

# Zuverlässige funkbasierte Bereichsortung im Tunnelbau

Masterarbeit in Kooperation mit der Ed. Züblin AG

Marius Wodtke | 30. November 2017

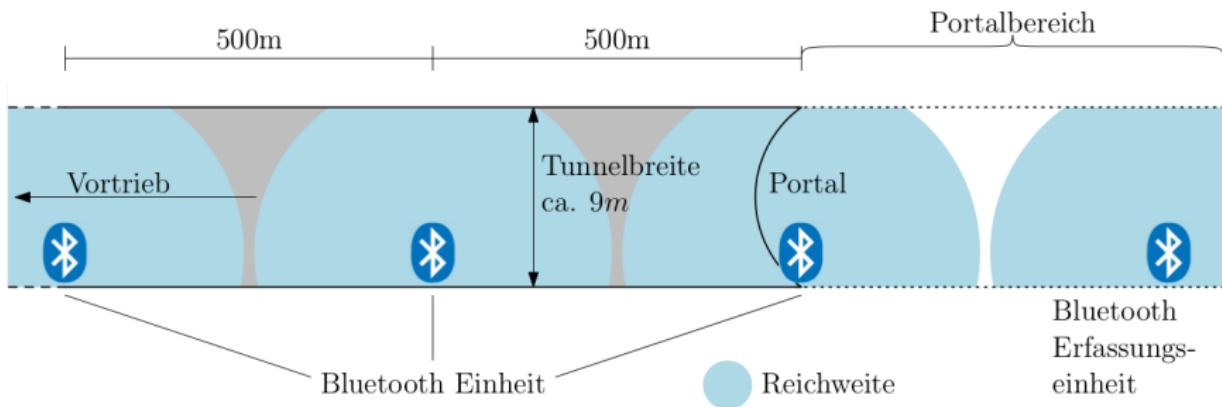
INSTITUT FÜR ANGEWANDTE INFORMATIK UND FORMALE BESCHREIBUNGSVERFAHREN



# Gliederung

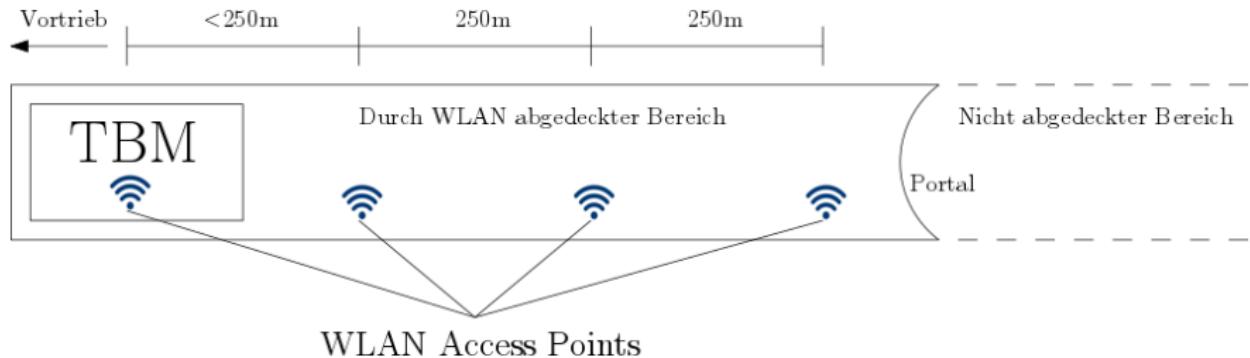
- 1 Motivation
- 2 Grundlagen & Analyse
- 3 Reichweiten
- 4 Implementierungen
  - RADAR
  - WiFi-LLS
  - Assoziations-Lokalisierung
  - Probe-Request-Lokalisierung
  - Bluetooth Low Energy
  - Lokalisierung mit LoRa
- 5 Zusammenfassung
- 6 Fazit

# Bisherige Situation



[4]

# Zukünftige Situation



# Aufgabe

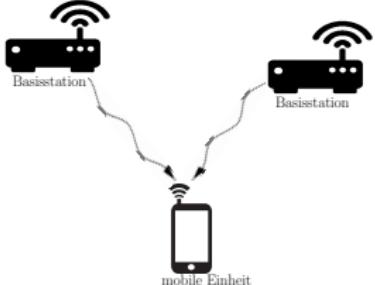
## Zielsetzung

- Funkbasiertes Ortungssystem
- Bereichsortung (250m Abschnitte)

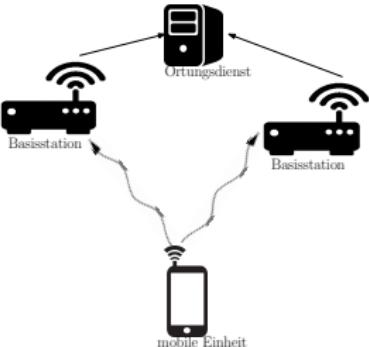
## Anforderungen

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

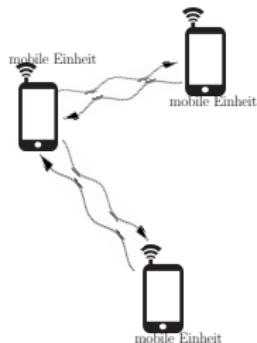
# Topologien



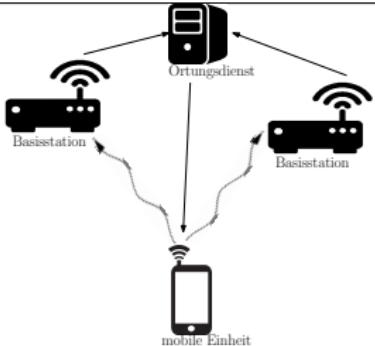
Direkte Selbstlokal.



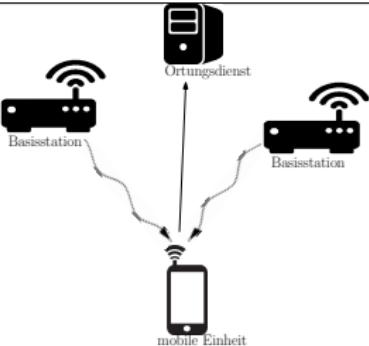
Direkte Fernlokal.



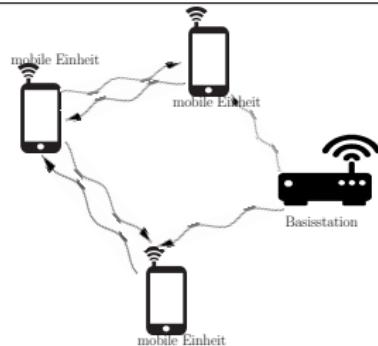
Ohne Basisstation



Indirekte Selbstlokal.

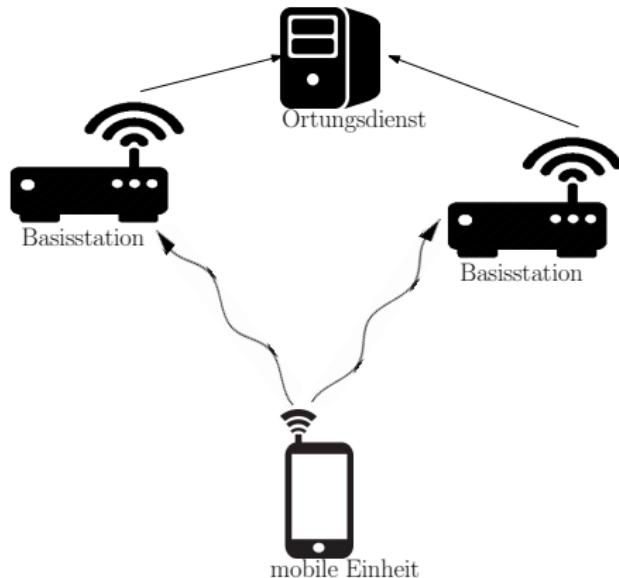


Indirekte Fernlokal.

