

Zuverlässige funkbasierte Bereichsortung im Tunnelbau

Masterarbeit in Kooperation mit der Ed. Züblin AG

Marius Wodtke | 13. Dezember 2017

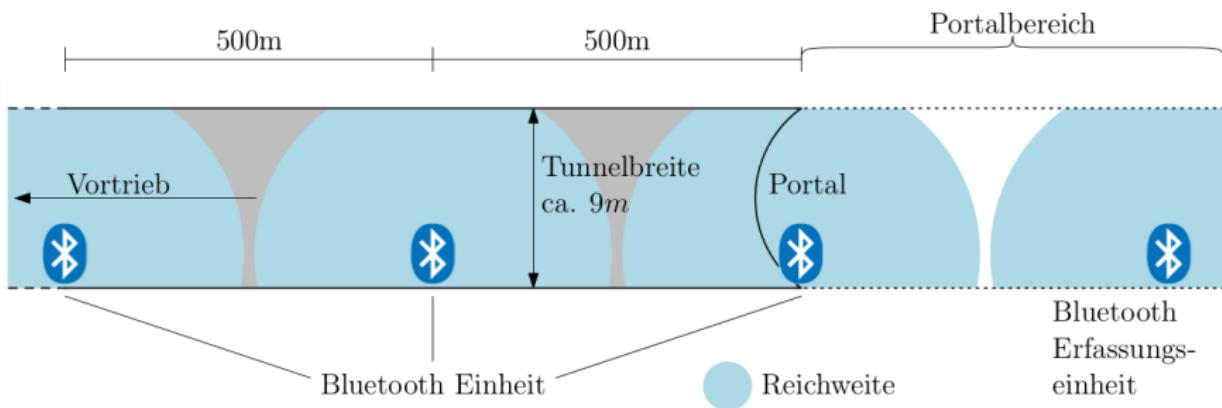
INSTITUT FÜR ANGEWANDTE INFORMATIK UND FORMALE BESCHREIBUNGSVERFAHREN



Gliederung

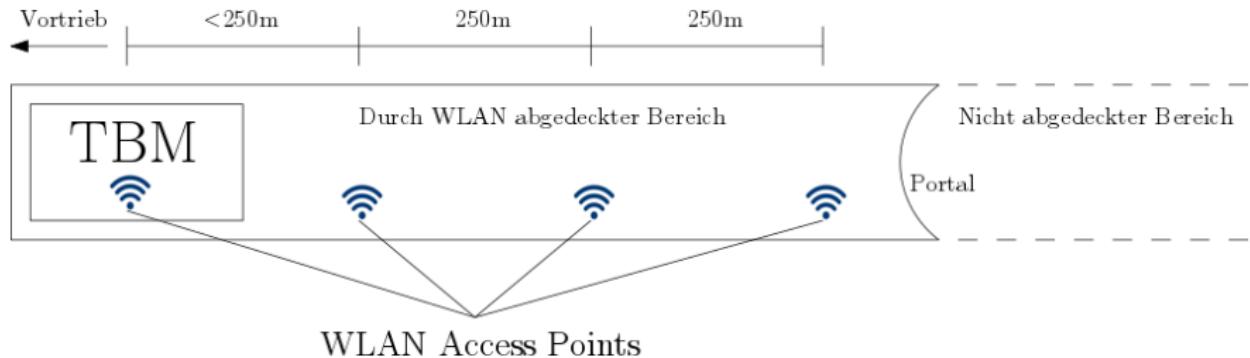
- 1 Motivation
- 2 Grundlagen & Analyse
- 3 Reichweiten
- 4 Implementierungen
 - RADAR
 - WiFi-LLS
 - Assoziations-Lokalisierung
 - Probe-Request-Lokalisierung
 - Bluetooth Low Energy
 - Lokalisierung mit LoRa
- 5 Zusammenfassung
- 6 Fazit

Bisherige Situation



[4]

Zukünftige Situation



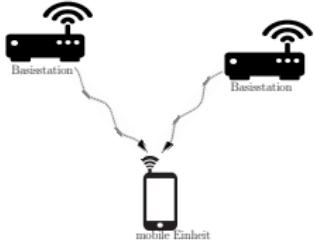
Aufgabe

Zielsetzung

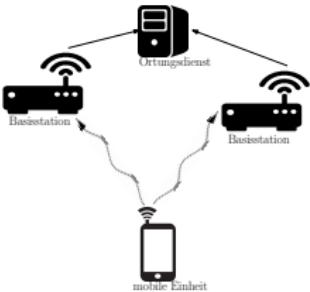
- Funkbasiertes Ortungssystem
- Bereichsortung (250m Abschnitte)

Anforderungen

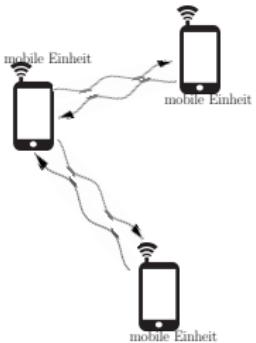
- Nichtintrusiv (Keine Tore, Schranken, ...)
- Zuverlässige Erkennung der Bereichsschsel
- Wenig Interaktion mit mobiler Einheit erforderlich



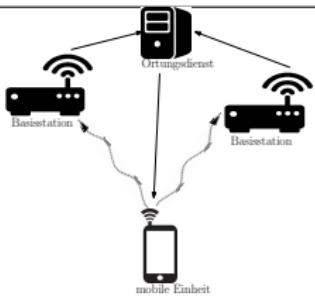
Direkte Selbstlokal.



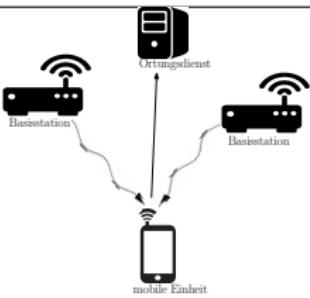
Direkte Fernlokal.



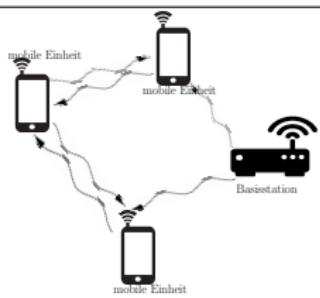
Ohne Basisstation



Indirekte Selbstlokal.

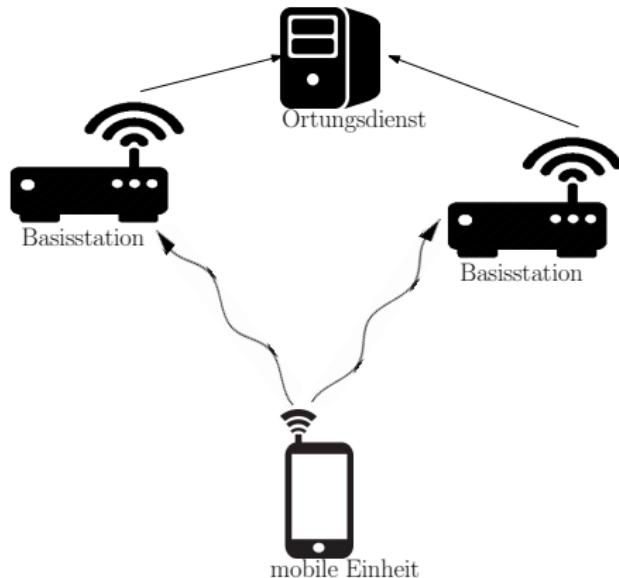


Indirekte Fernlokal.

