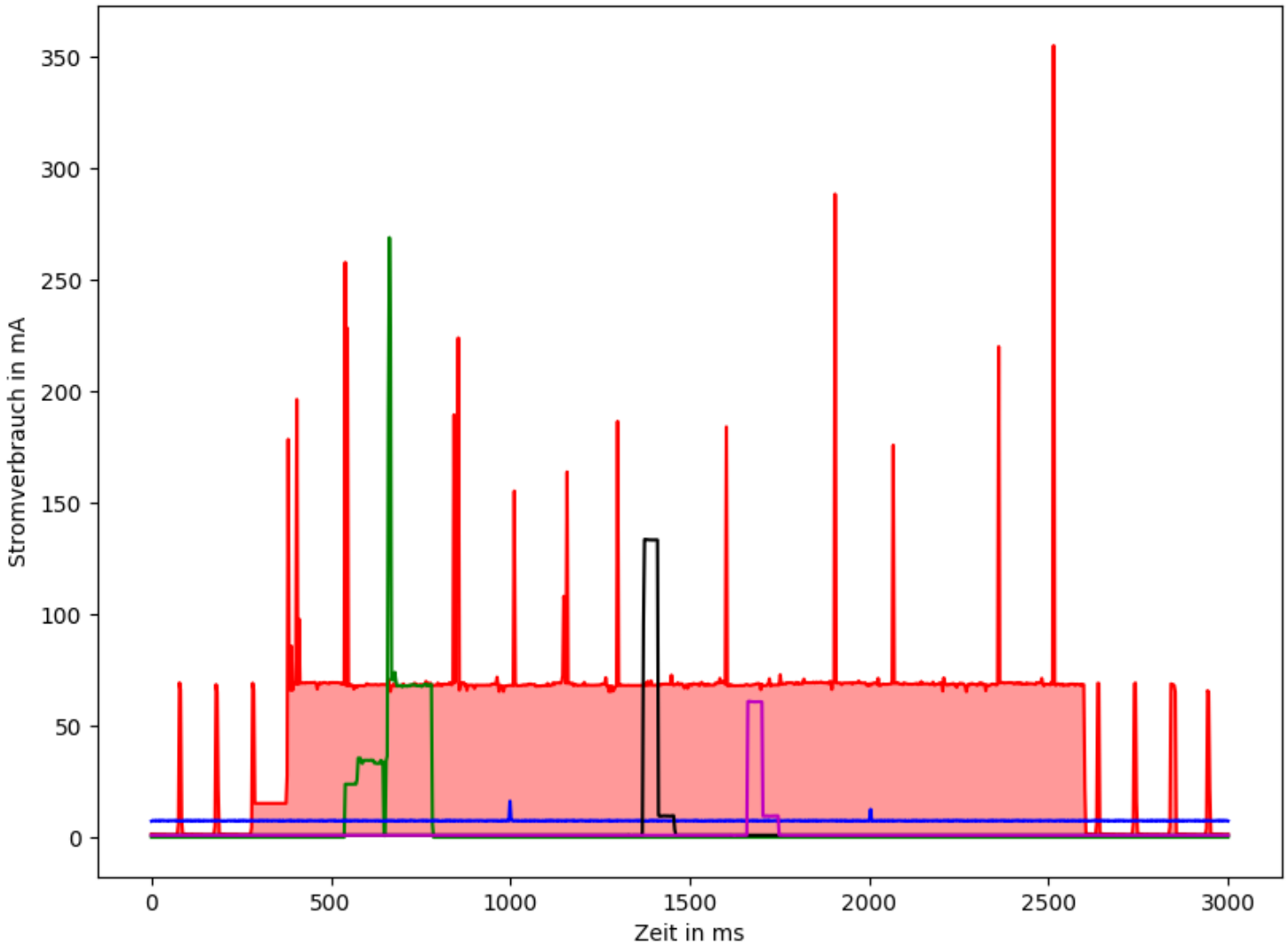
- Direkte Fernlokalisierung
- RSSI an Basisstation gemessen
- Geometrische Bestimmung