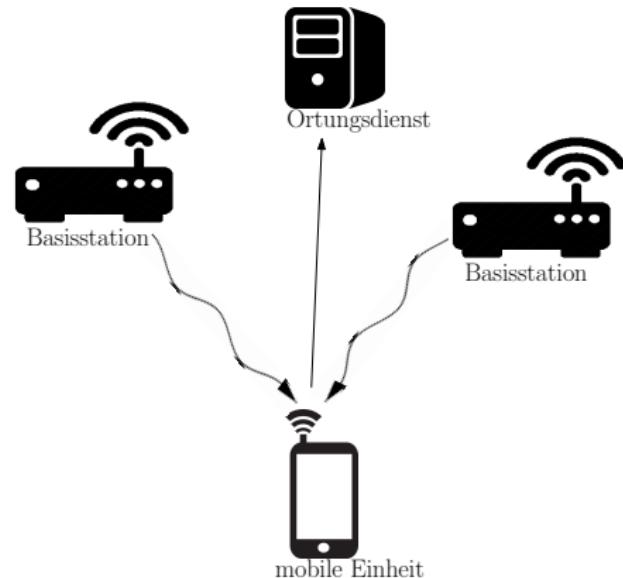


Hybride Topologie

# Fernlokalisierung



Direkte Fernlokalisierung



Indirekte Fernlokalisierung

## Messgrößen

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

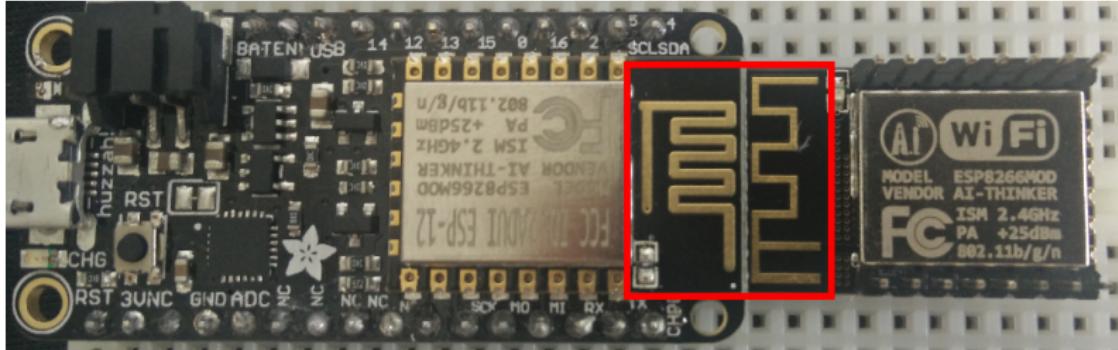
## Lokalisierungsprinzip

- Umgebungsprinzip
- Geometrische Bestimmung
- Szenenanalyse

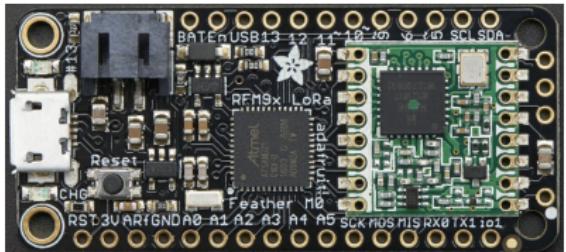
## Protokolle

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

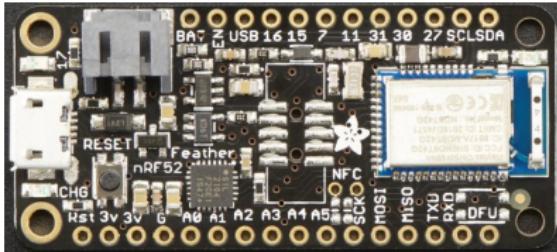
# Hardware



Adafruit Feather HUZZAH ESP8266

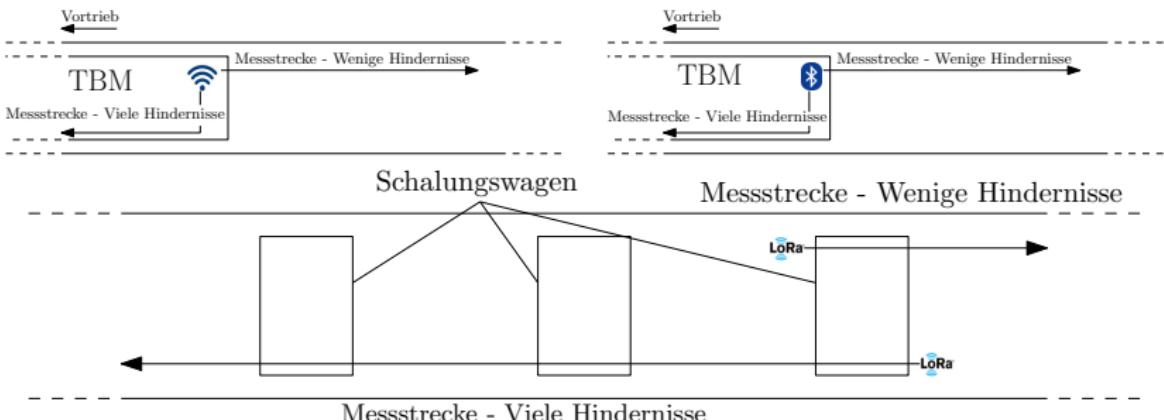


Feather M0 RFM95 LoRa Radio



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

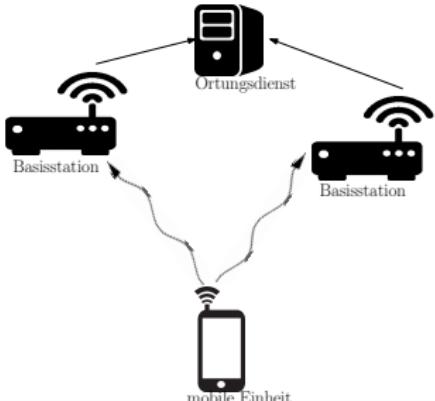
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# RADAR

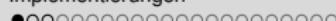
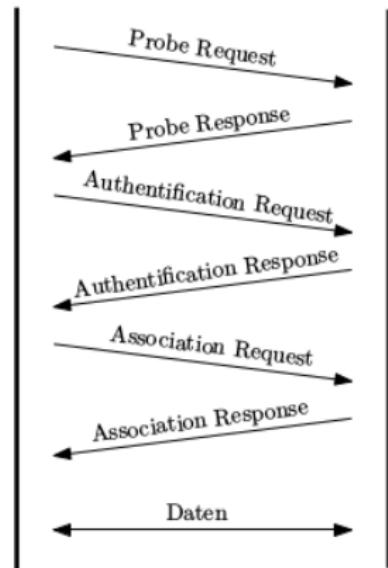
# RADAR

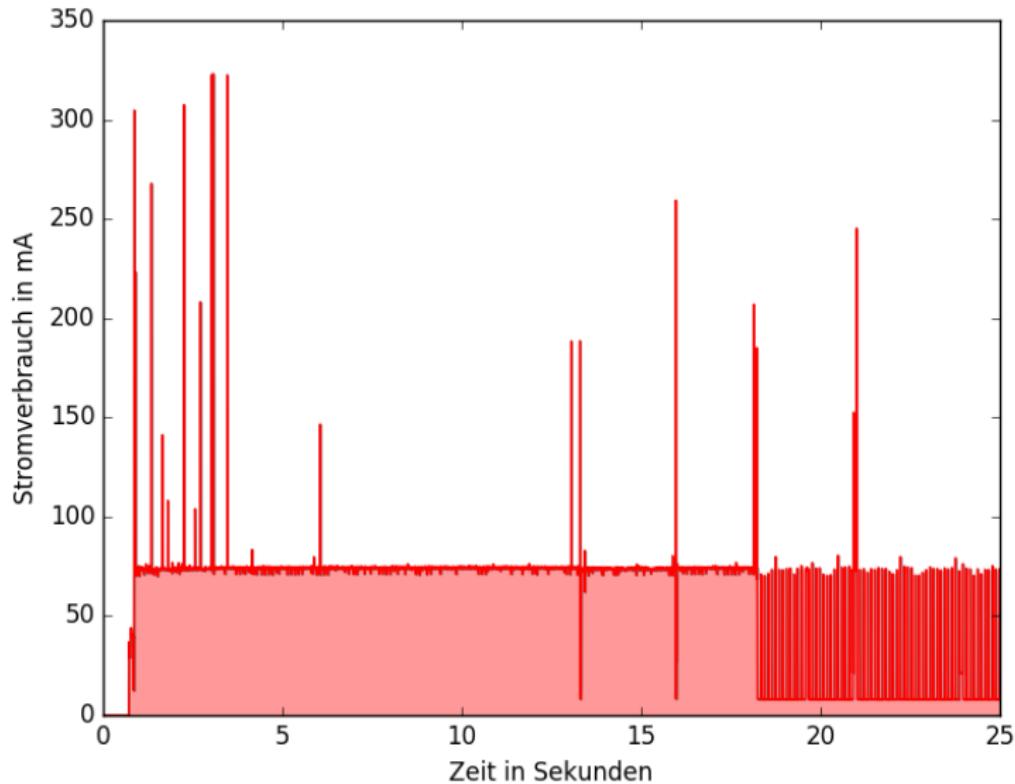
- Bahl et al. [1]
  - Direkte Fernlokalisierung
  - 6 Byte mit UDP
  - RSSI an Basisstation messen
  - Szenenanalyse