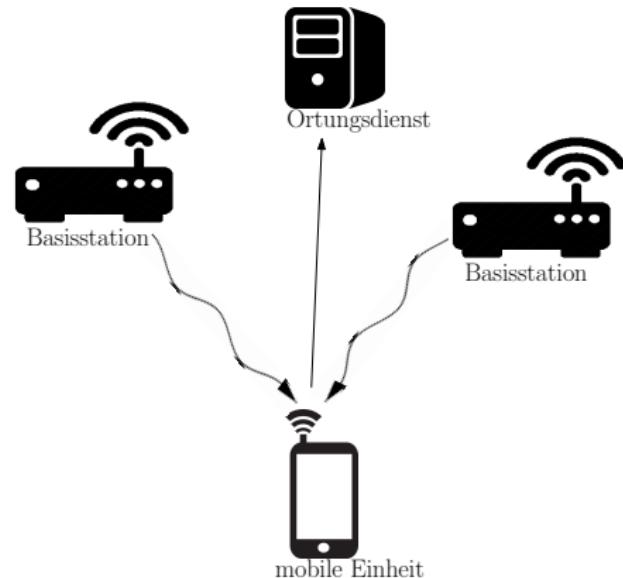


Hybride Topologie

Fernlokalisierung



Direkte Fernlokalisierung



Indirekte Fernlokalisierung

Messgrößen

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

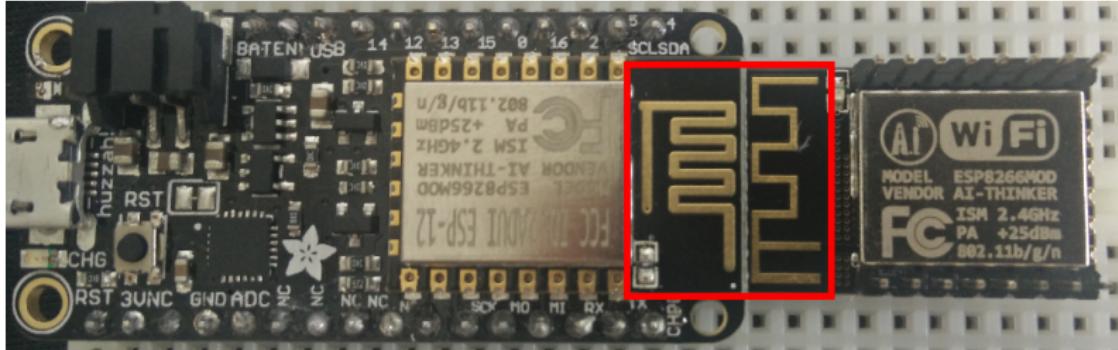
Lokalisierungsprinzip

- Umgebungsprinzip
- Geometrische Bestimmung
- Szenenanalyse

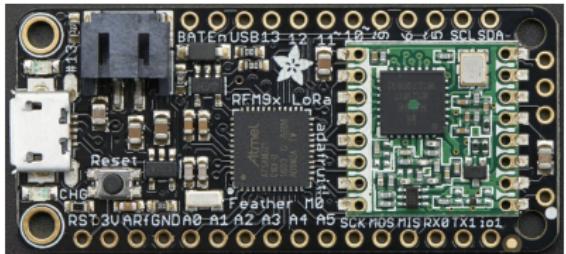
Protokolle

- IEEE 802.11
- Bluetooth (Low Energy)
- Long Range (IEEE 802.15.4g)

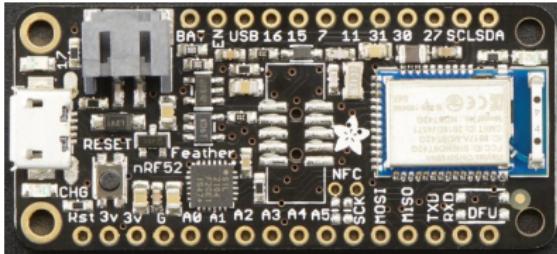
Hardware



Adafruit Feather HUZZAH ESP8266

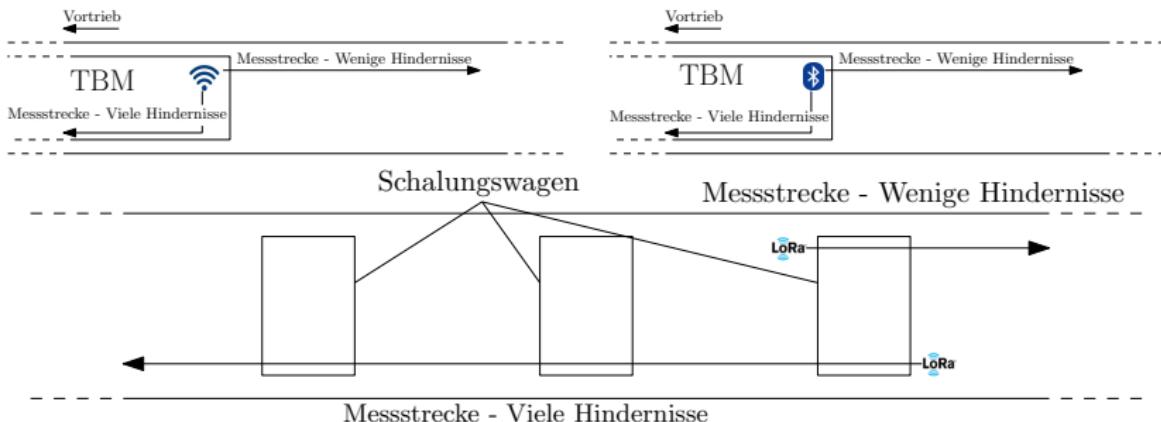


Feather M0 RFM95 LoRa Radio



Feather nRF52 Bluefruit

Reichweiterevaluation - Aufbau



Reichweitenevaluation - Ergebnisse

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

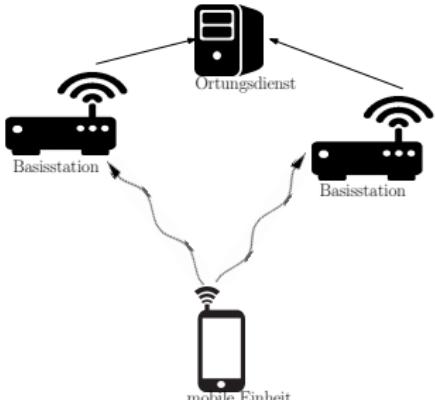
Reichweitenevaluation - Ergebnisse

Protokoll	Strecke	Reichweite
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RADAR