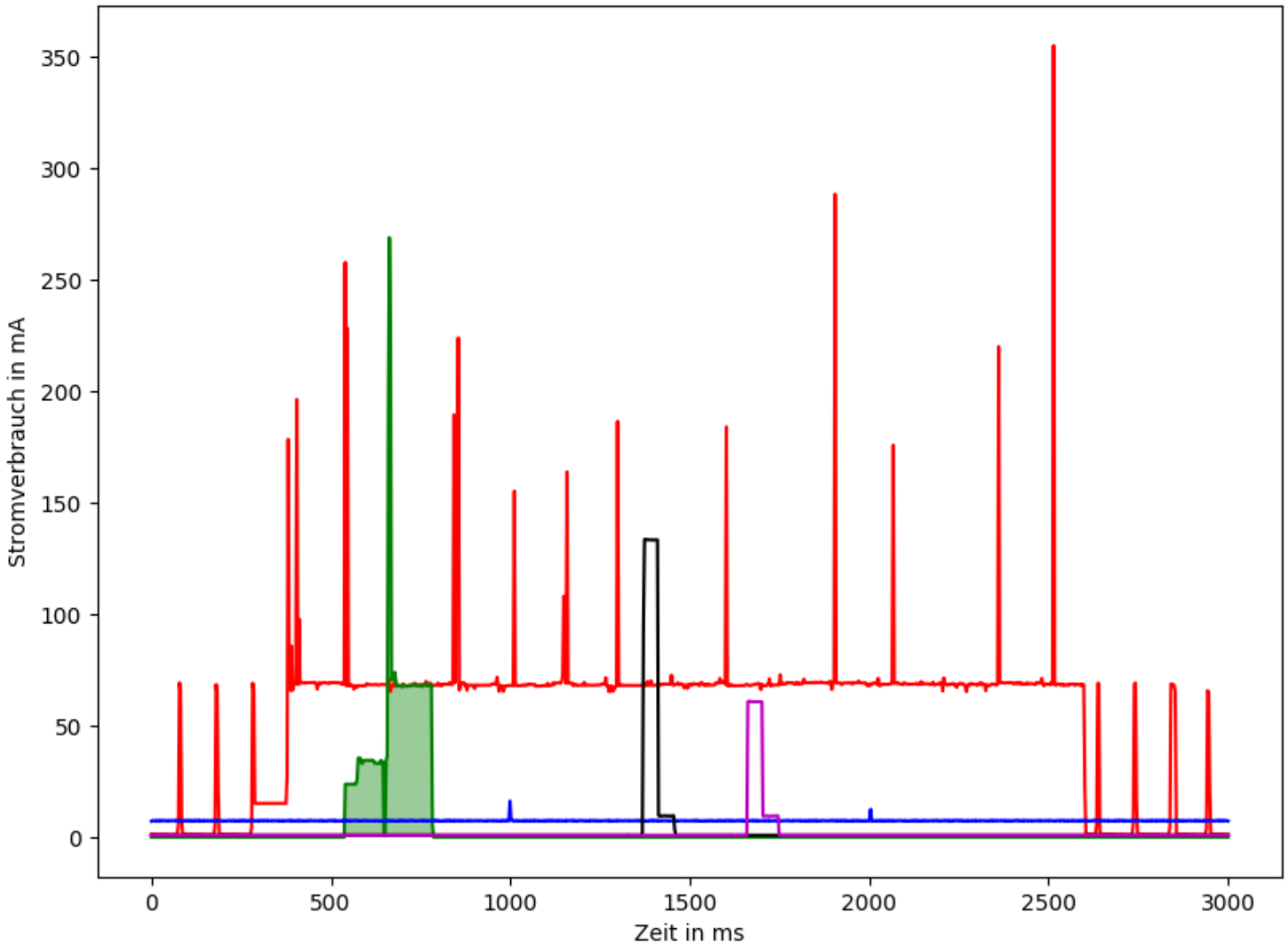


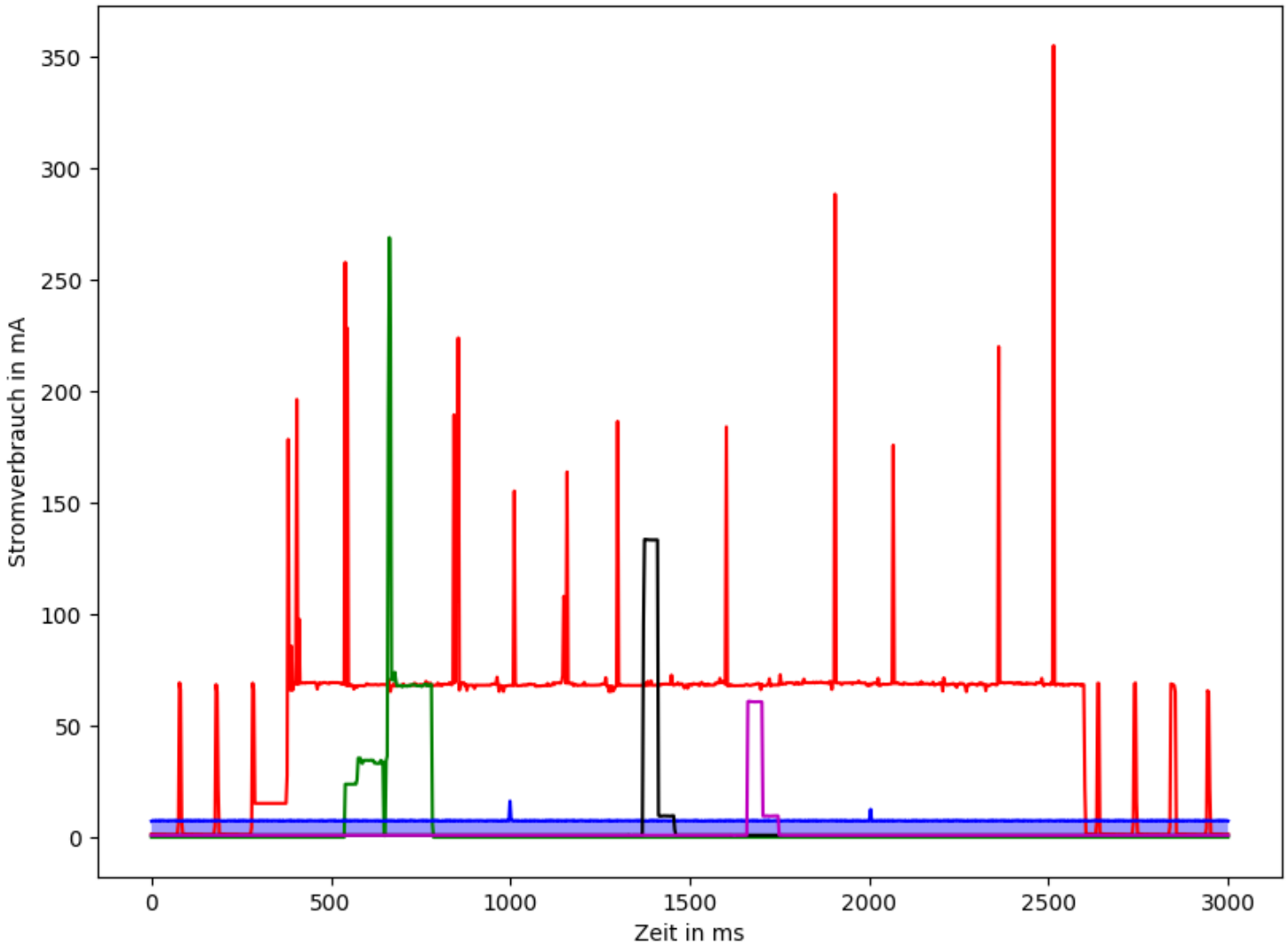

Stromverbrauch in mA
Zeit in Sekunden
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16