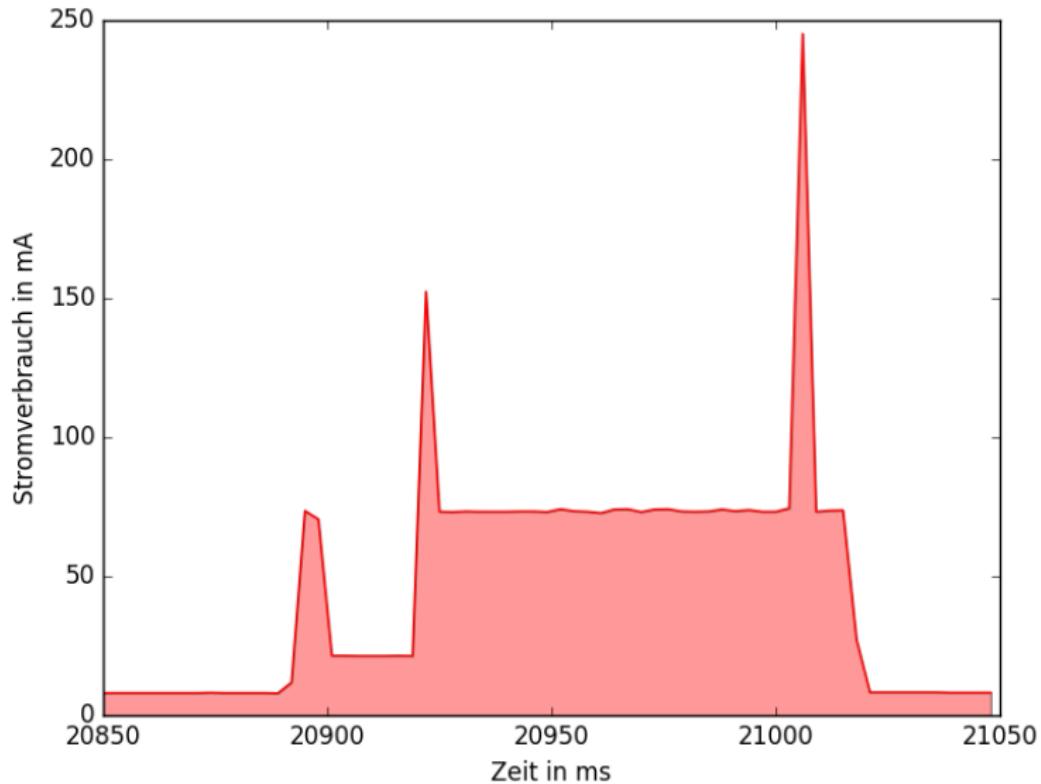


mobile Einheit

## Access Point 1

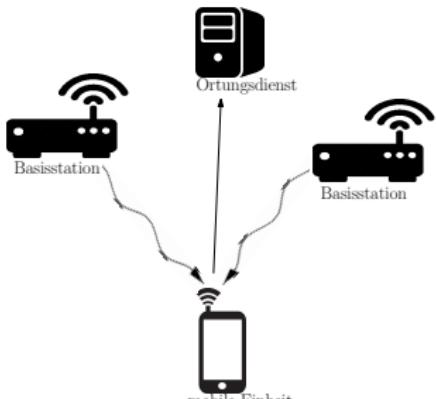






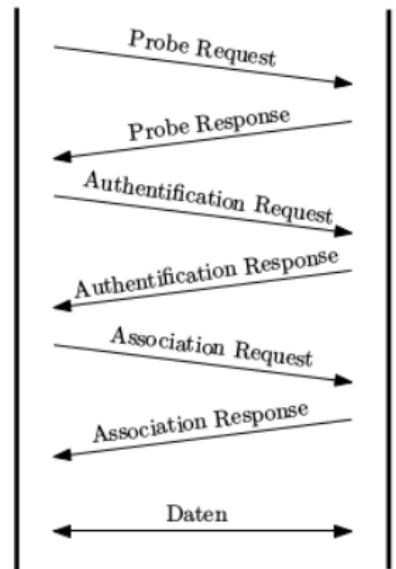
WiFi-LLS

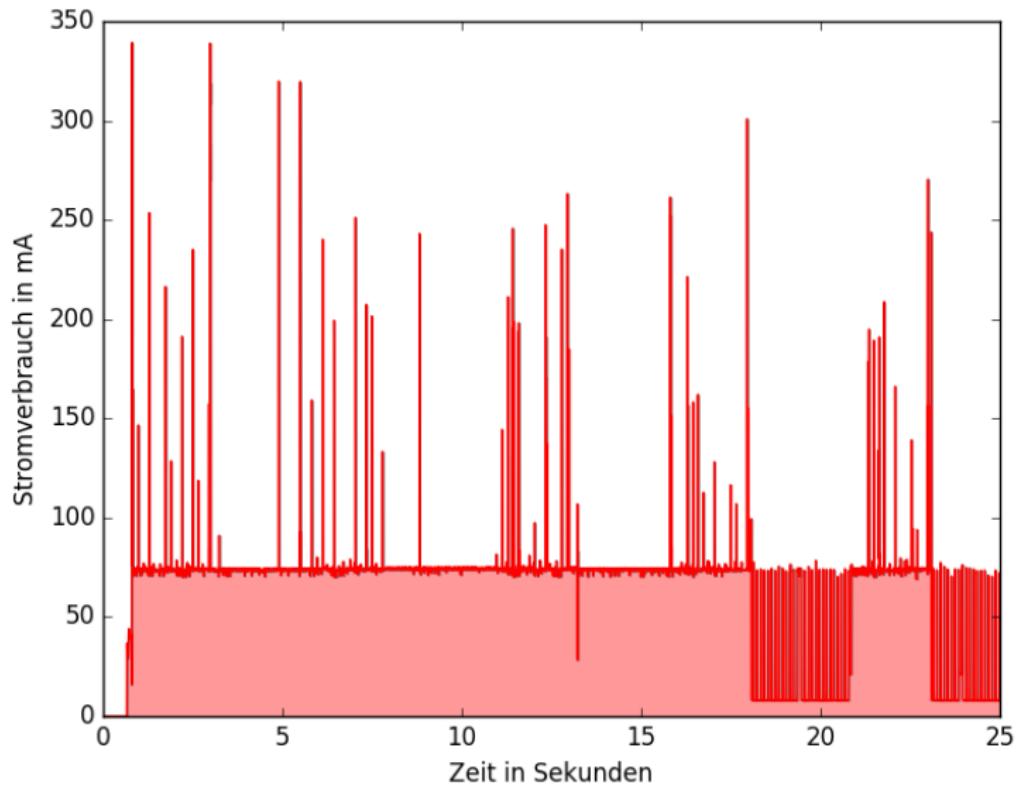
- Chen et al. [2]
  - Indirekte Fernlokalisierung
  - RSSI der Probe Responses
  - An mobiler Einheit gemessen
  - Geometrische Bestimmung