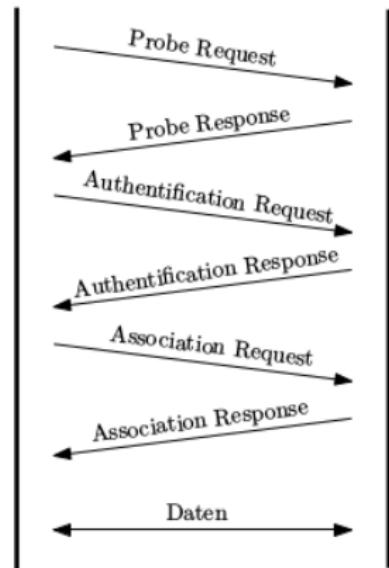
RADAR

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

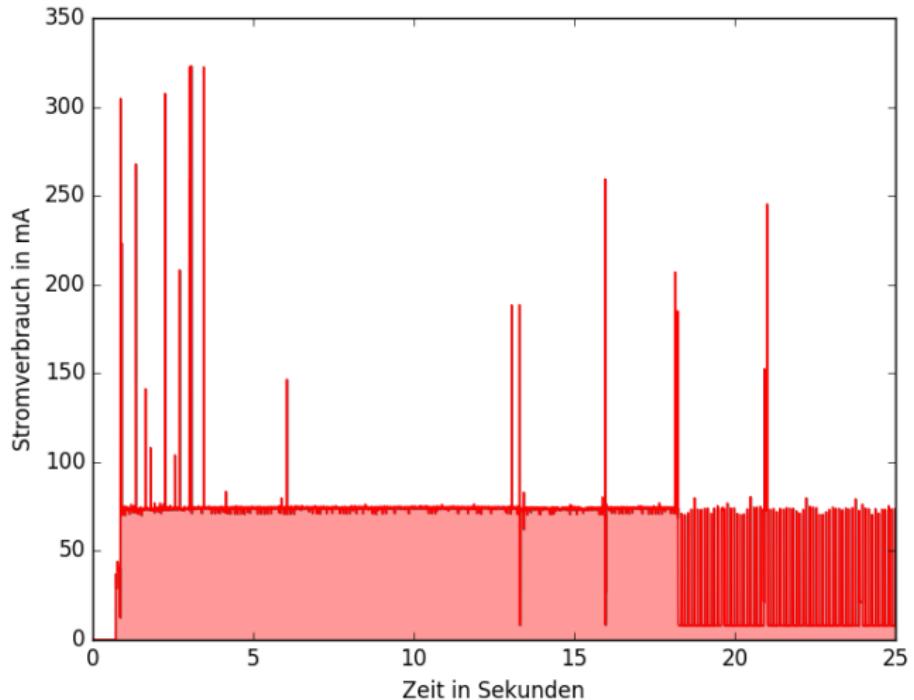


mobile Einheit

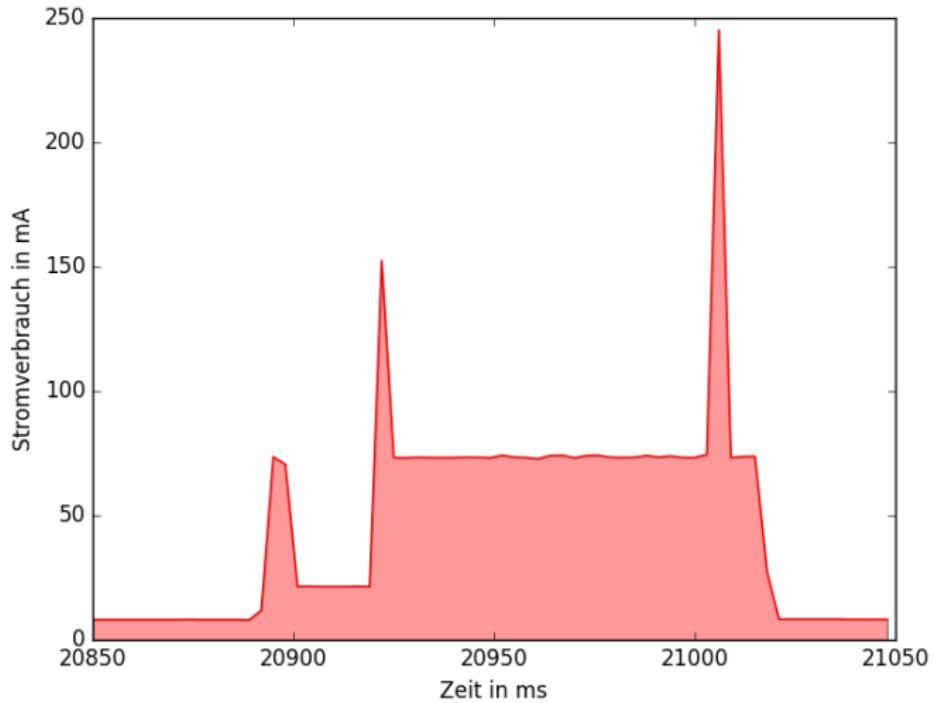
Access Point 1



Stromverbrauch - RADAR

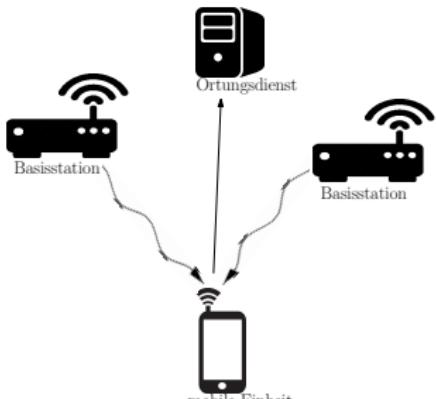


Stromverbrauch - RADAR



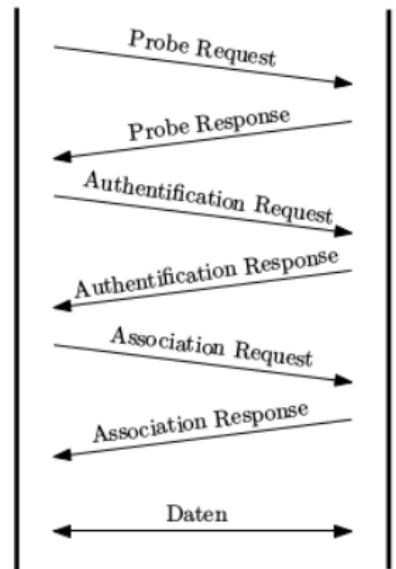
WiFi-LLS

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

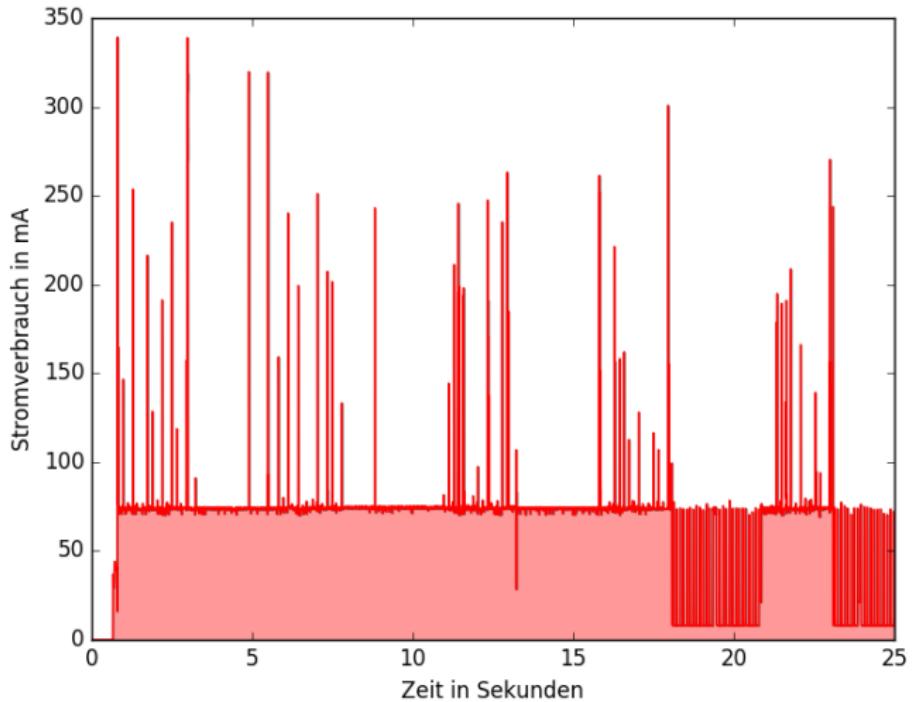


mobile Einheit

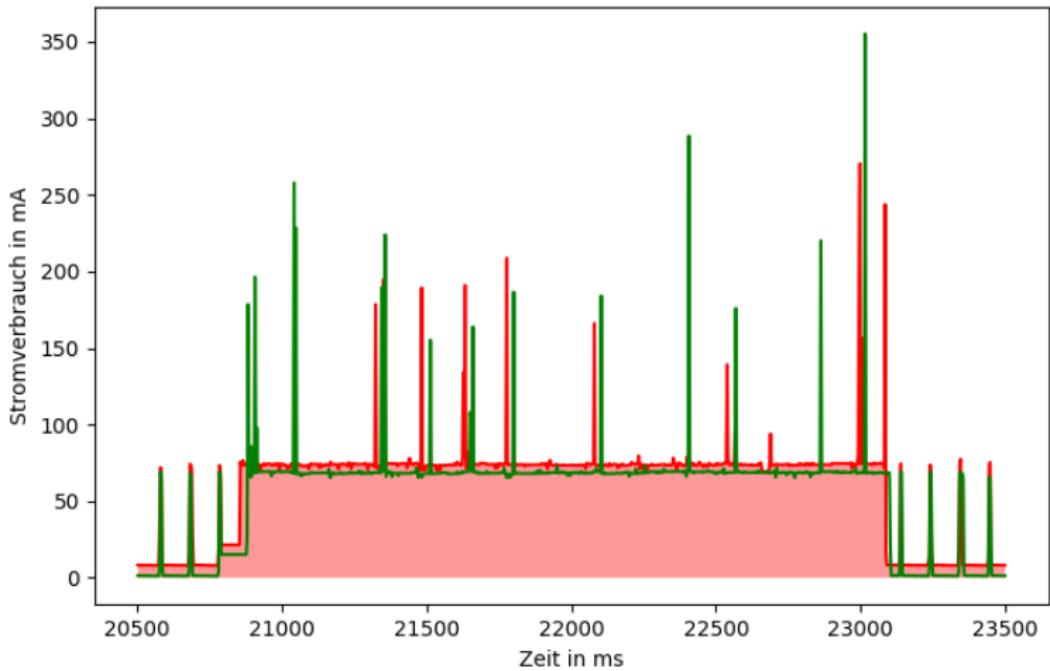
Access Point 1



Stromverbrauch - WiFi-LLS



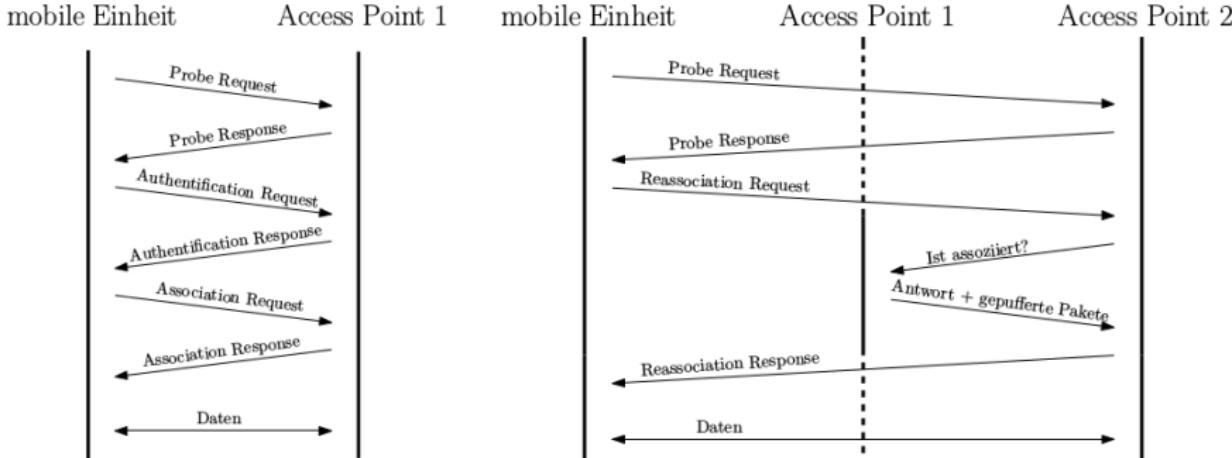
Stromverbrauch - WiFi-LLS



Stromverbrauch - Ergebnisse

Protokoll	Modul	Programm	Ø Verbrauch in mA (normalisiert)
IEEE 802.11	<i>ESP8266 Feather</i>	<i>RADAR</i>	16,70 (8,60)
IEEE 802.11	<i>ESP-12F</i>	<i>RADAR</i>	10,10 (8,80)
IEEE 802.11	<i>ESP8266 Feather</i>	<i>WiFi-LLS</i>	42,20 (34,10)
IEEE 802.11	<i>ESP-12F</i>	<i>WiFi-LLS</i>	36,50 (35,20)