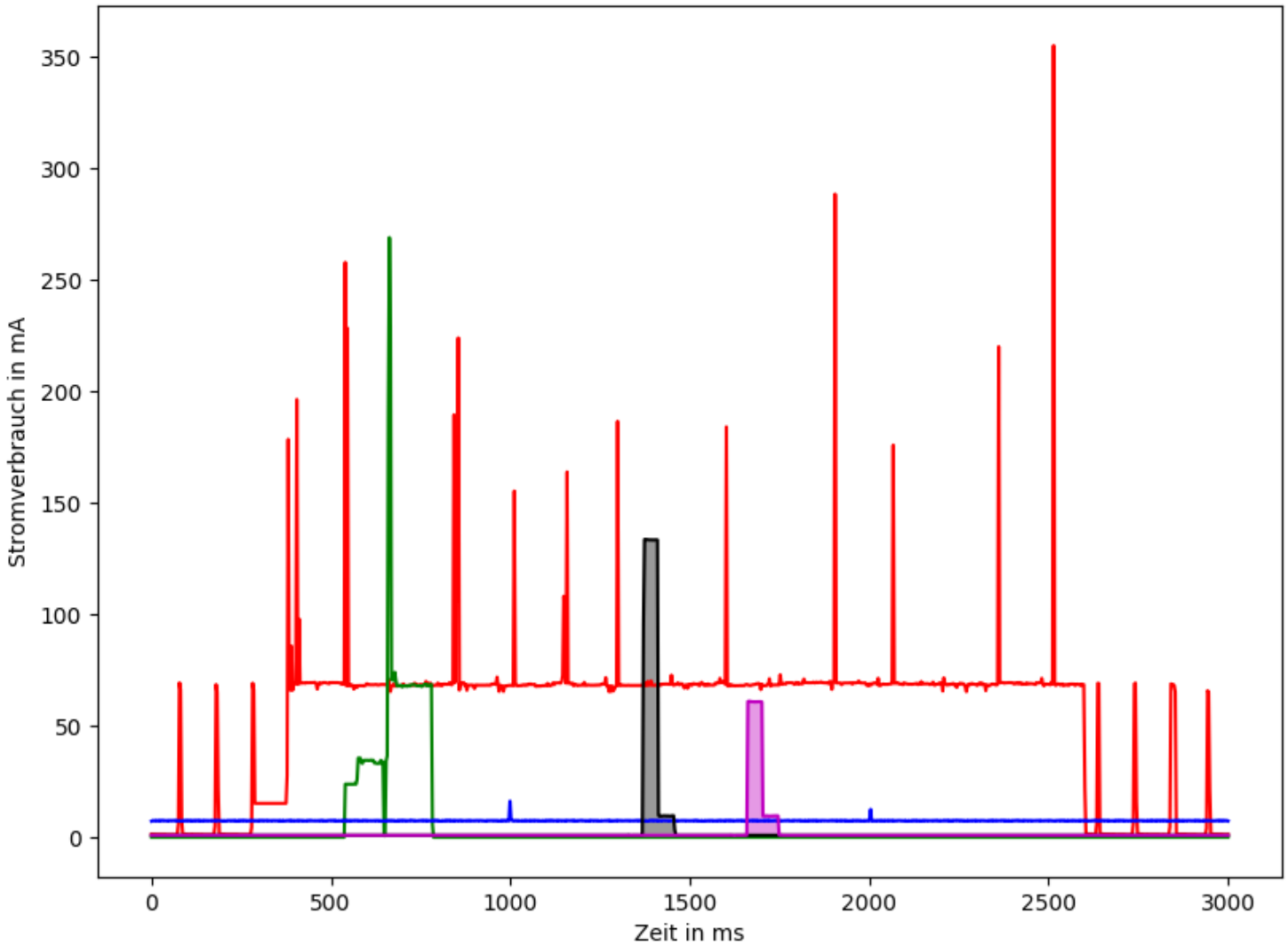

140
120
100
80
60
40
20
0
Stromverbrauch in mA
14640
14660
14680
14700
14720
14740
14760
14780
14800
Zeit in ms

Protokoll	Modul	Programm	∅ Verbrauch (normalisiert)
IEEE 802.11	*ESP-12F*	*Probe-Request-Lokalisierung*	1,80 (1,80)
BLE	*nRF52* Feather	Ortung mit *BLE-Advertising*	7,37 (0,04)
LoRa	*RFM95* Feather 5 dBM	Ortung mit LoRa RSSI	1,20 (0,30)
LoRa	*RFM95* Feather 23 dBM	Ortung mit LoRa RSSI	1,47 (0,57)