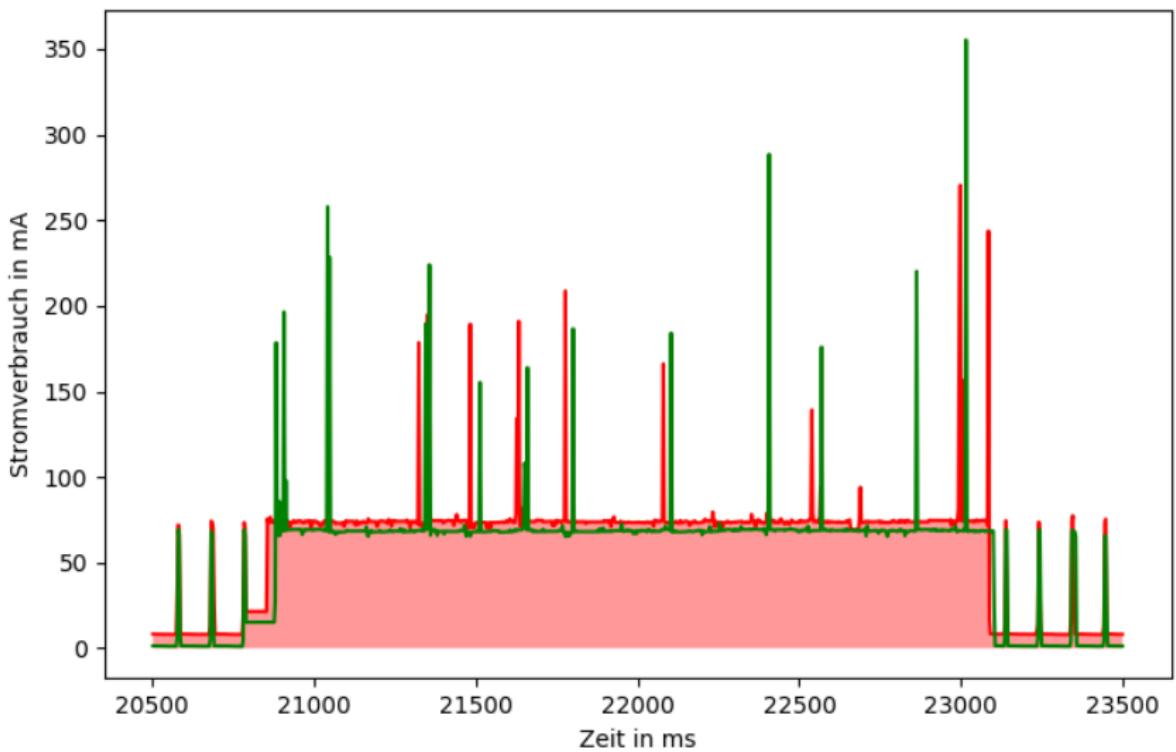


mobile Einheit

## Access Point 1

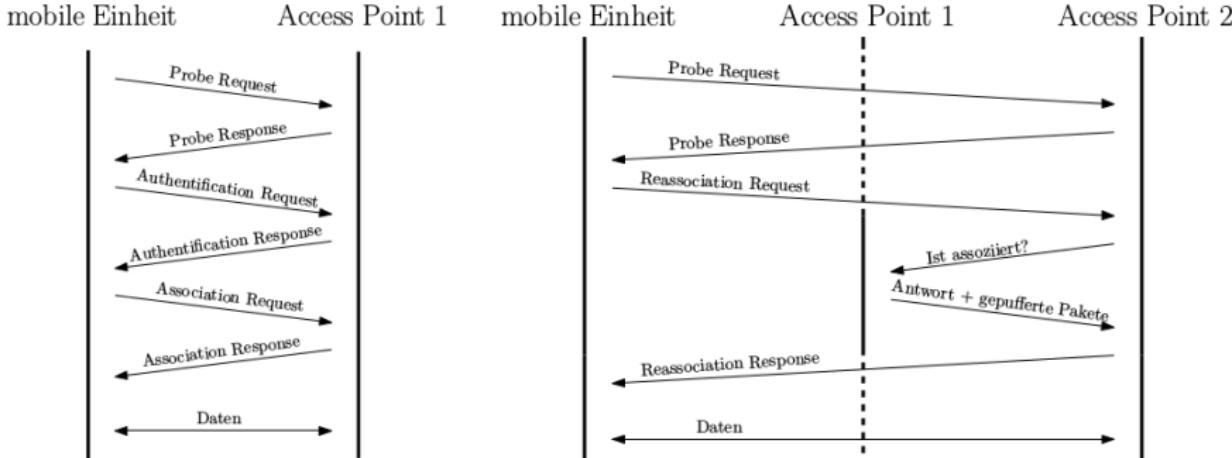






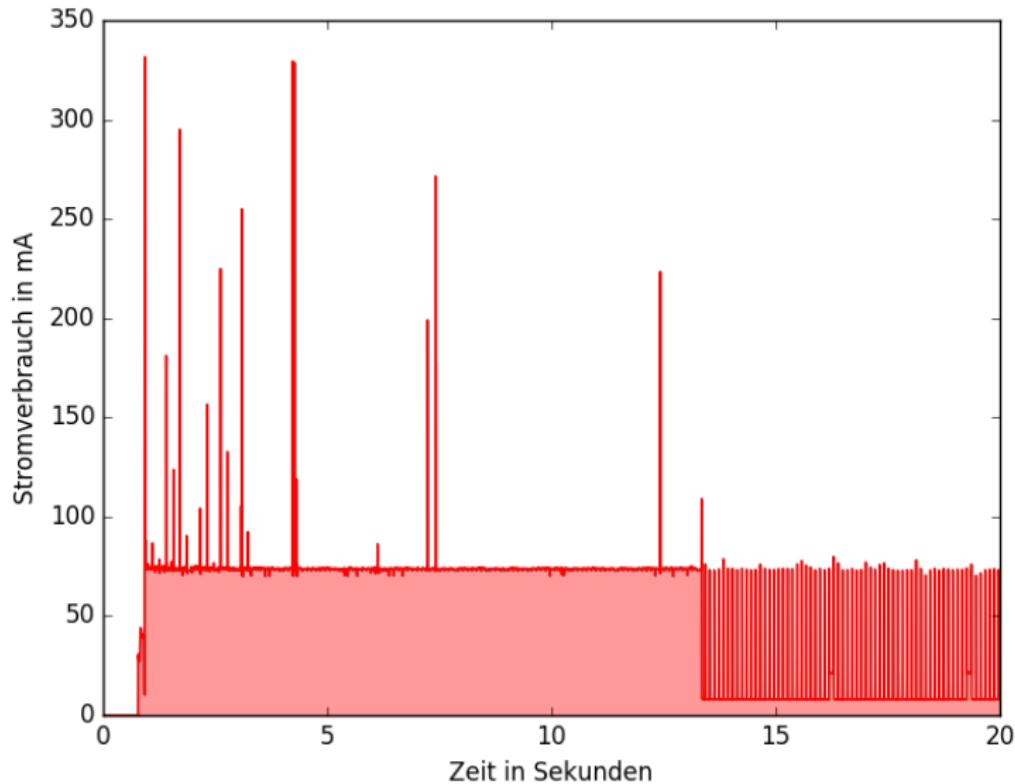
Protokoll	Modul	Programm	$\emptyset$ Verbrauch (normalisiert)
IEEE 802.11	<i>ESP8266 Feather</i>	<i>RADAR</i>	16,70 (8,60)
IEEE 802.11	<i>ESP-12F</i>	<i>RADAR</i>	10,10 (8,80)
IEEE 802.11	<i>ESP8266 Feather</i>	<i>WiFi-LLS</i>	42,20 (34,10)
IEEE 802.11	<i>ESP-12F</i>	<i>WiFi-LLS</i>	36,50 (35,20)

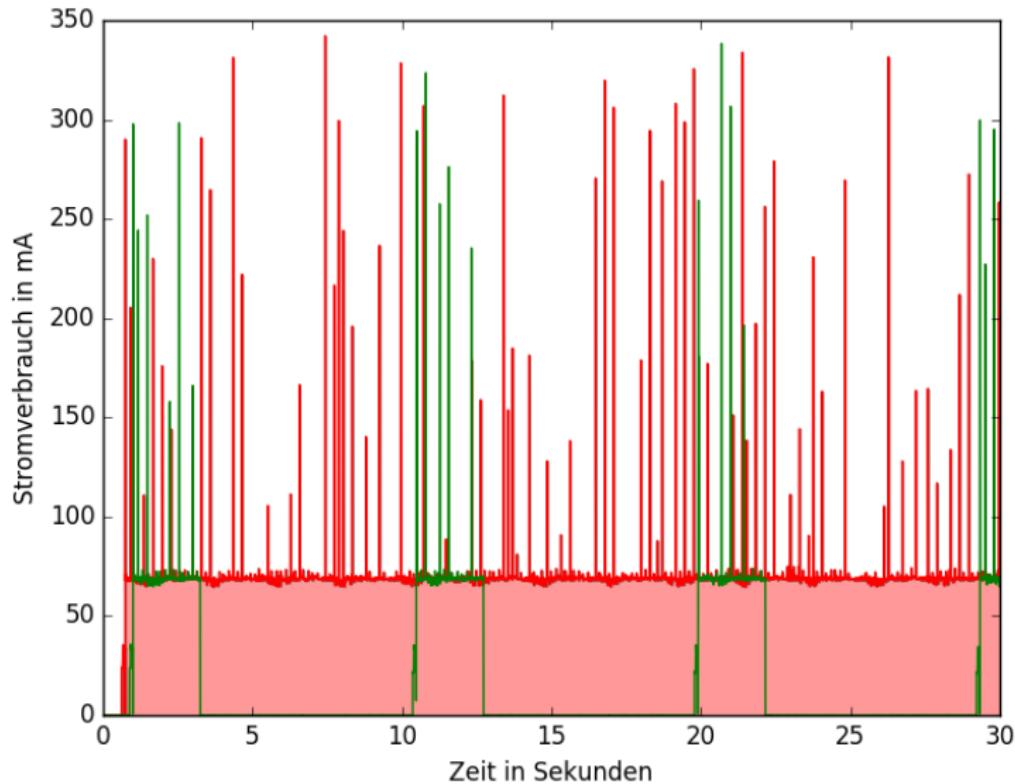
## Assoziations-Lokalisierung



## Assoziations-Lokalisierung

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

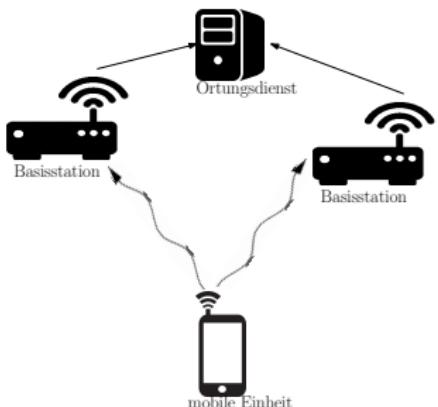




Protokoll	Modul	Programm	$\emptyset$ Verbrauch (normalisiert)
IEEE 802.11	<i>ESP8266 Feather</i>	<i>RADAR</i>	16,70 (8,60)
IEEE 802.11	<i>ESP-12F</i>	<i>RADAR</i>	10,10 (8,80)
IEEE 802.11	<i>ESP8266 Feather</i>	<i>WiFi-LLS</i>	42,20 (34,10)
IEEE 802.11	<i>ESP-12F</i>	<i>WiFi-LLS</i>	36,50 (35,20)
IEEE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

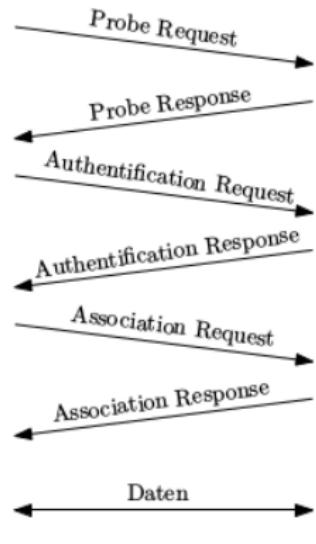
## Probe-Request-Lokalisierung

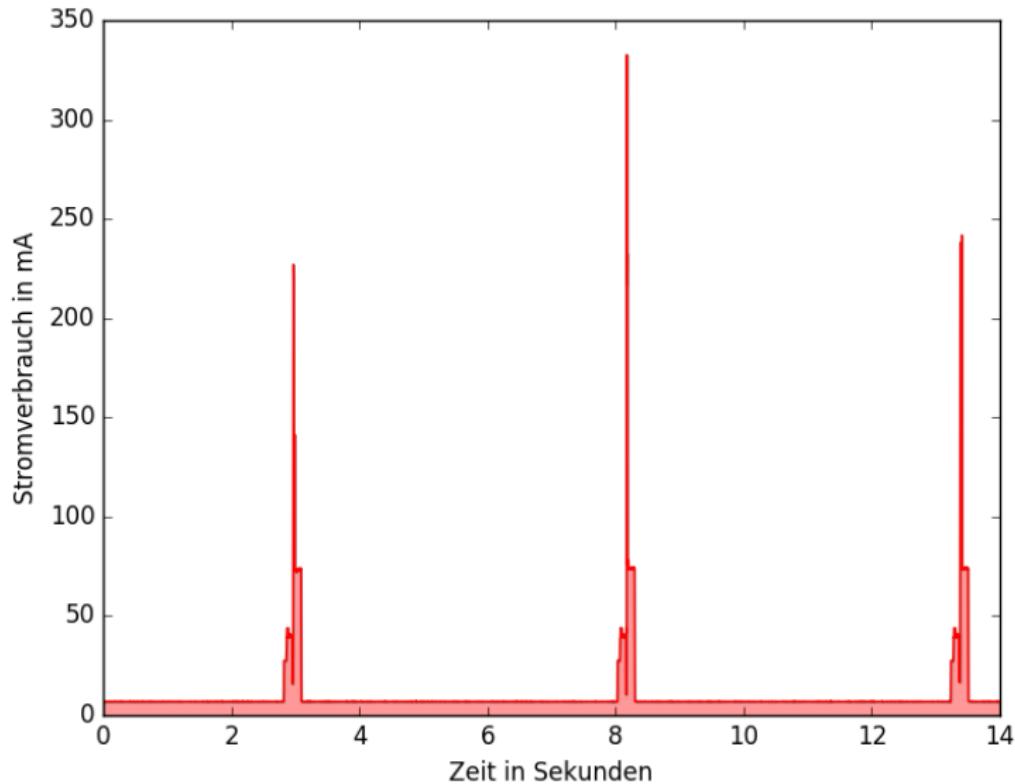
- Direkte Fernlokalisierung
- RSSI der Probe Requests
- An Access Point gemessen
- Umgebungsprinzip