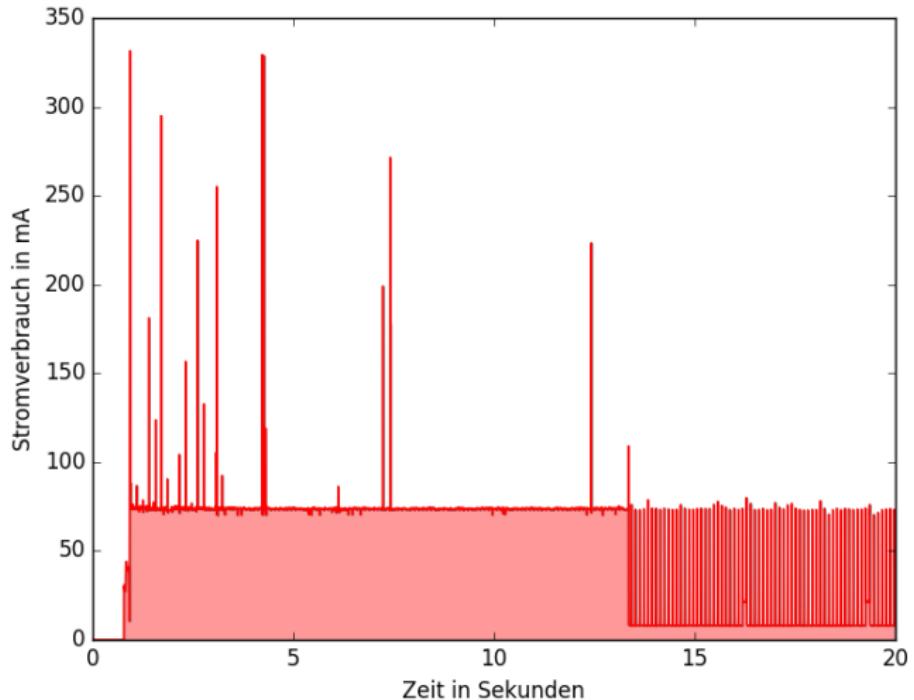
Assoziations-Lokalisierung



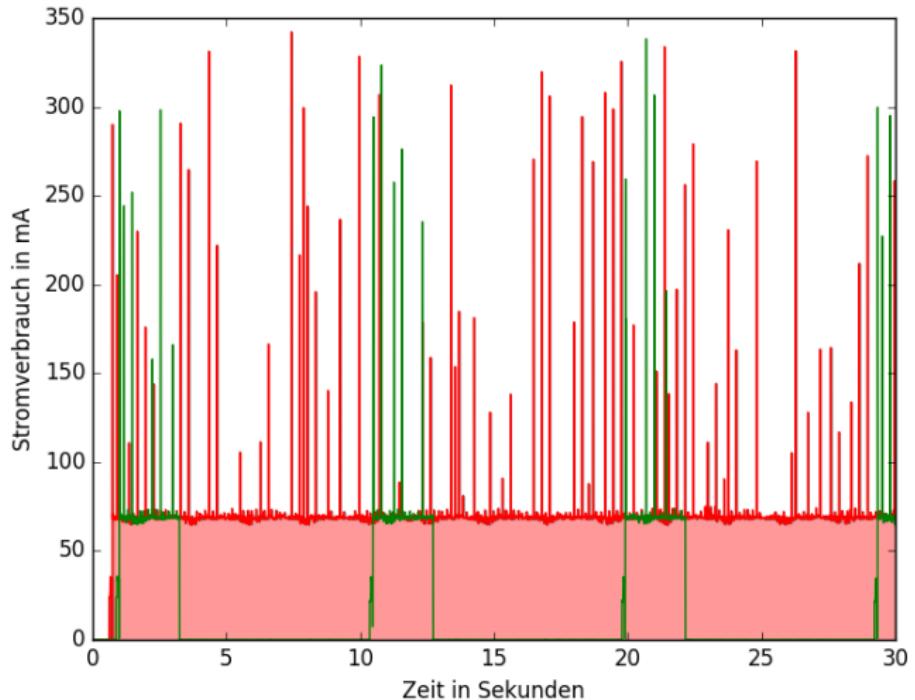
Assoziations-Lokalisierung

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

Stromverbrauch - Assoziations-Lok.



Stromverbrauch - Assoziations-Lok.



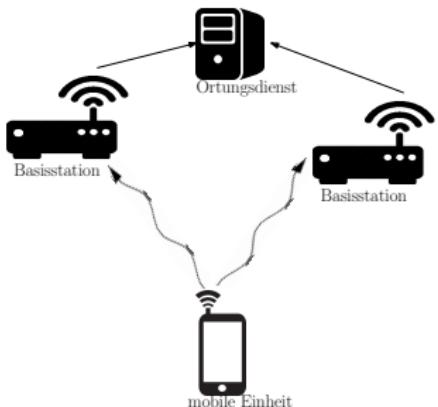
Stromverbrauch - Ergebnisse

Protokoll	Modul	Programm	\emptyset Verbrauch in mA (normalisiert)
IEEE 802.11	<i>ESP8266 Feather</i>	<i>RADAR</i>	16,70 (8,60)
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IEEE 802.11	<i>ESP8266 Feather</i>	<i>WiFi-LLS</i>	42,20 (34,10)
IEEE 802.11	<i>ESP-12F</i>	<i>WiFi-LLS</i>	36,50 (35,20)
IEEE 802.11	<i>ESP-12F</i>	<i>Assoziations- Lokalisierung</i>	8,80 (7,50)
IEEE 802.11	<i>ESP-12F</i>	<i>Assoziations- Lokalisierung</i> (kein <i>Access Point</i>)	17,10 (17,10)