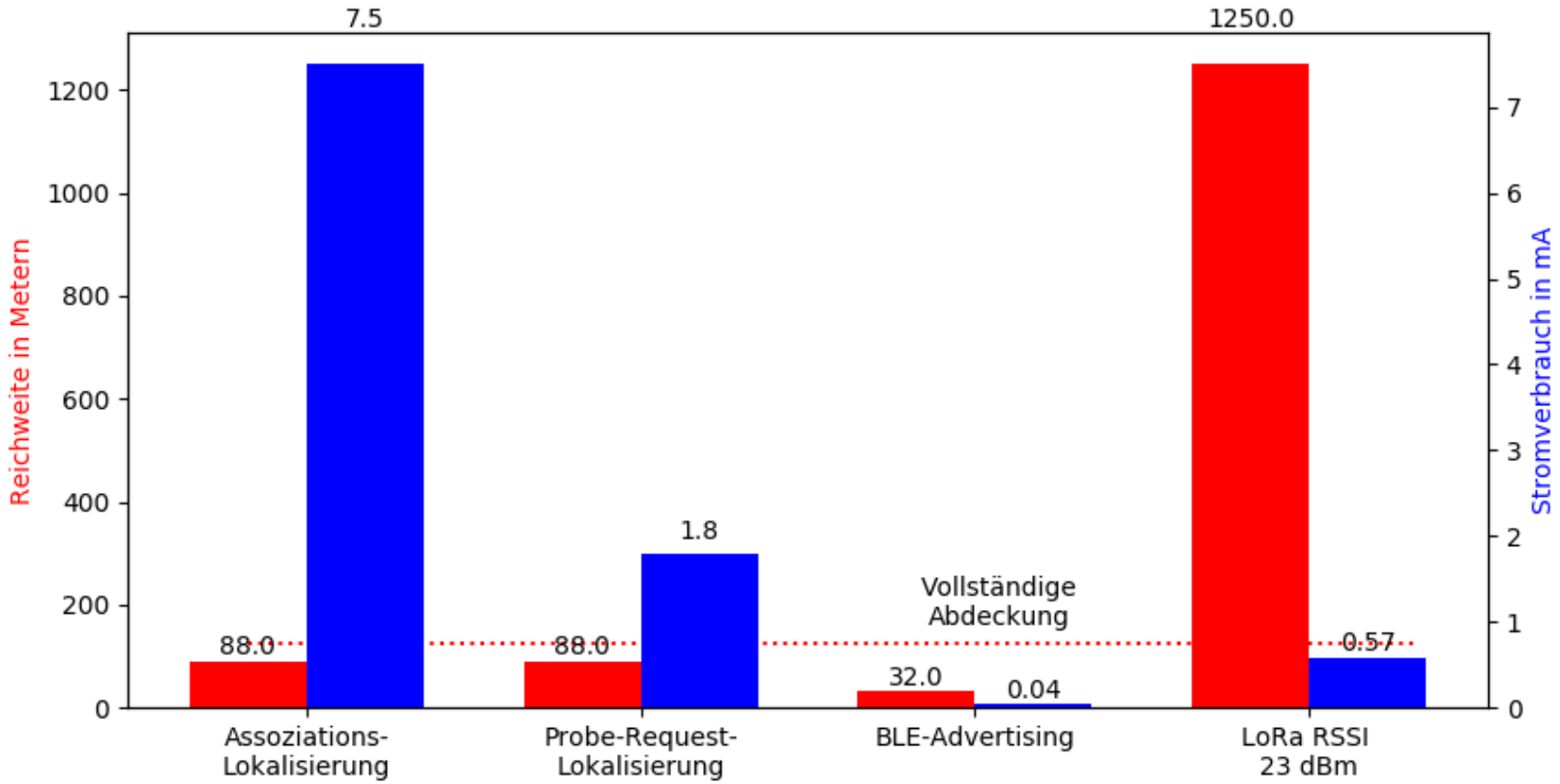

Stromverbrauch in mA
Zeit in ms
0
50
100
150
200
250
300
350
0
500
1000
1500
2000
2500
3000


Stromverbrauch in mA
Zeit in ms
0
50
100
150
200
250
300
350
0
500
1000
1500
2000
2500
3000


Stromverbrauch in mA
Zeit in ms
0
50
100
150
200
250
300
350
0
500
1000
1500
2000
2500
3000


Stromverbrauch in mA
Zeit in ms
0
50
100
150
200
250
300
350
0
500
1000
1500
2000
2500
3000

Protokoll	Modul	Programm	∅ Verbrauch (normalisiert)
IEEE 802.11	*ESP-12F*	*RADAR*	10,10 (8,80)
IEEE 802.11	*ESP-12F*	*WiFi-LLS*	36,50 (35,20)
IEEE 802.11	*ESP-12F*	*Assoziations-Lokalisierung*	8,80 (7,50)
IEEE 802.11	*ESP-12F*	*Assoziations-Lokalisierung* (kein *Access Point*)	17,10 (17,10)
IEEE 802.11	*ESP-12F*	*Probe-Request-Lokalisierung*	1,80 (1,80)
BLE	*nRF52* Feather	Ortung mit *BLE-Advertising*	7,37 (0,04)
LoRa	*RFM95* Feather 5 dBM	Ortung mit LoRa RSSI	1,20 (0,30)
LoRa	*RFM95* Feather 23 dBM	Ortung mit LoRa RSSI	1,47 (0,57)



Fazit

- LoRa > 802.11
- LoRa ohne Erfassungslücken => Hohe Zuverlässigkeit
- BLE hat niedrigen Stromverbrauch => Wenig Interaktion notwendig

References I

[1] Paramvir Bahl und Venkata N Padmanabhan. “RADAR: An in-building RF-based user location and tracking system”. In: *INFOCOM 2000. Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE*. Bd. 2. Ieee. 2000, S. 775–784.

[2] Yibo Chen und Rong Luo. “Design and implementation of a wifi-based local locating system”. In: *Portable Information Devices, 2007. PORTABLE07. IEEE International Conference on*. IEEE. 2007, S. 1–5.

[3] Zhu Jianyong u. a. “RSSI based Bluetooth low energy indoor positioning”. In: *Indoor Positioning and Indoor Navigation (IPIN), 2014 International Conference on*. IEEE. 2014, S. 526–533.