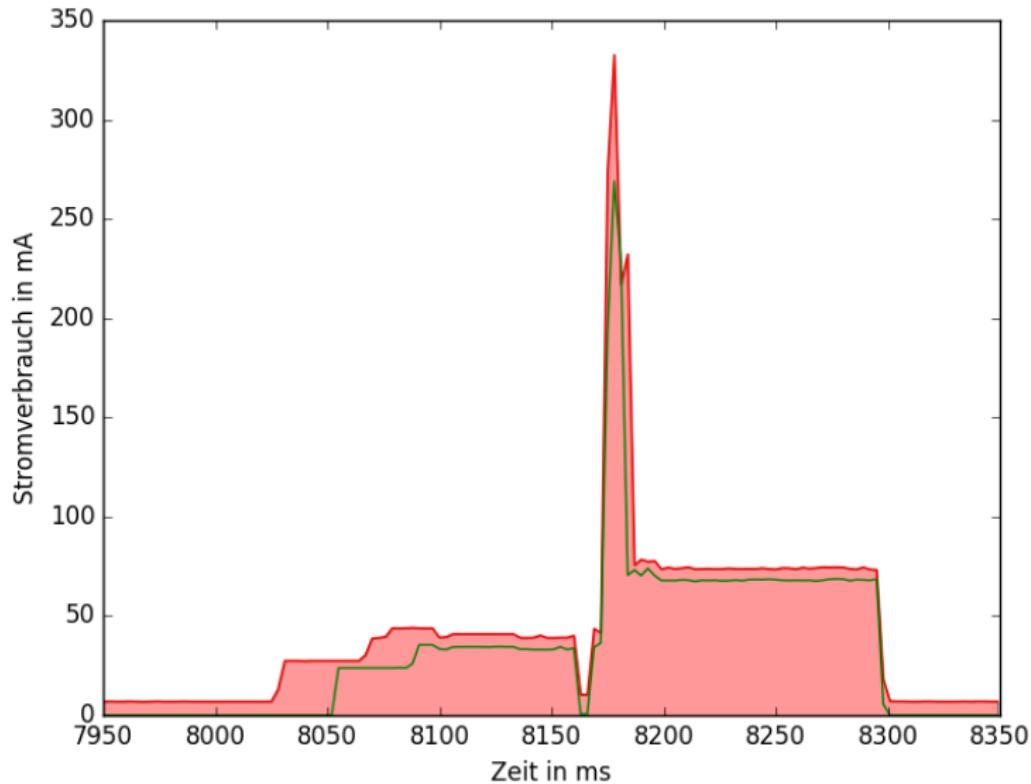


mobile Einheit

Access Point 1





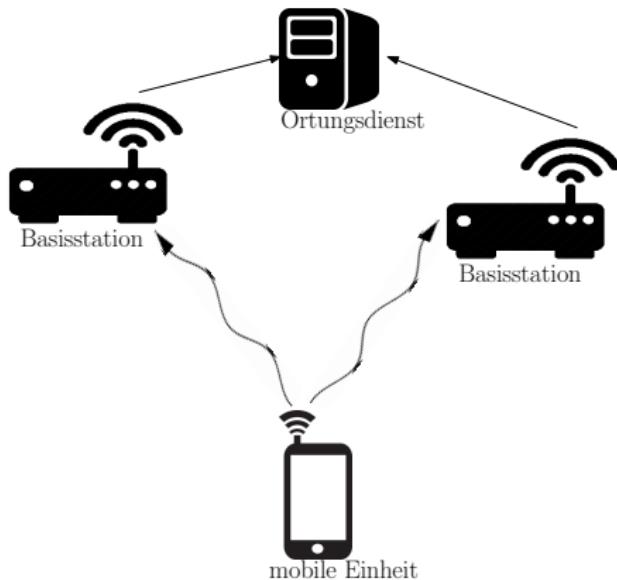


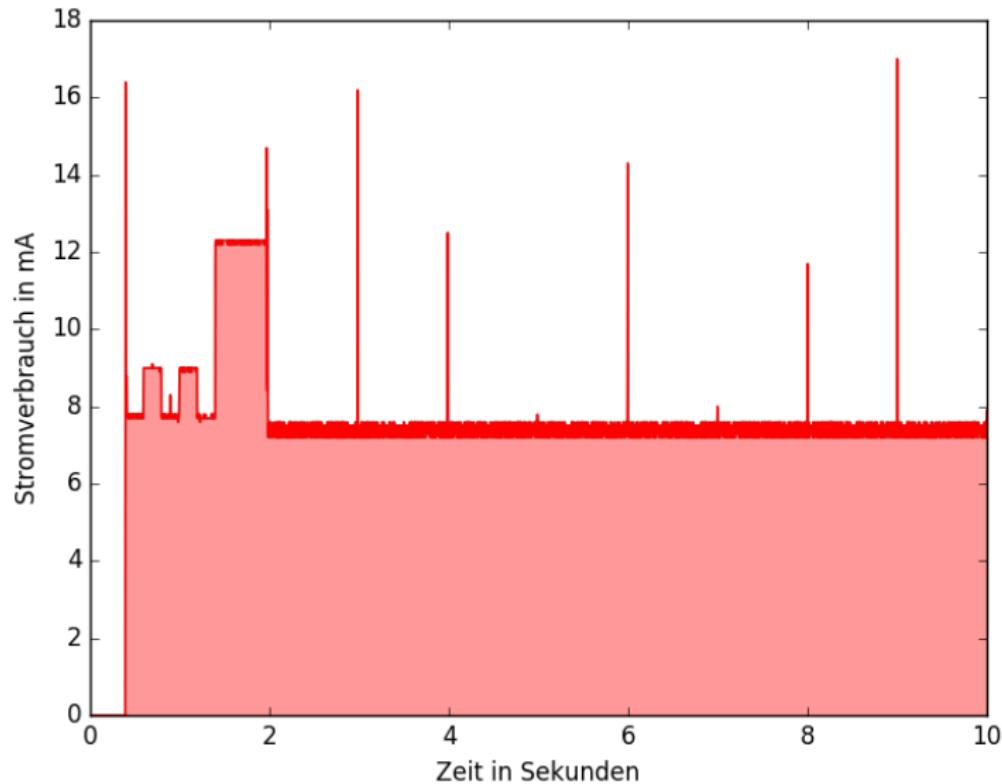
Protokoll	Modul	Programm	$\emptyset$ Verbrauch (normalisiert)
IEEE 802.11	<i>ESP-12F</i>	<i>Assoziations-Lokalisierung</i>	8,80 (7,50)
IEEE 802.11	<i>ESP-12F</i>	<i>Assoziations-Lokalisierung</i> (kein Access Point)	17,10 (17,10)
IEEE 802.11	<i>ESP8266 Feather</i>	<i>Probe-Request-Lokalisierung</i>	9,70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