Probe-Request-Lokalisierung

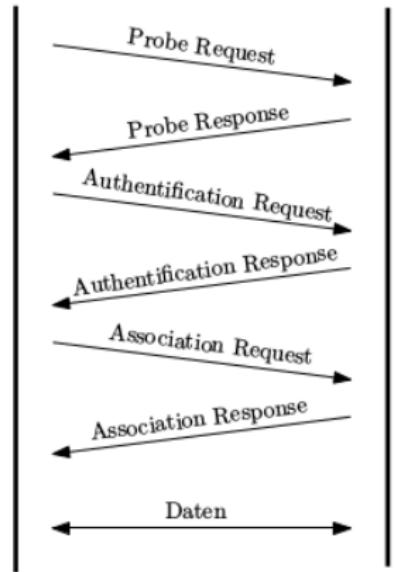
Probe-Request-Lokalisierung

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

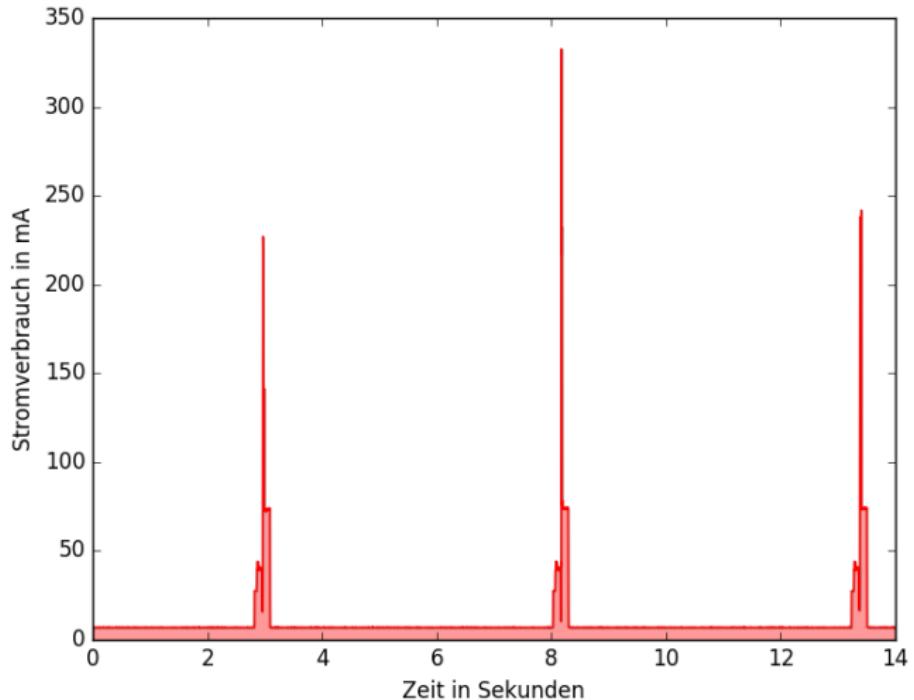


mobile Einheit

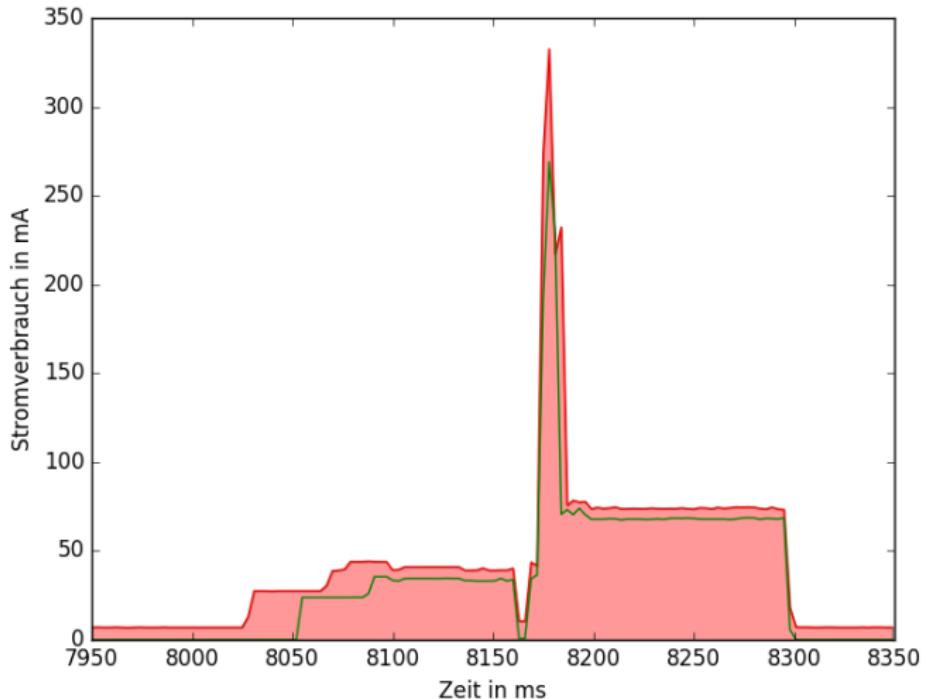
Access Point 1



Stromverbrauch - Probe-Request-Lok.



Stromverbrauch - Probe-Request-Lok.



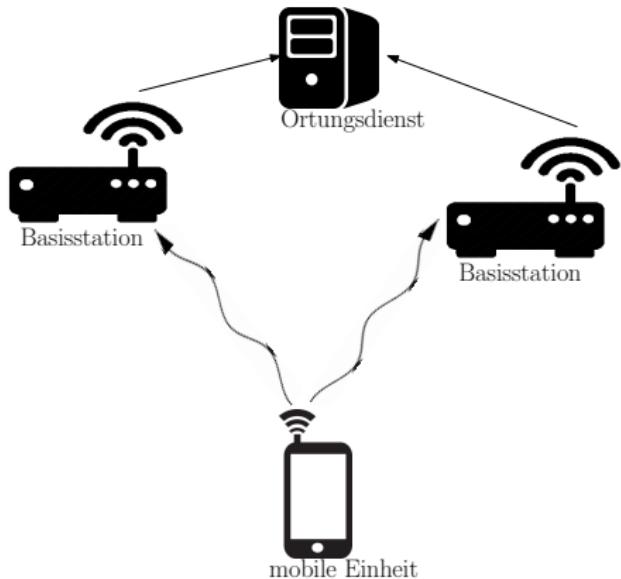
Stromverbrauch - Ergebnisse

Protokoll	Modul	Programm	\emptyset Verbrauch in mA (normalisiert)
IEEE 802.11	<i>ESP-12F</i>	<i>Assoziations-Lokalisierung</i>	8,80 (7,50)
IEEE 802.11	<i>ESP-12F</i>	<i>Assoziations-Lokalisierung</i> (kein Access Point)	17,10 (17,10)
IEEE 802.11	<i>ESP8266 Feather</i>	<i>Probe-Request-Lokalisierung</i>	9,70 (2,70)
IEEE 802.11	<i>ESP-12F</i>	<i>Probe-Request-Lokalisierung</i>	1,80 (1,80)

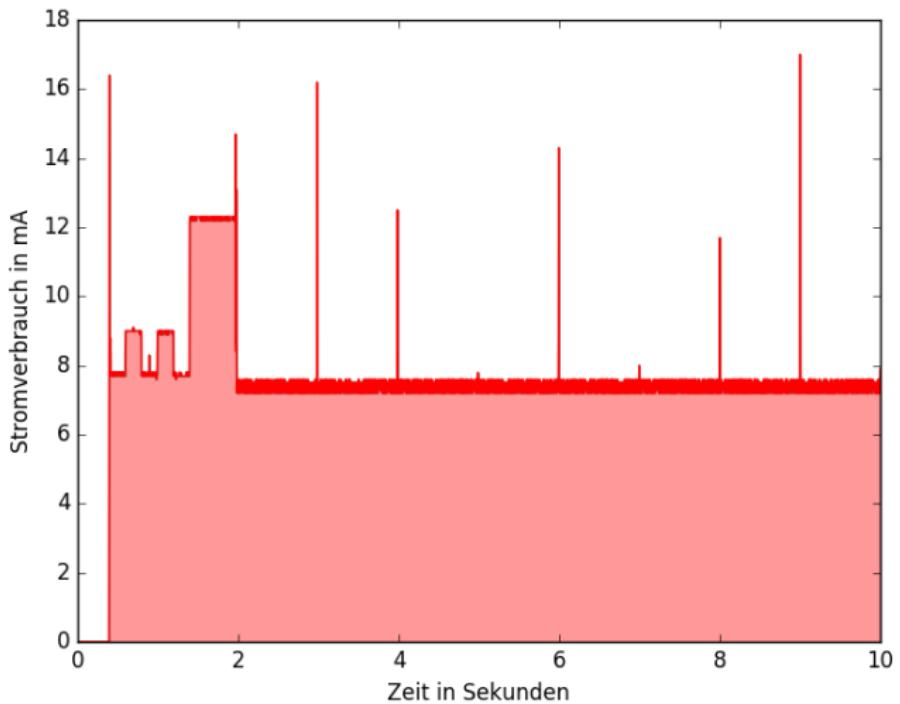
Bluetooth Low Energy

BLE-Advertising

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



Stromverbrauch - BLE-Advertising



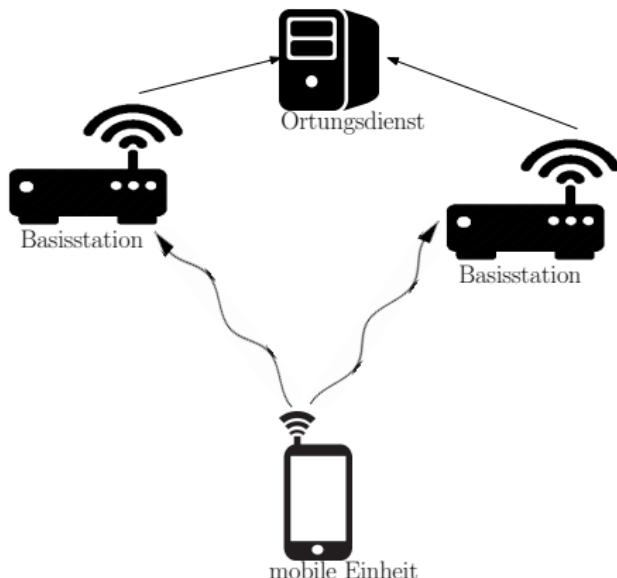
Stromverbrauch - Ergebnisse

Protokoll	Modul	Programm	Ø Verbrauch in mA (normalisiert)
IEEE 802.11	<i>ESP8266 Feather</i>	<i>Probe-Request-Lokalisierung</i>	9,70 (2,70)
IEEE 802.11	<i>ESP-12F</i>	<i>Probe-Request-Lokalisierung</i>	1,80 (1,80)
BLE	<i>nRF52 Feather</i>	Ortung mit <i>BLE-Advertising</i>	7,37 (0,04)