References II

[4] Devorie Maurer. *Unterstützung der Sicherheitstechnik im Tunnelbau durch eine Applikation*. Karlsruher Institut für Technologie, 2016.

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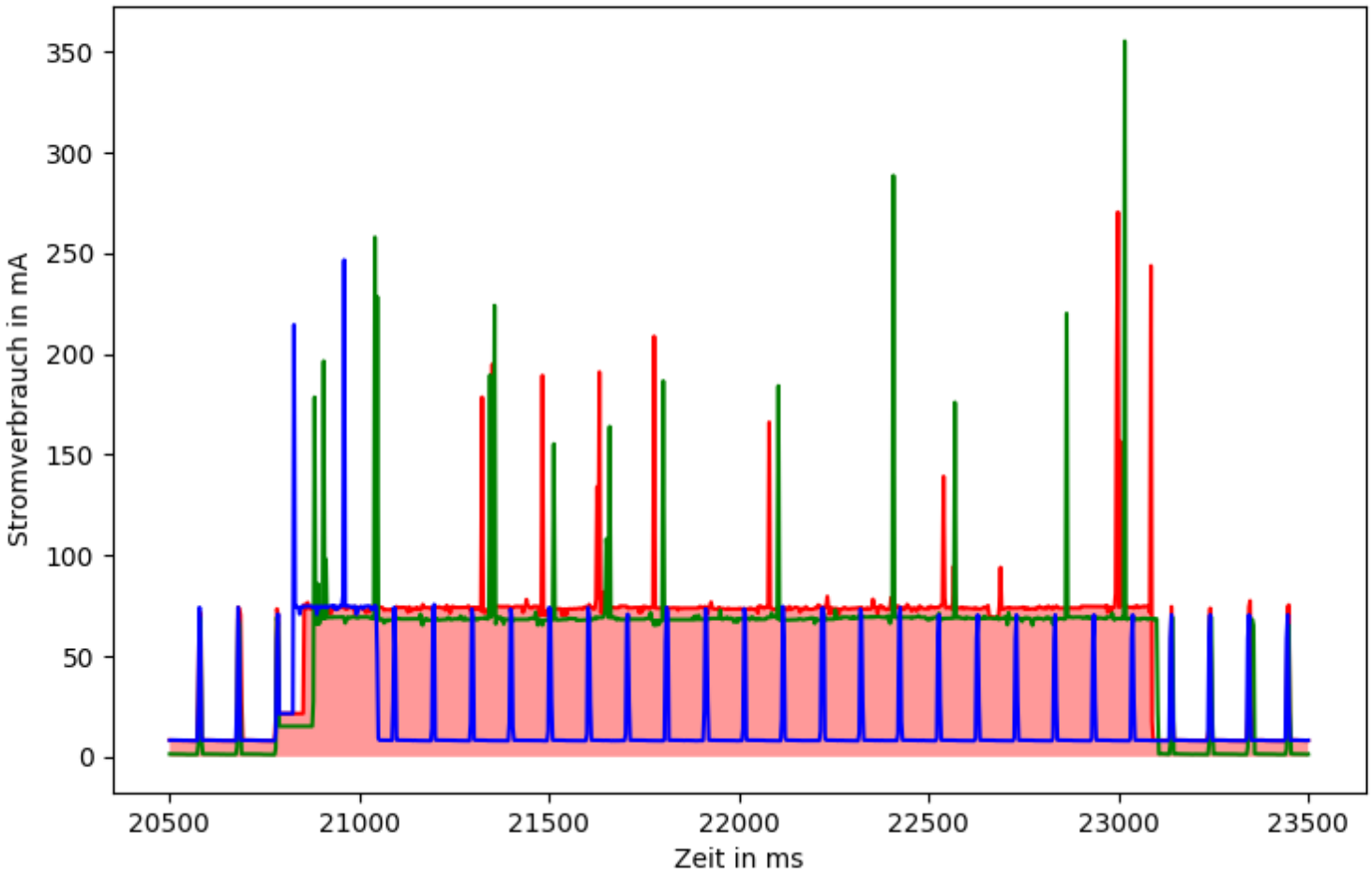
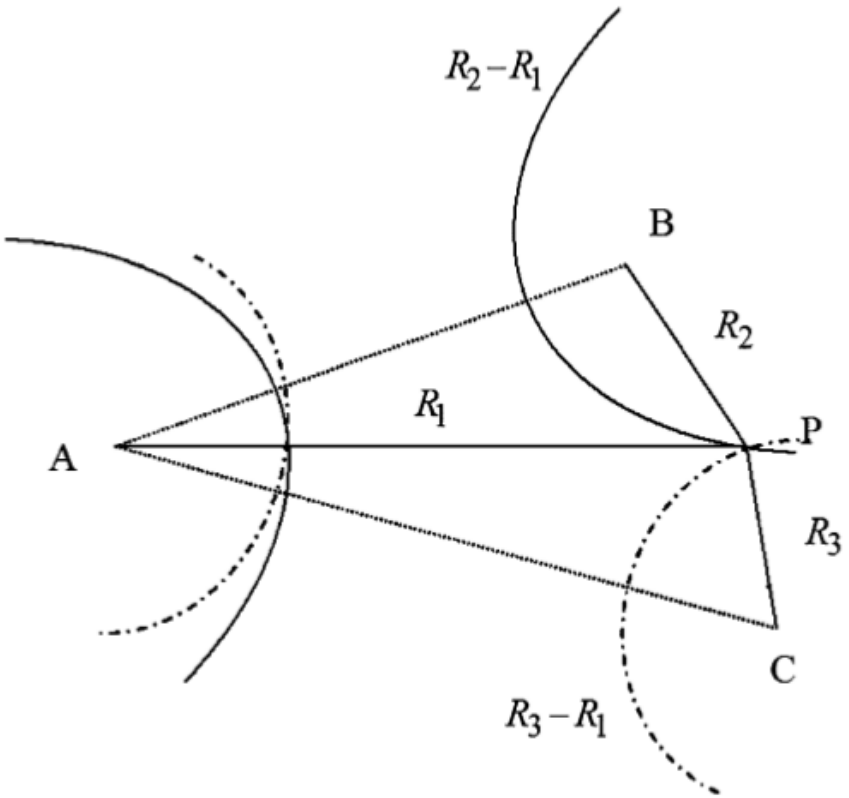
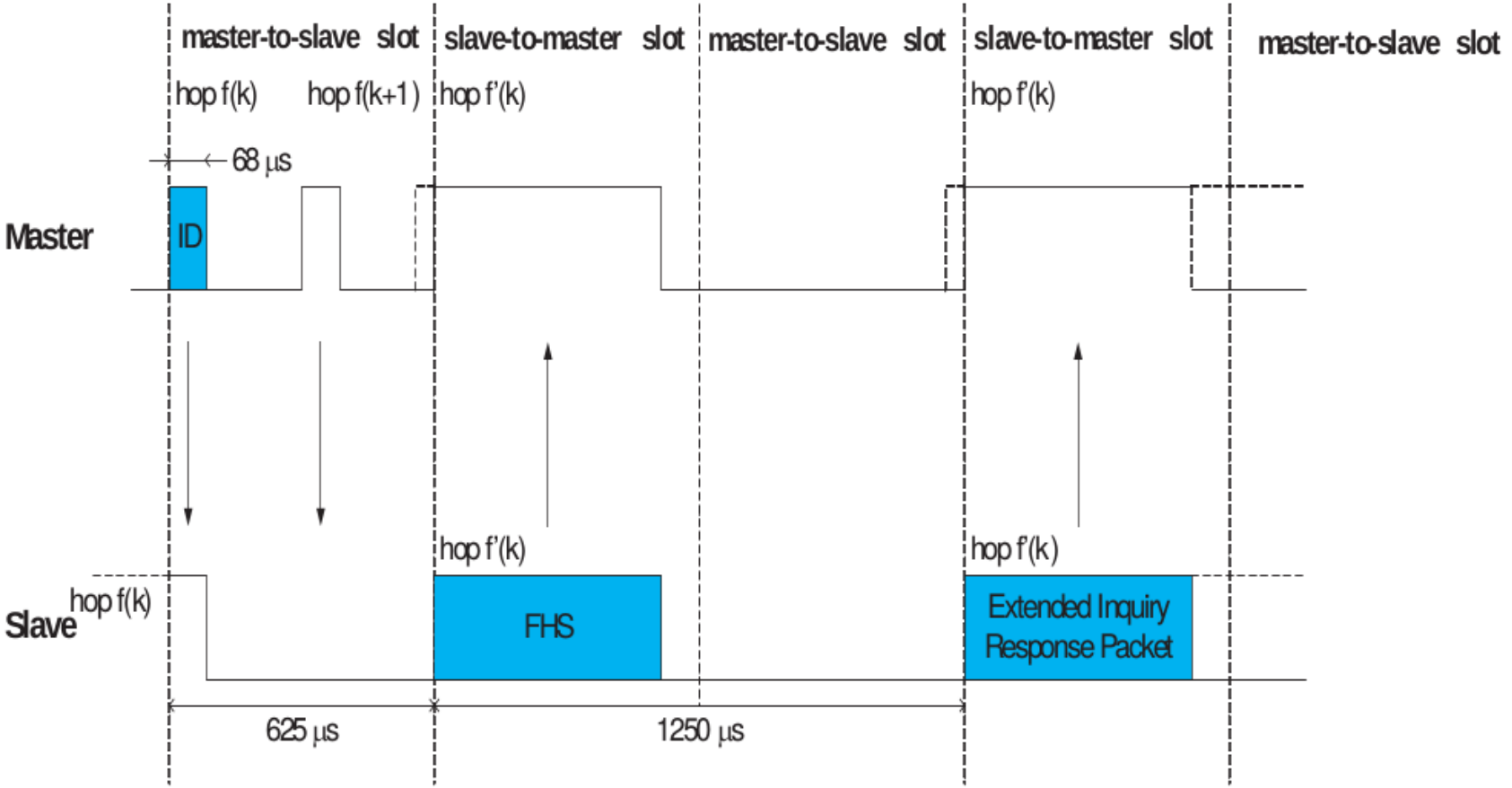