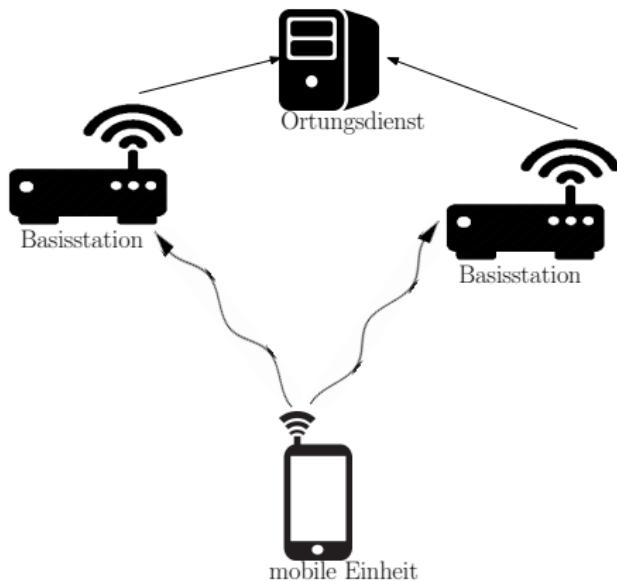


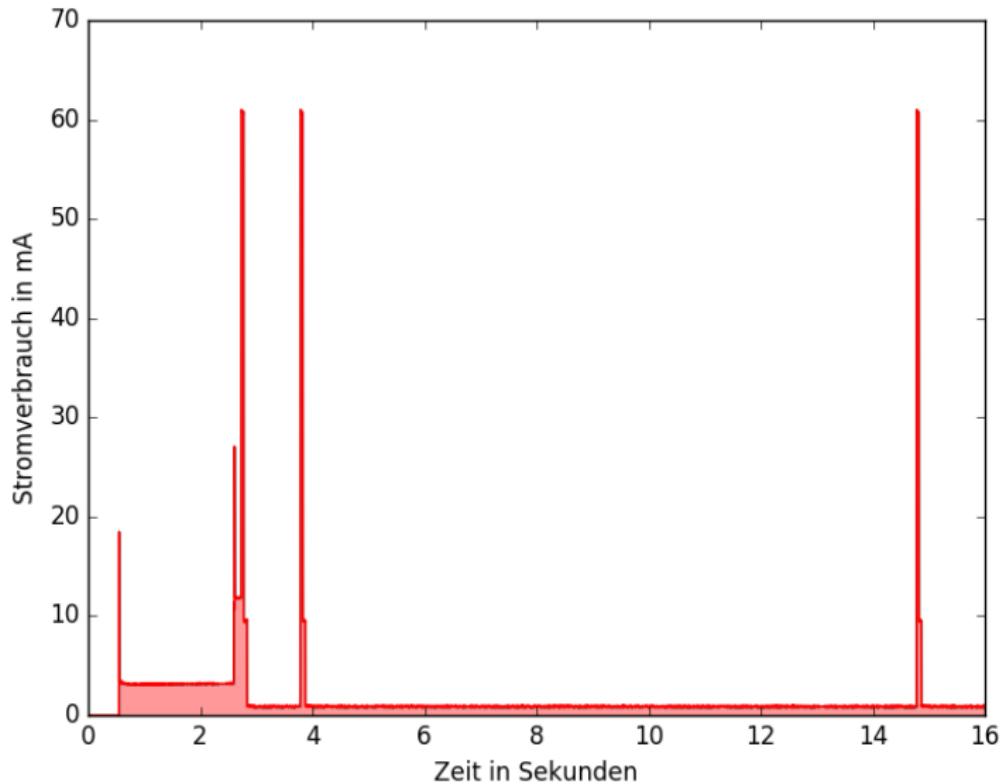
Protokoll	Modul	Programm	$\emptyset$ Verbrauch (normalisiert)
IEEE 802.11	<i>ESP8266 Feather</i>	<i>Probe-Request-Lokalisierung</i>	9,70 (2,70)
IEEE 802.11	<i>ESP-12F</i>	<i>Probe-Request-Lokalisierung</i>	1,80 (1,80)
BLE	<i>nRF52 Feather</i>	Ortung mit <i>BLE-Advertising</i>	7,37 (0,04)

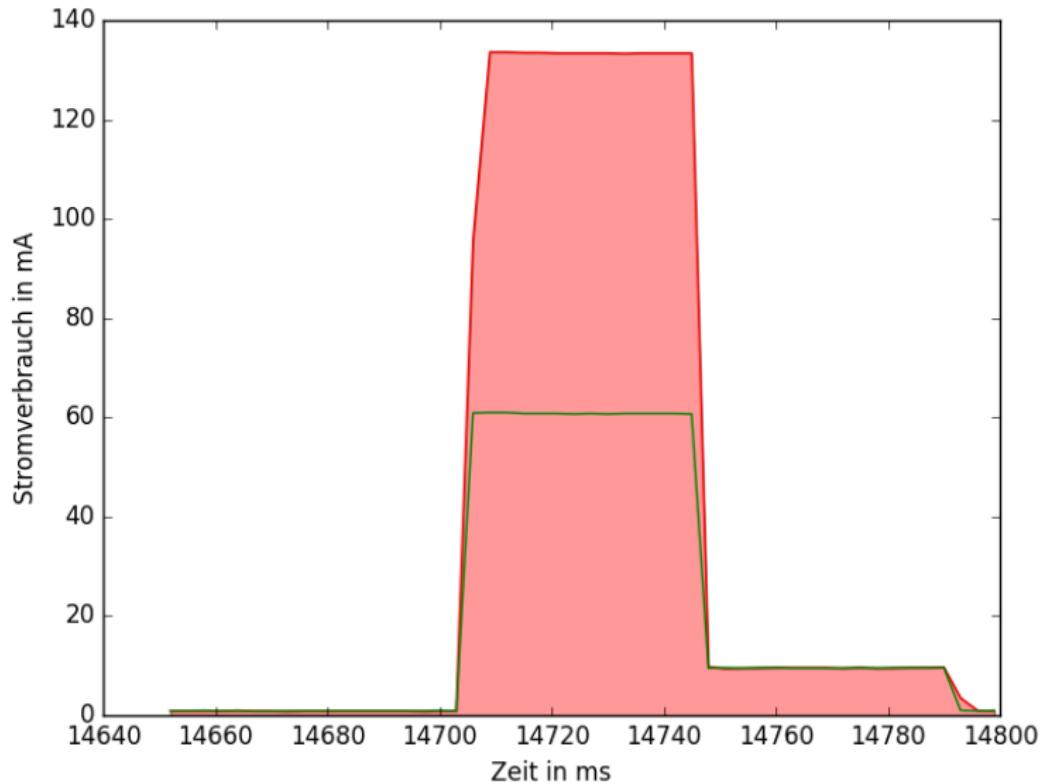
# Lokalisierung mit LoRa

## Lokalisierung mit LoRa

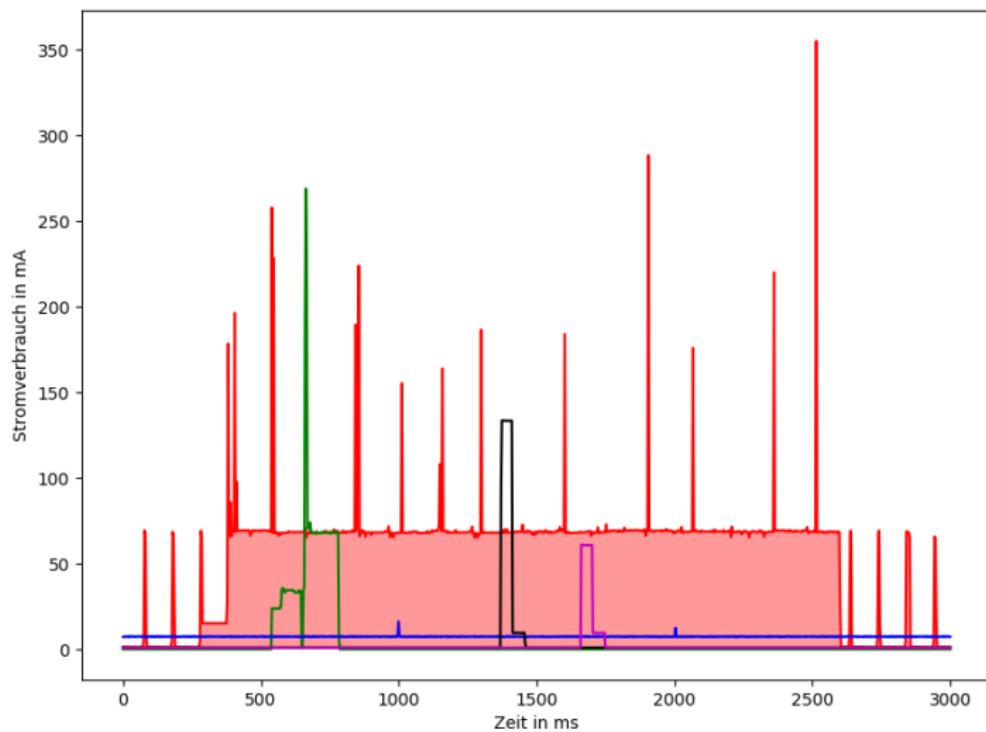
- Direkte Fernlokalisierung
- RSSI an Basisstation  
gemessen
- Geometrische Bestimmung