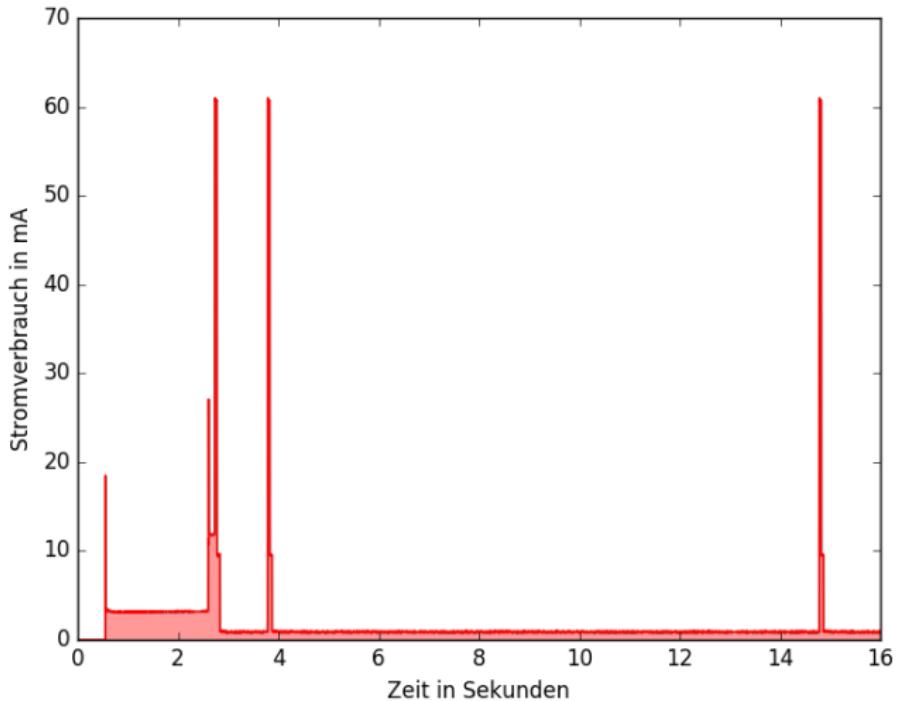
Lokalisierung mit LoRa

Lokalisierung mit LoRa

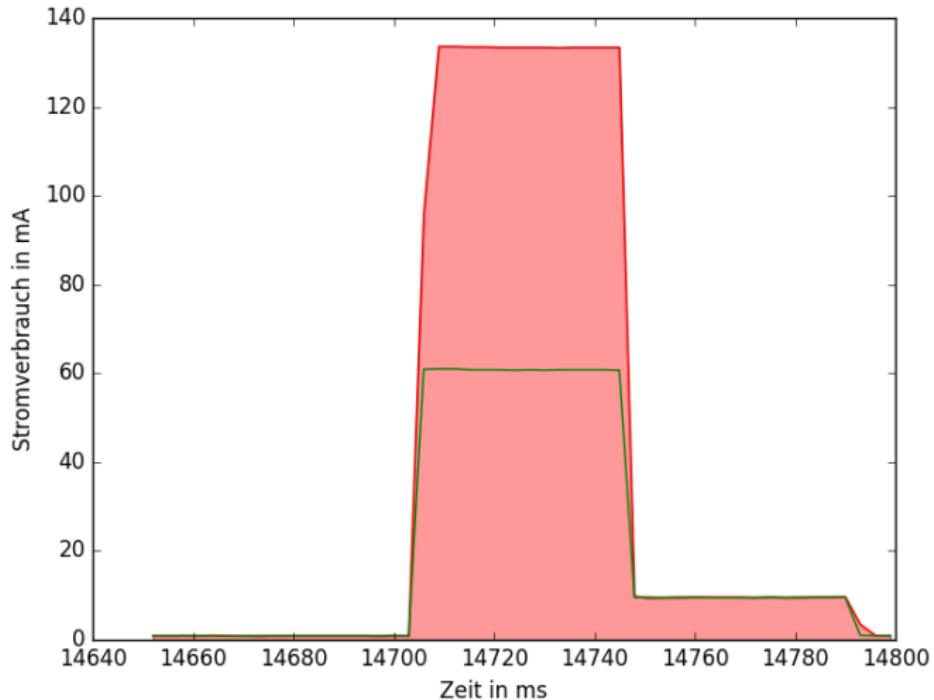
- Direkte Fernlokalisierung
- RSSI an Basisstation
gemessen
- Geometrische Bestimmung



Stromverbrauch - LoRa



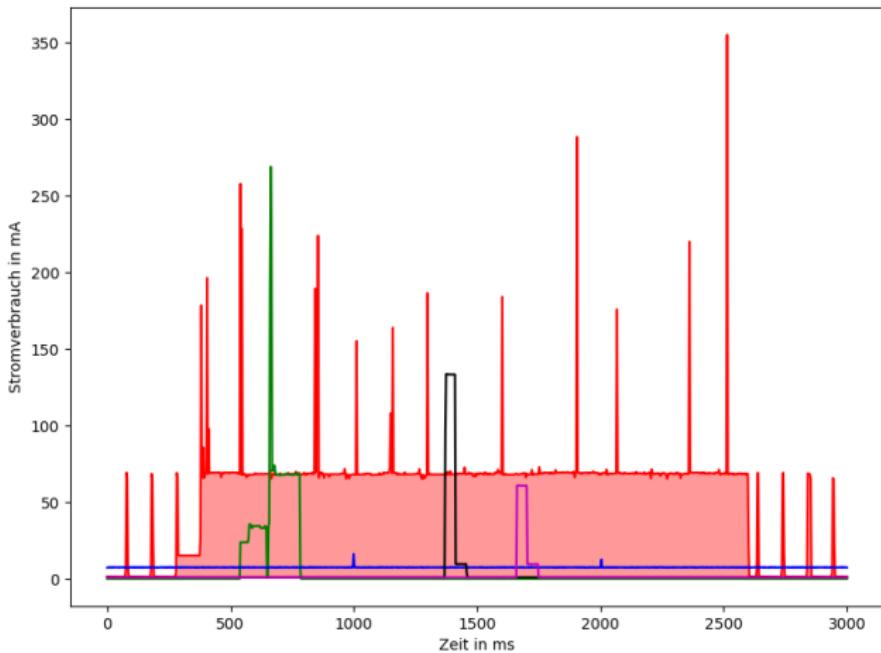
Stromverbrauch - LoRa



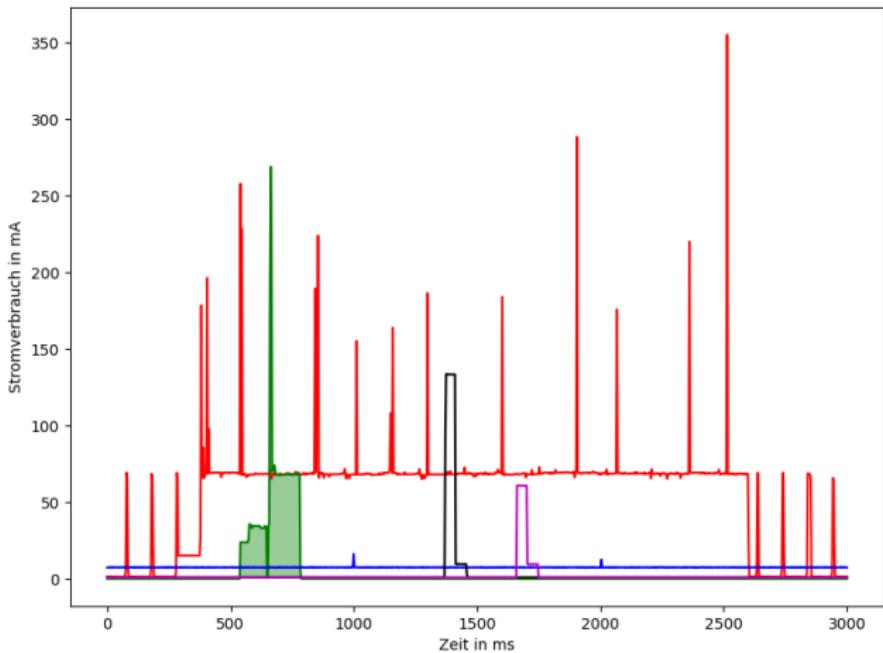
Stromverbrauch - Ergebnisse

Protokoll	Modul	Programm	Ø Verbrauch in mA (normalisiert)
IEEE 802.11	<i>ESP-12F</i>	<i>Probe-Request-Lokalisierung</i>	1,80 (1,80)
BLE	<i>nRF52 Feather</i>	Ortung mit <i>BLE-Advertising</i>	7,37 (0,04)
LoRa	<i>RFM95 Feather</i> 5 dBm	Ortung mit LoRa RSSI	1,20 (0,30)
LoRa	<i>RFM95 Feather</i> 23 dBm	Ortung mit LoRa RSSI	1,47 (0,57)