TDOA

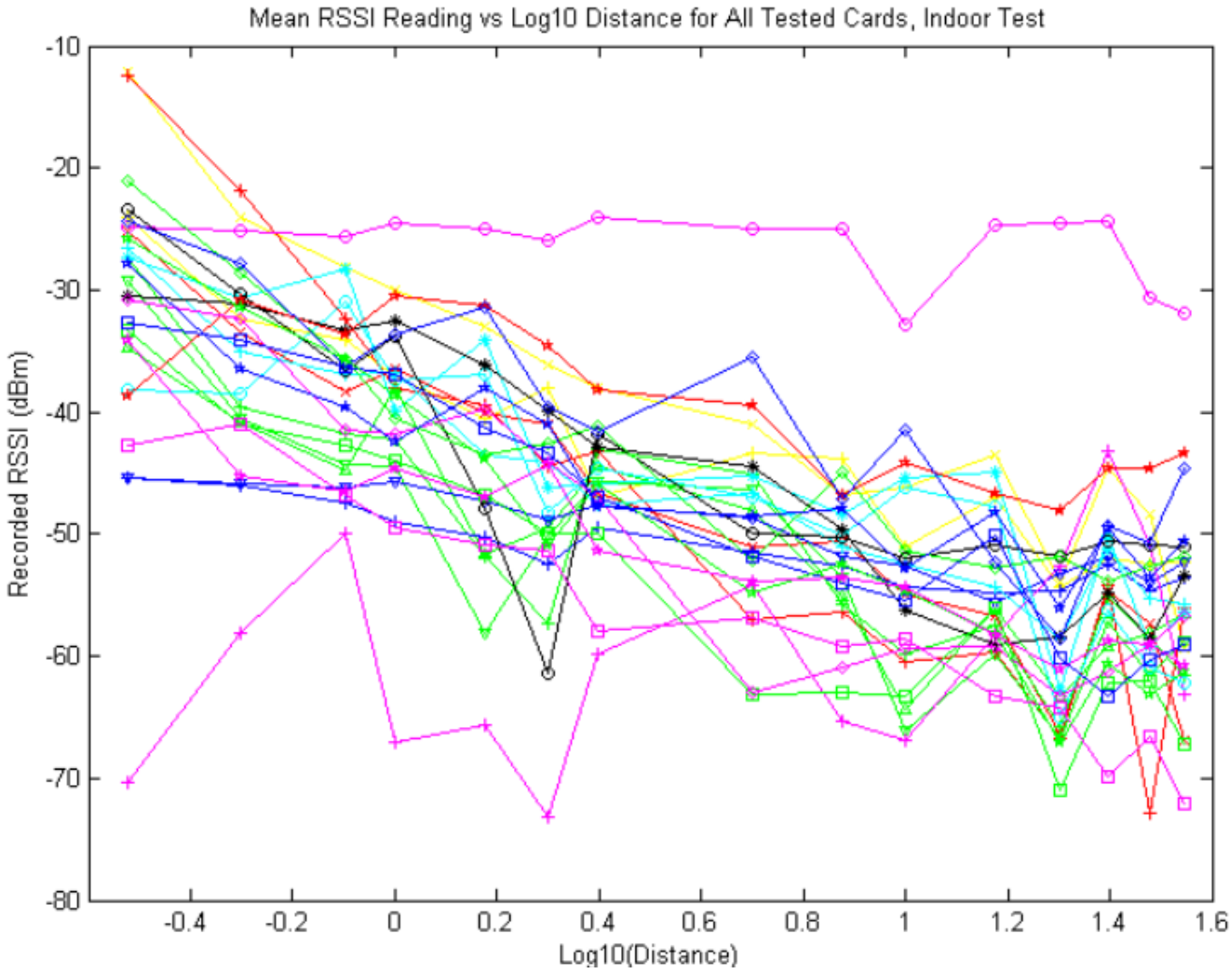


$$R_{i,j} = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} - \sqrt{(x_j - x)^2 + (y_j - y)^2 + (z_j - z)^2}$$