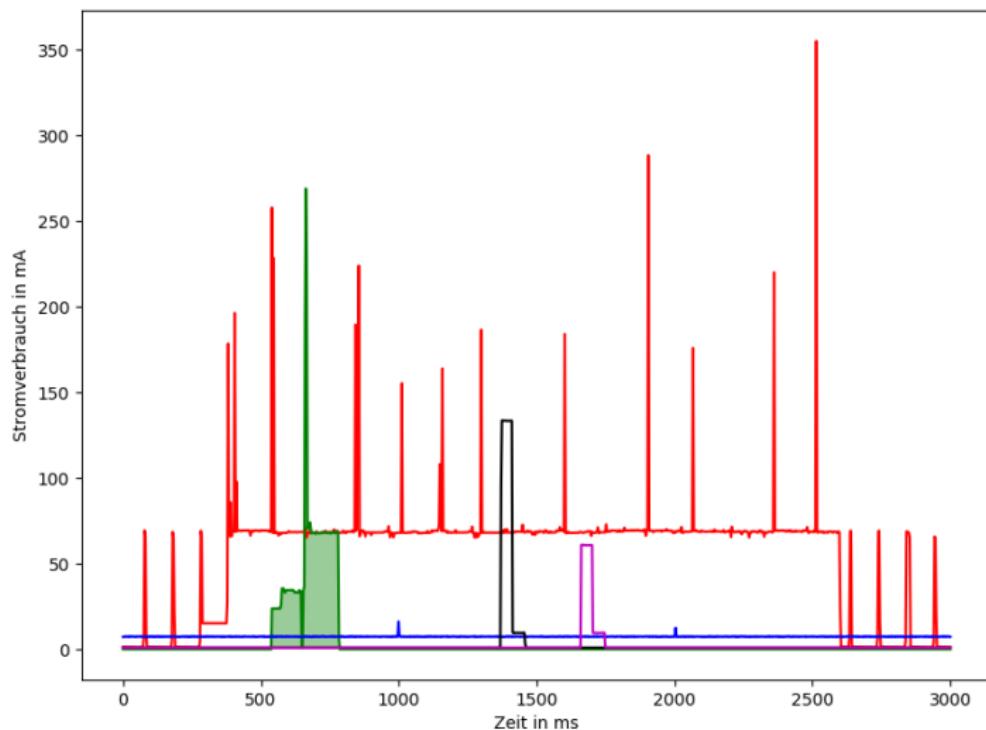


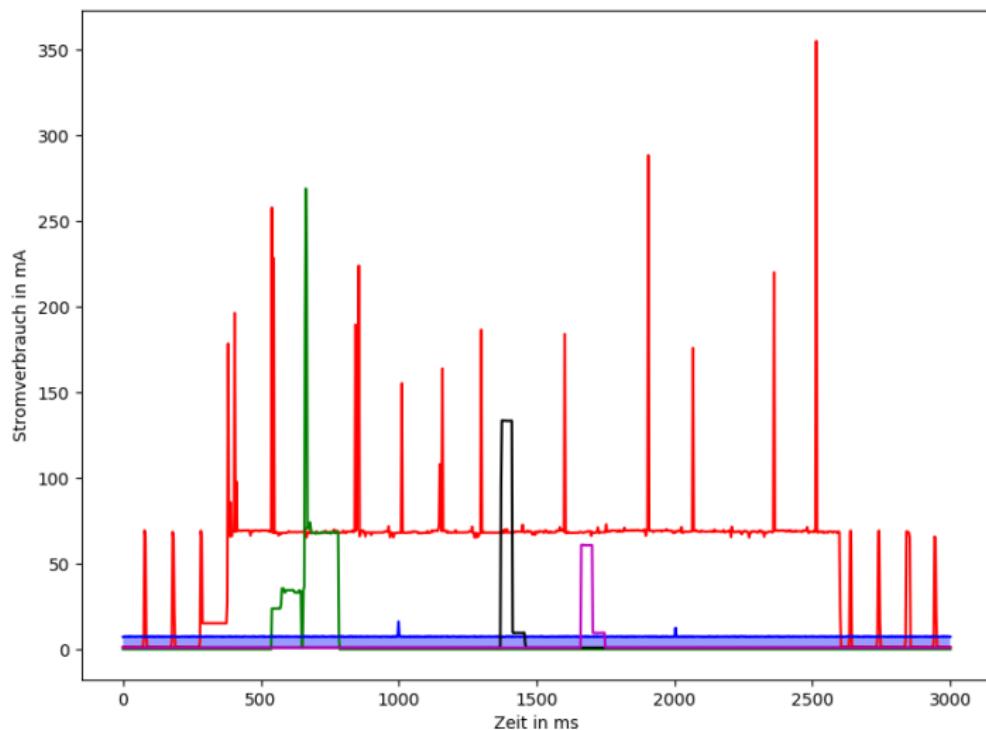


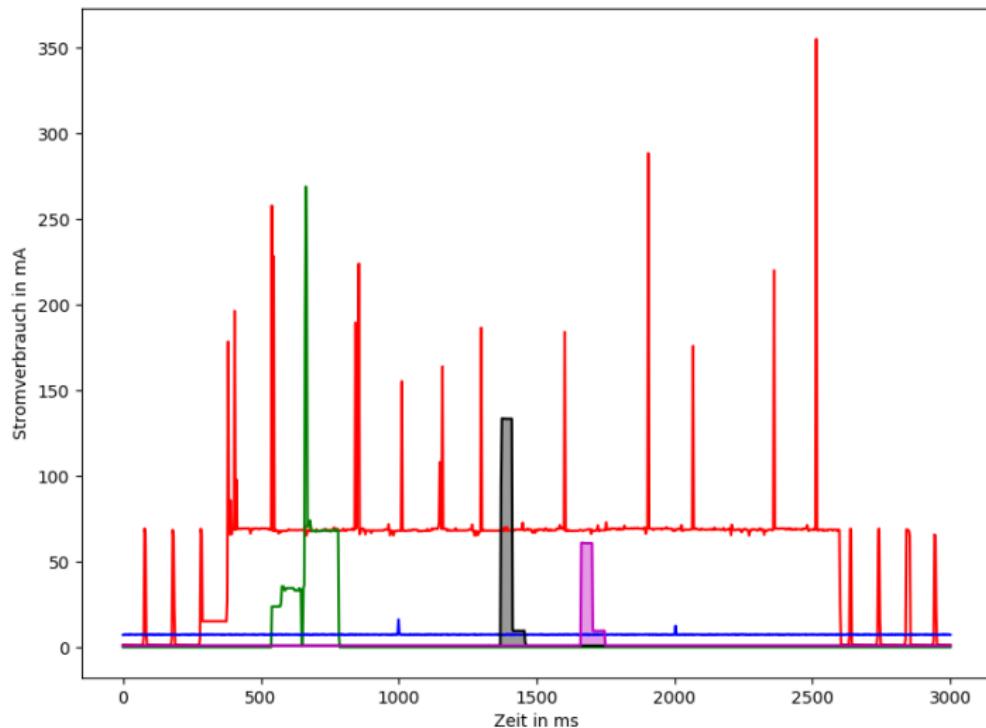


Protokoll	Modul	Programm	$\varnothing$ Verbrauch (normalisiert)
IEEE 802.11	<i>ESP-12F</i>	<i>Probe-Request-Lokalisierung</i>	1,80 (1,80)
BLE	<i>nRF52 Feather</i>	Ortung mit <i>BLE-Advertising</i>	7,37 (0,04)
LoRa	<i>RFM95 Feather 5 dBm</i>	Ortung mit LoRa RSSI	1,20 (0,30)
LoRa	<i>RFM95 Feather 23 dBm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



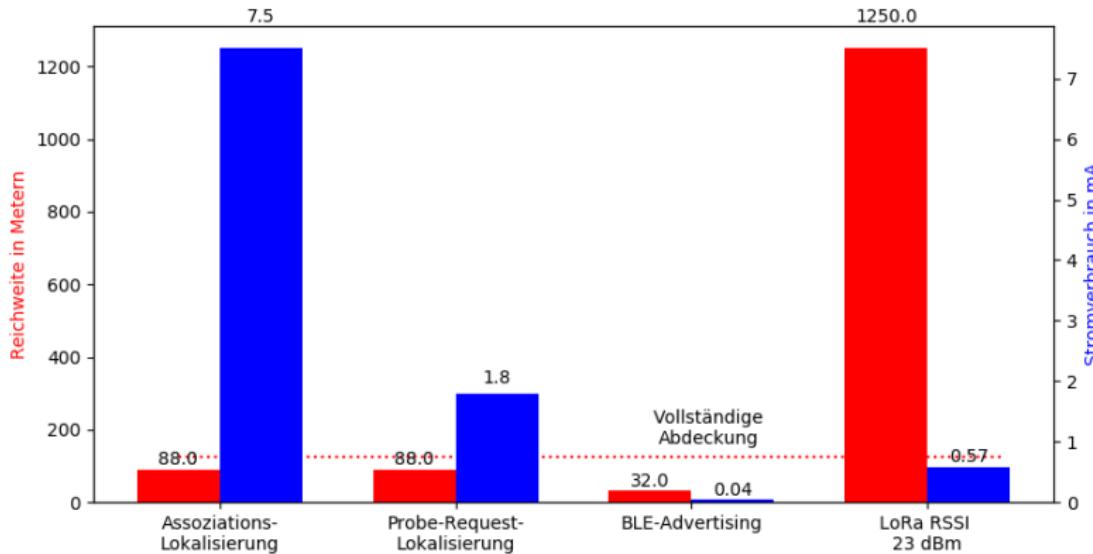






Protokoll	Modul	Programm	$\emptyset$ Verbrauch (normalisiert)
IEEE 802.11	<i>ESP-12F</i>	<i>RADAR</i>	10,10 (8,80)
IEEE 802.11	<i>ESP-12F</i>	<i>WiFi-LLS</i>	36,50 (35,20)
IEEE 802.11	<i>ESP-12F</i>	<i>Assoziations-Lokalisierung</i>	8,80 (7,50)
IEEE 802.11	<i>ESP-12F</i>	<i>Assoziations-Lokalisierung</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</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)





## Fazit

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

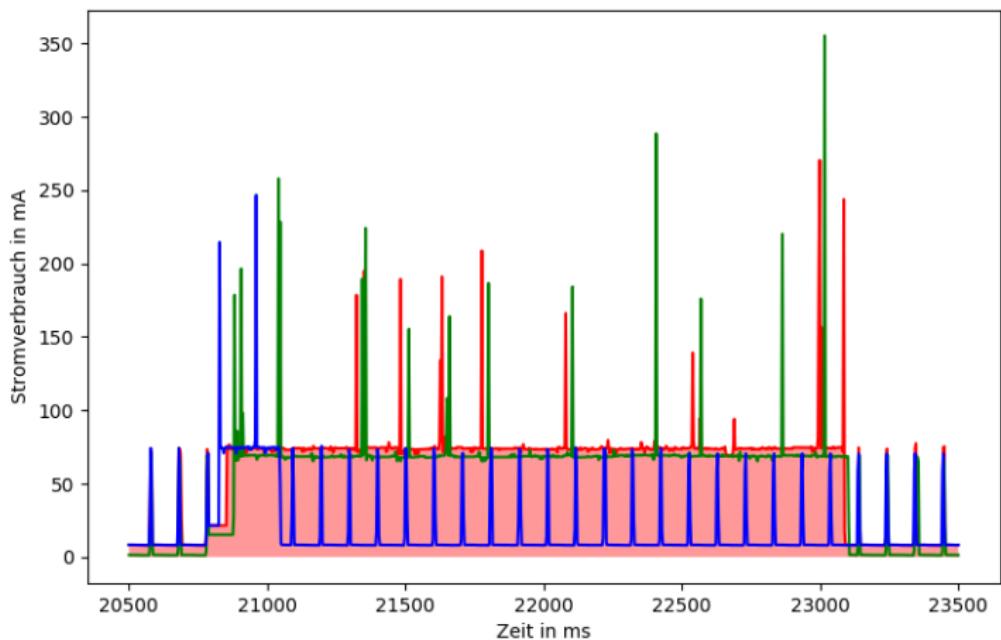
# References I

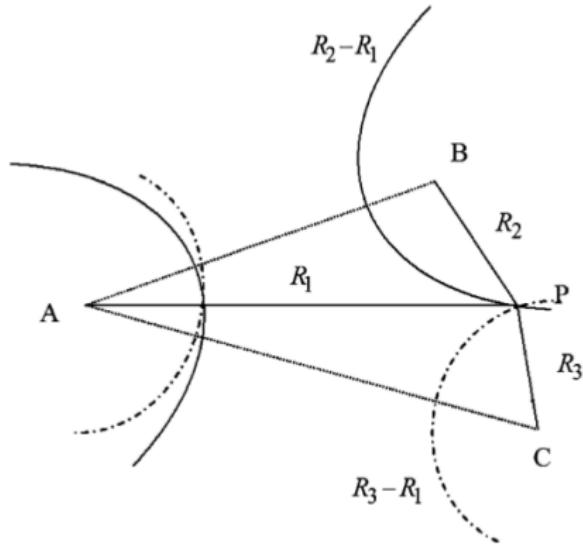
- [1] Paramvir Bahl und Venkata N Padmanabhan. "RADAR: An in-building RF-based user location and tracking system". In: *INFOCOM 2000. Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE*. Bd. 2. ieee. 2000, S. 775–784.
- [2] Yibo Chen und Rong Luo.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