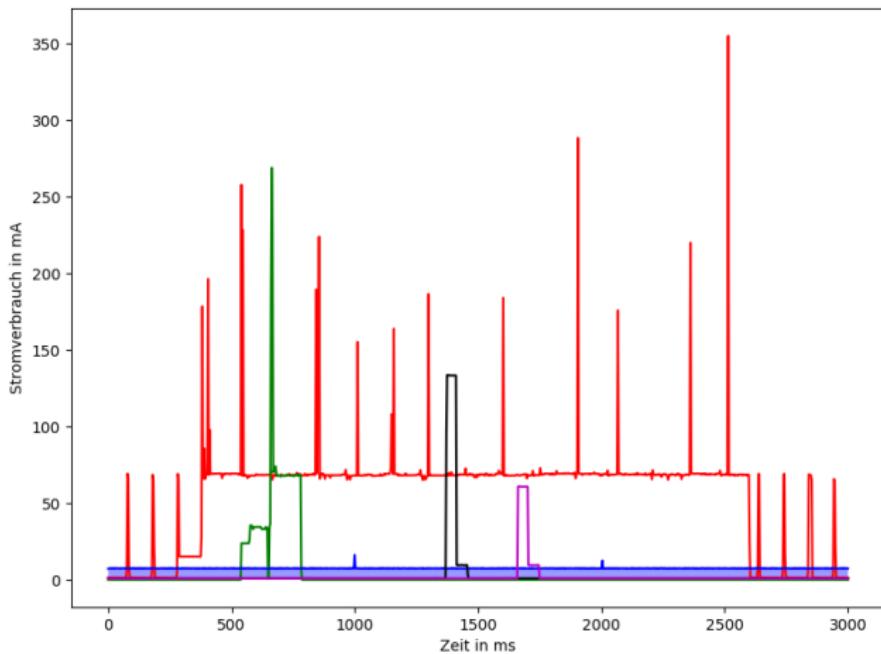
Stromverbrauch - Vergleich



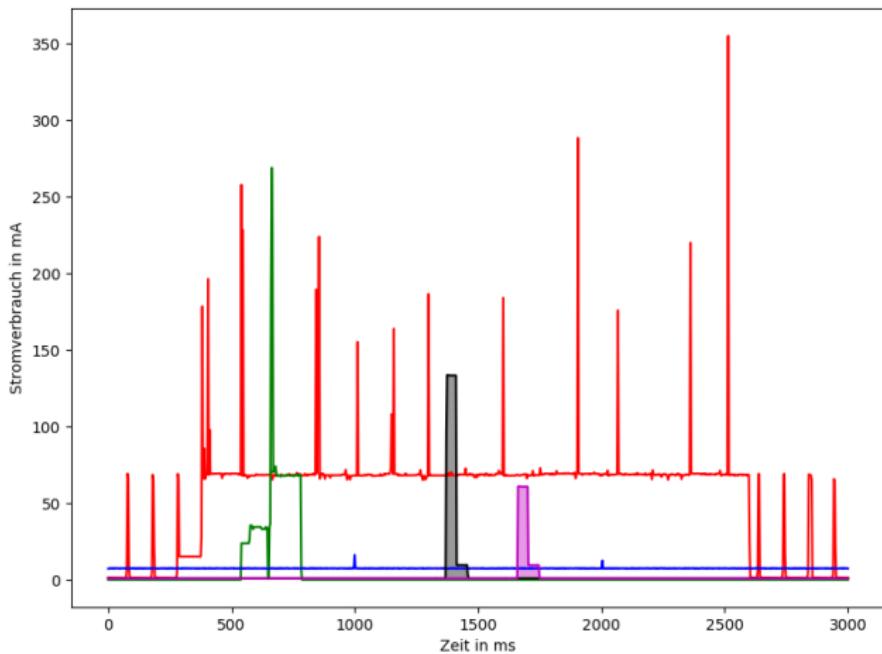
Stromverbrauch - Vergleich



Stromverbrauch - Vergleich



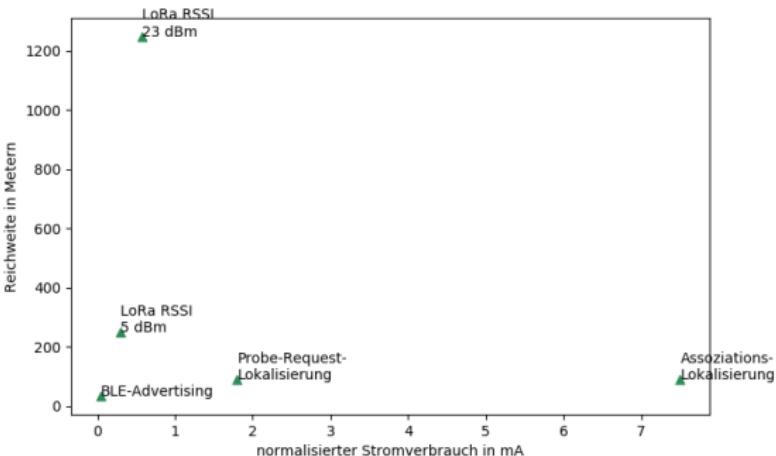
Stromverbrauch - Vergleich



Stromverbrauch - Ergebnisse

Protokoll	Modul	Programm	Ø Verbrauch in mA (normalisiert)
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IEEE 802.11	<i>ESP-12F</i>	<i>WiFi-LLS</i>	36,50 (35,20)
IEEE 802.11	<i>ESP-12F</i>	<i>Assoziations-Lokalisierung</i>	8,80 (7,50)
IEEE 802.11	<i>ESP-12F</i>	<i>Assoziations-Lokalisierung</i> (kein Access Point)	17,10 (17,10)
IEEE 802.11	<i>ESP-12F</i>	<i>Probe-Request-Lokalisierung</i>	1,80 (1,80)
BLE	<i>nRF52 Feather</i>	Ortung mit <i>BLE-Advertising</i>	7,37 (0,04)
LoRa	<i>RFM95 Feather 5 dBm</i>	Ortung mit LoRa RSSI	1,20 (0,30)





Konklusion

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

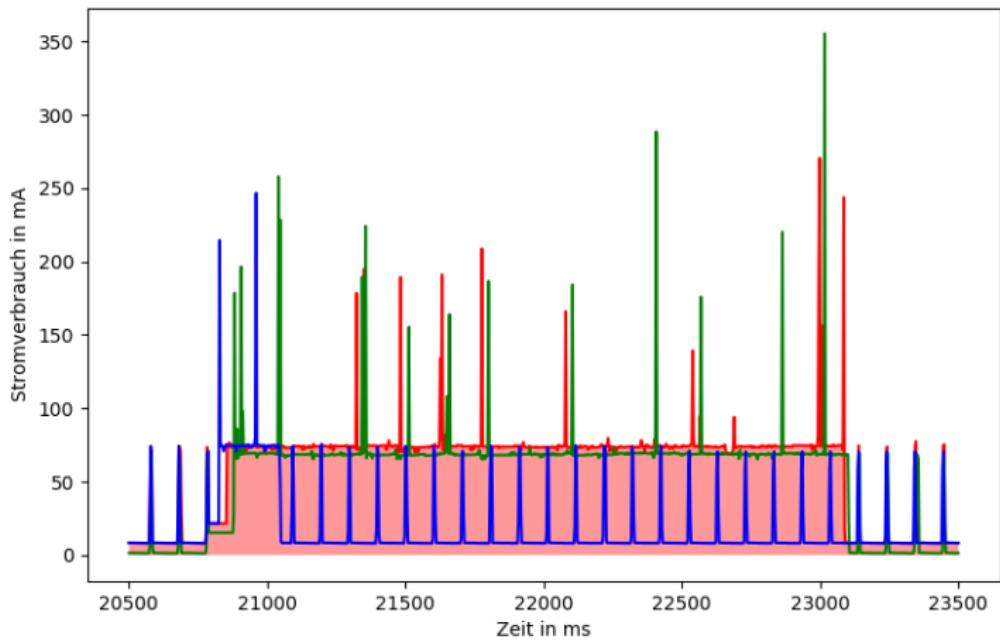
References I

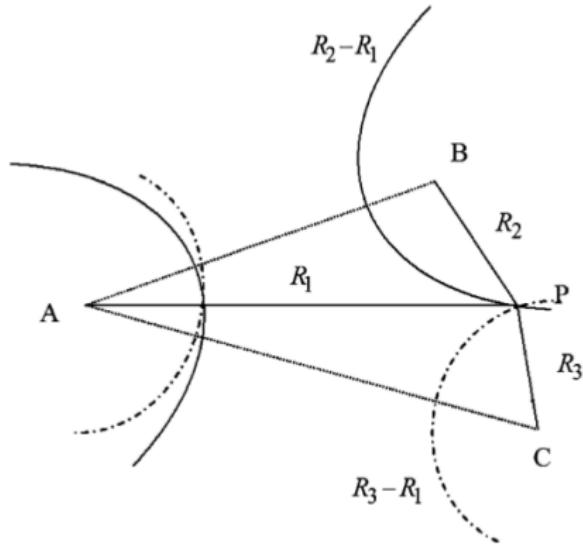
- [1] Paramvir Bahl und Venkata N Padmanabhan. "RADAR: An in-building RF-based user location and tracking system". In: *INFOCOM 2000. Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE*. Bd. 2. ieee. 2000, S. 775–784.
- [2] Yibo Chen und Rong Luo.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