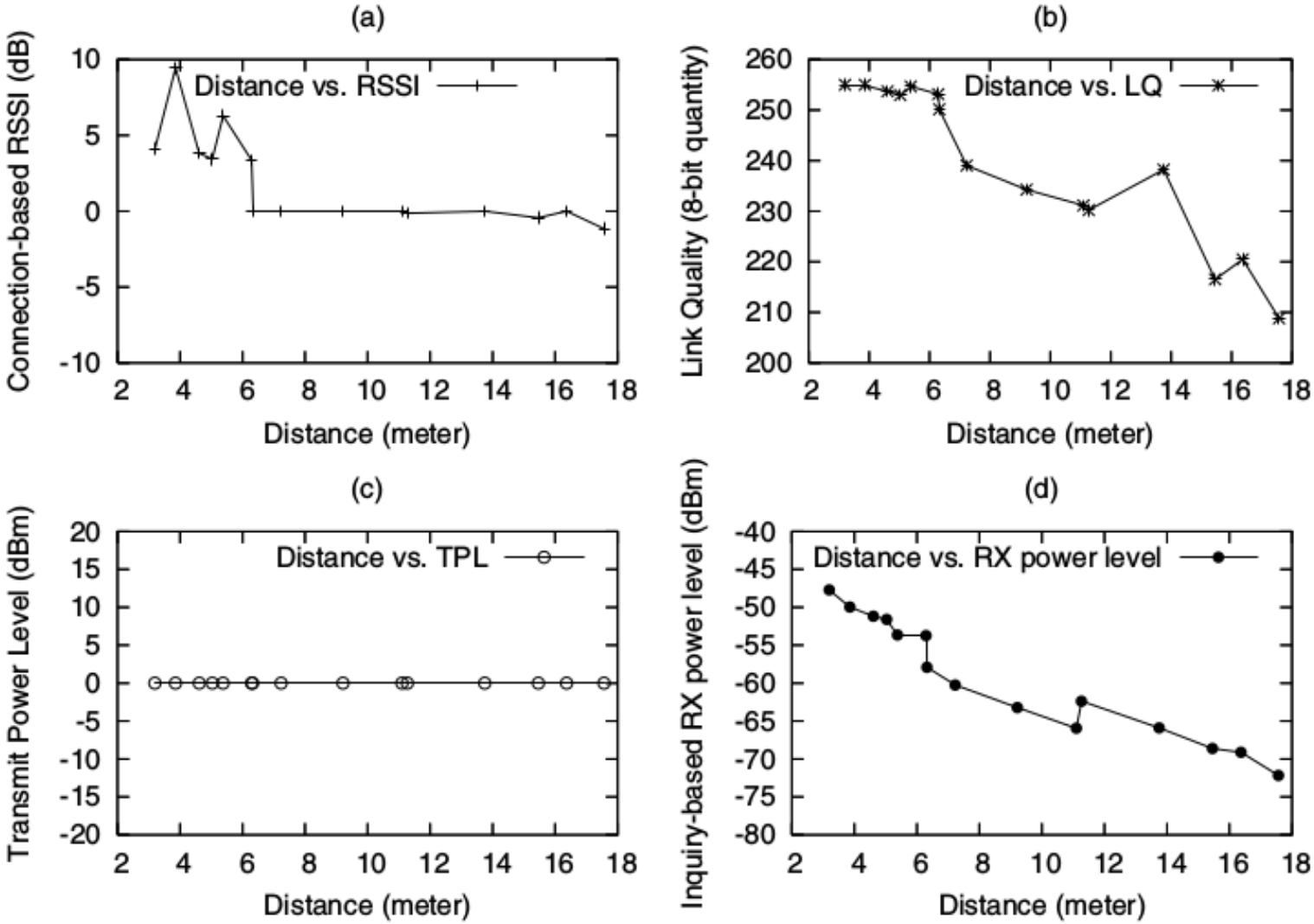
Inquiry Scan



IEEE 802.11 RSSI



Bluetooth Messgrößen



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Parameters	Min	Typical	Max	Unit
Tx802.11b, CCK 11Mbps, P OUT=+17dBm	-	170	-	mA
Tx 802.11g, OFDM 54Mbps, P OUT =+15dBm	-	140	-	mA
Tx 802.11n, MCS7, P OUT =+13dBm	-	120	-	mA
Rx 802.11b, 1024 bytes packet length , -80dBm	-	50	-	mA
Rx 802.11g, 1024 bytes packet length, -70dBm	-	56	-	mA
Rx 802.11n, 1024 bytes packet length, -65dBm	-	56	-	mA
Modem-sleep①	-	15	-	mA
Light-sleep②	-	0.9	-	mA
Deep-sleep③	-	20	-	µA
Power Off	-	0.5	-	µA

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Current consumption: Radio

Symbol	Description	Min.	Typ.	Max.	Units
I_{RADIO_TX0}	0 dBm TX @ 1 Mb/s Bluetooth Low Energy mode, Clock = HFXO		7.1		mA
I_{RADIO_TX1}	-40 dBm TX @ 1 Mb/s Bluetooth Low Energy mode, Clock = HFXO		4.1		mA
I_{RADIO_RX0}	Radio RX @ 1 Mb/s Bluetooth Low Energy mode, Clock = HFXO		6.5		mA

Current consumption: Radio protocol configurations

Symbol	Description	Min.	Typ.	Max.	Units
I_{S0}	CPU running CoreMark from Flash, Radio 0 dBm TX @ 1 Mb/s Bluetooth Low Energy mode, Clock = HFXO, Cache enabled		9.6		mA
I_{S1}	CPU running CoreMark from Flash, Radio RX @ 1 Mb/s Bluetooth Low Energy mode, Clock = HFXO, Cache enabled		9.0		mA

Current consumption: Ultra-low power

Symbol	Description	Min.	Typ.	Max.	Units
$I_{ON\_RAMOFF\_EVENT}$	System ON, No RAM retention, Wake on any event		1.2		µA
$I_{ON\_RAMON\_EVENT}$	System ON, Full RAM retention, Wake on any event		1.5		µA
$I_{ON\_RAMOFF\_RTC}$	System ON, No RAM retention, Wake on RTC		1.9		µA
$I_{OFF\_RAMOFF\_RESET}$	System OFF, No RAM retention, Wake on reset		0.3		µA
$I_{OFF\_RAMOFF\_GPIO}$	System OFF, No RAM retention, Wake on GPIO		1.2		µA
$I_{OFF\_RAMOFF\_LPCOMP}$	System OFF, No RAM retention, Wake on LPCOMP		1.9		µA
$I_{OFF\_RAMOFF\_NFC}$	System OFF, No RAM retention, Wake on NFC field		0.7		µA
$I_{OFF\_RAMON\_RESET}$	System OFF, Full 64 kB RAM retention, Wake on reset		0.7		µA

Literatur

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Symbol	Parameter	Conditions		Min	Typ[1]	Max	Unit
V_{DD}	supply voltage (core and external rail)			1.8	3.3	3.6	V
I_{DD}	supply current	Active mode; code `while(1){}` executed from flash					
		system clock = 12 MHz V_{DD} = 3.3 V	[2][3][4][5][6]	-	2	-	mA
		system clock = 50 MHz V_{DD} = 3.3 V	[2][3][5][6][7]	-	7	-	mA
		Sleep mode; system clock = 12 MHz V_{DD} = 3.3 V	[2][3][4][5][6]	-	1	-	mA
		Deep-sleep mode; V_{DD} = 3.3 V	[2][3][8]	-	2	-	µA

Symbol	Description	Conditions	Min	Typ	Max	Unit
IDDSL	Supply current in Sleep mode		-	0.2	1	uA
IDDIDLE	Supply current in Idle mode	RC oscillator enabled	-	1.5	-	uA
IDDST	Supply current in Standby mode	Crystal oscillator enabled	-	1.6	1.8	mA
IDDFS	Supply current in Synthesizer mode	FSRx	-	5.8	-	mA
IDDR	Supply current in Receive mode	*LnaBoost* Off, higher bands *LnaBoost* On, higher bands Lower bands	- - -	10.8 11.5 12.1	- - -	mA
IDDT	Supply current in Transmit mode with impedance matching	RFOP = +20 dBm, on PA_BOOST RFOP = +17 dBm, on PA_BOOST RFOP = +13 dBm, on RFO_LF/HF pin RFOP = + 7 dBm, on RFO_LF/HF pin	- - - -	120 87 29 20	- - - -	mA mA mA mA