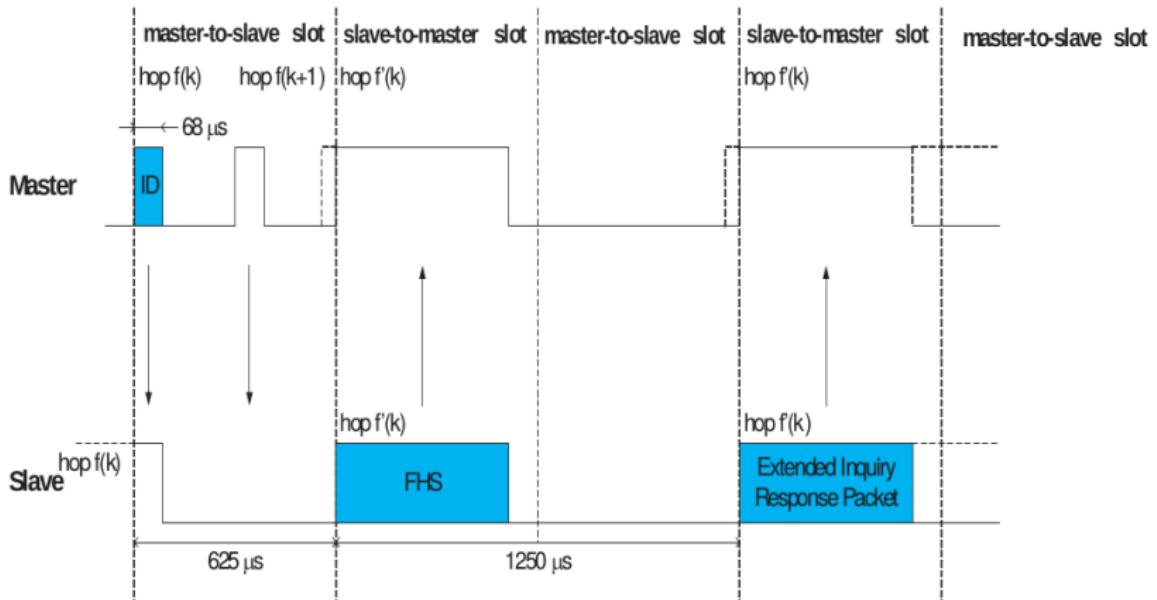
# ESP8266 Verbrauch



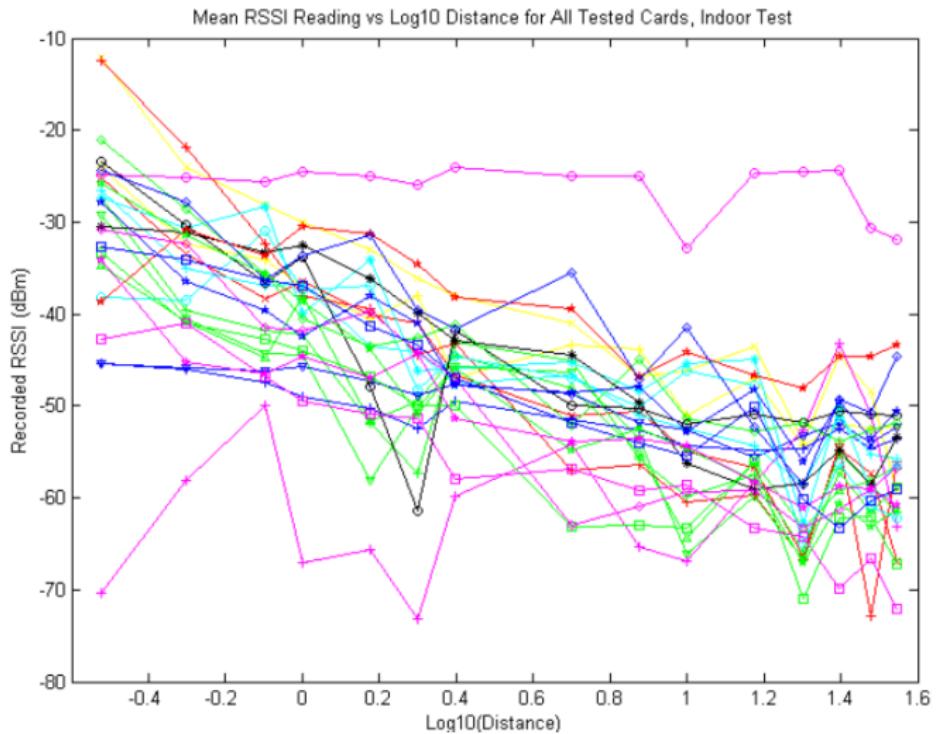


$$R_{i,j} = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} - \sqrt{(x_j - x)^2 + (y_j - y)^2 + (z_j - z)^2}$$

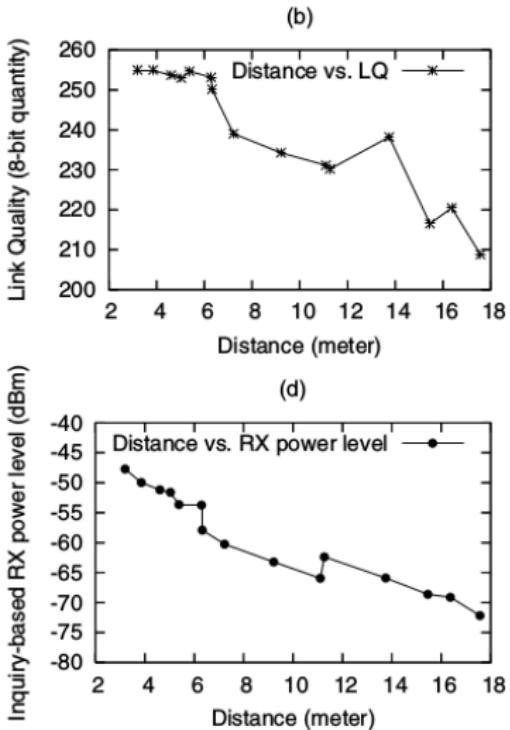
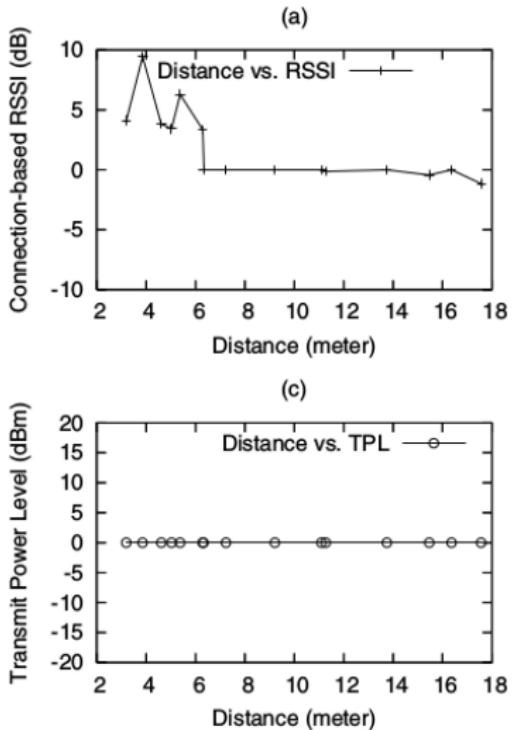
# Inquiry Scan



# IEEE 802.11 RSSI



# 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 <sup>①</sup>	-	15	-	mA
Light-sleep <sup>②</sup>	-	0.9	-	mA
Deep-sleep <sup>③</sup>	-	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 <sup>[1]</sup>	Max	Unit
$V_{DD}$	supply voltage (core and external rail)		1.8	3.3	3.6	V
$I_{DD}$	supply current	Active mode; code <pre>while(1){} executed from flash</pre>				
		system clock = 12 MHz $V_{DD} = 3.3\text{ V}$	[2][3][4] [5][6]	-	2	-
		system clock = 50 MHz $V_{DD} = 3.3\text{ V}$	[2][3][5] [6][7]	-	7	-
		Sleep mode; system clock = 12 MHz $V_{DD} = 3.3\text{ V}$	[2][3][4] [5][6]	-	1	-
		Deep-sleep mode; $V_{DD} = 3.3\text{ V}$	[2][3][6]	-	2	-
						$\mu\text{A}$

Symbol	Description	
IDDSL	Supply current in Sleep mode	
IDDIDLE	Supply current in Idle mode	RC oscil.
IDDST	Supply current in Standby mode	Crystal o.
IDDFS	Supply current in Synthesizer mode	FSRx
IDDR	Supply current in Receive mode	<i>LnaBoos</i> <i>LnaBoos</i> Lower b.
IDDT	Supply current in Transmit mode with impedance matching	RFOP = RFOP = RFOP = RFOP = RFOP =