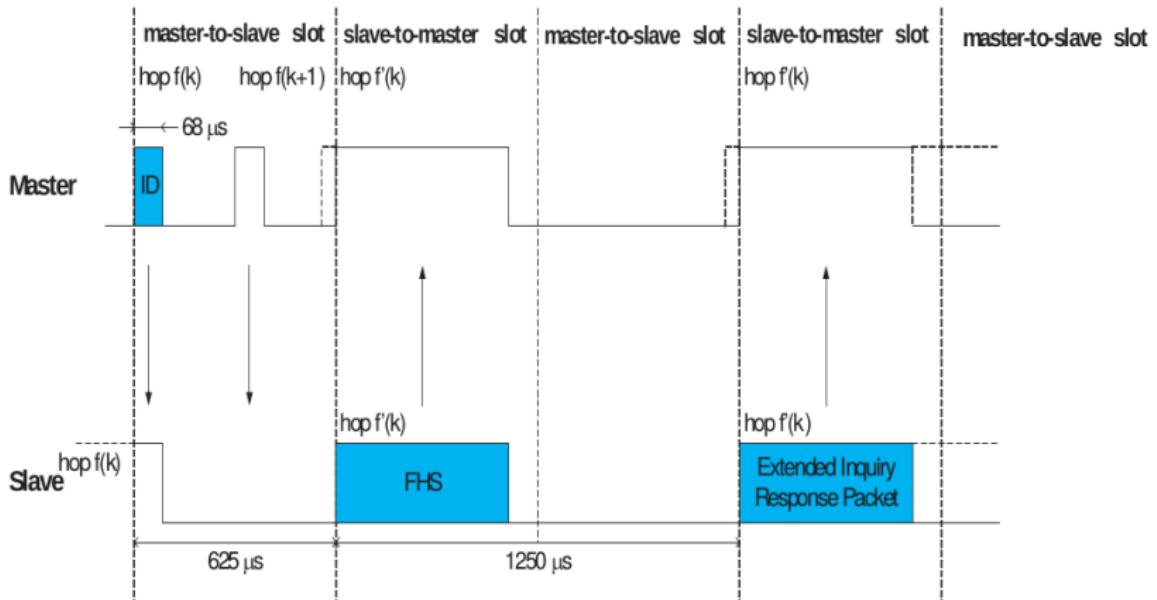
ESP8266 Verbrauch





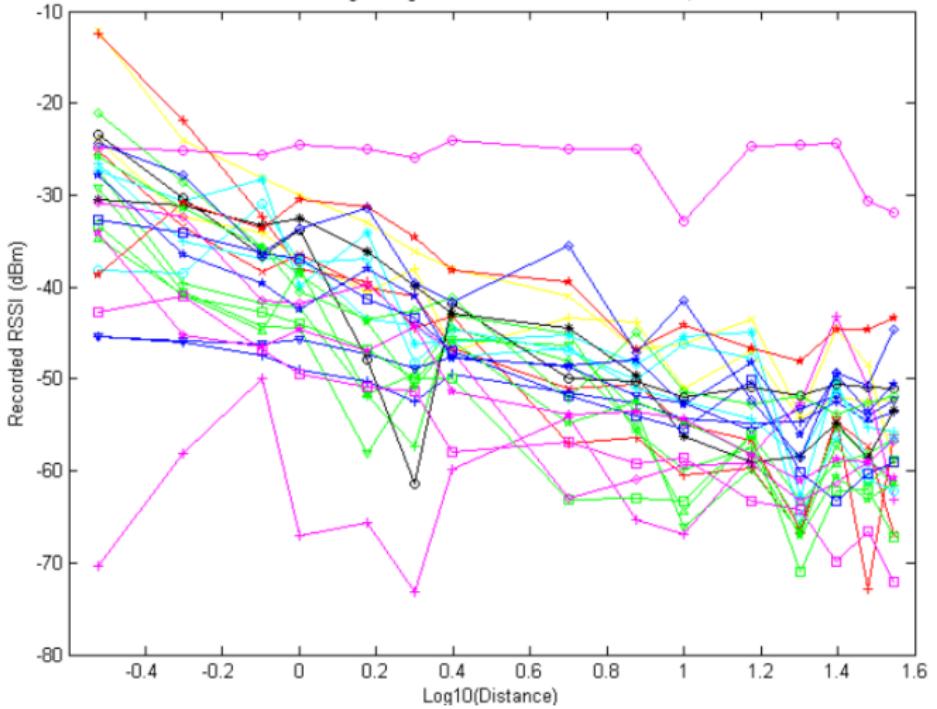
$$R_{i,j} = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} - \sqrt{(x_j - x)^2 + (y_j - y)^2 + (z_j - z)^2}$$

Inquiry Scan

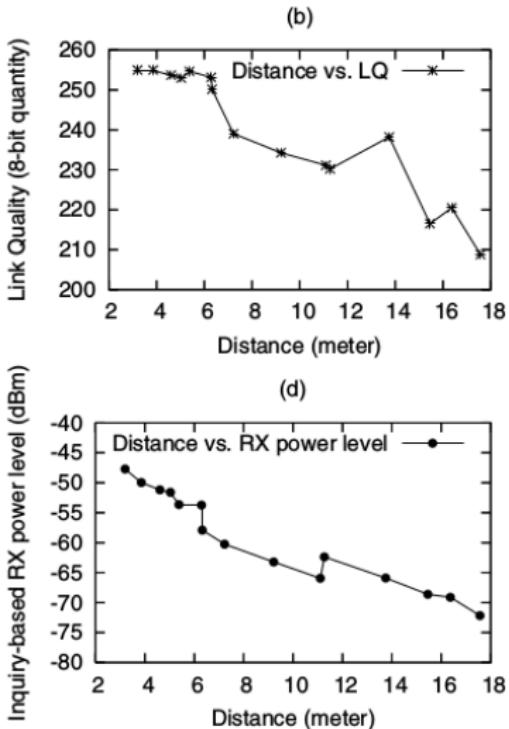
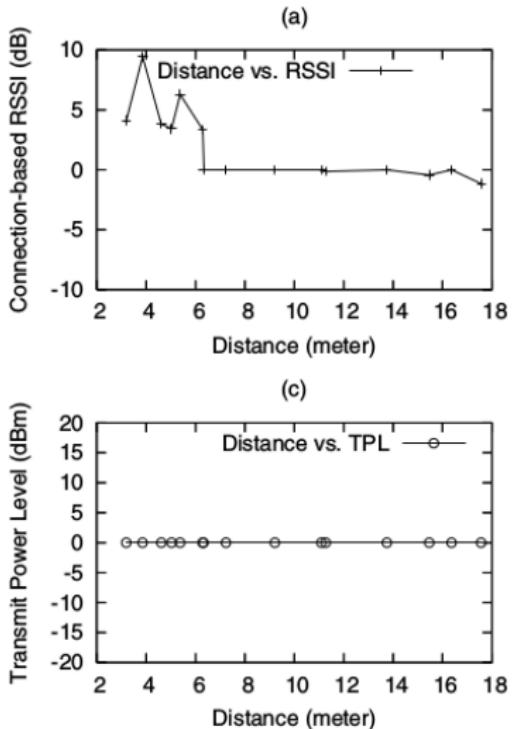


IEEE 802.11 RSSI

Mean RSSI Reading vs Log10 Distance for All Tested Cards, Indoor Test



Bluetooth Messgrößen



ESP8266 Verbrauch

Parameters	Min	Typical	Max	Unit
Tx 802.11b, 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-sleep ^①	-	15	-	mA
Light-sleep ^②	-	0.9	-	mA
Deep-sleep ^③	-	20	-	µA
Power Off	-	0.5	-	µA

nRF52 Verbrauch

Current consumption: Radio

Symbol	Description	Min.	Typ.	Max.	Units
I_{RADIO_TXD}	0 dBm TX @ 1 Mb/s Bluetooth Low Energy mode, Clock = HFXO	7.1			mA
I_{RADIO_TXI}	-40 dBm TX @ 1 Mb/s Bluetooth Low Energy mode, Clock = HFXO	4.1			mA
I_{RADIO_RXD}	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

M0/RFM95 Verbrauch

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] [5][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