Usage of the LTE Testbed
A Tutorial

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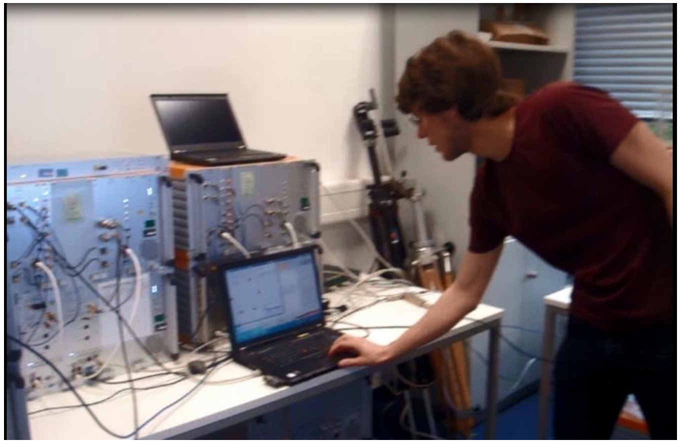
Outline

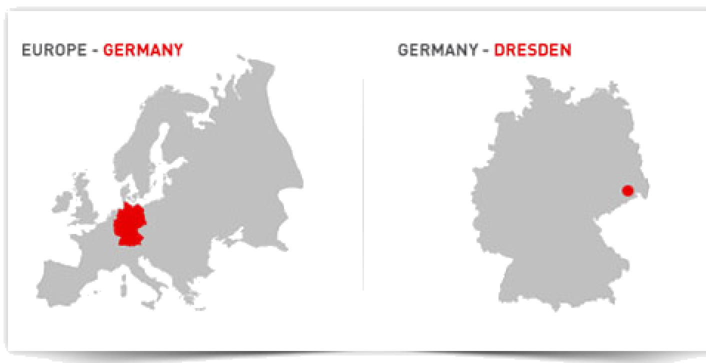
- Introduction
- Available hardware
- Example scenarios
- Setup
- Requirements for 3rd party usage
- Support & contact
- Outlook



Introduction

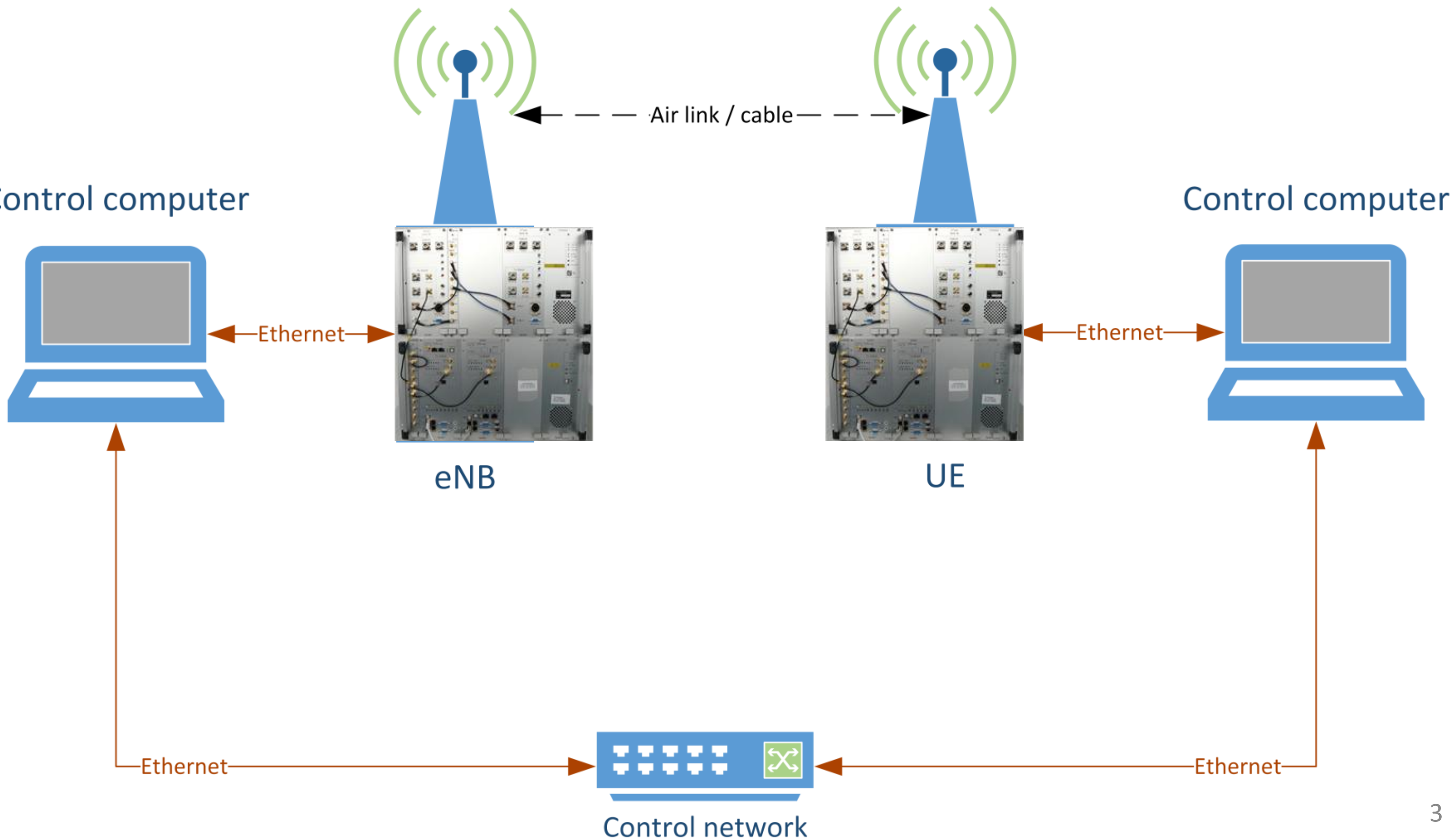
Usage and operation:

- LTE/LTE-A experimental wireless test bed
  - → E.g. to study cognitive radio (CR) in cellular systems
  - → Operated by TUD Vodafone Chair research team
- LTE-like cellular infrastructure
  - → Network parameters are monitored and recorded
- Benchmark the impact of various CR schemes and devices



Basic LTE testbed

- 1 eNB stationary on the desk/tower
- 1 UE portable/moveable in studio rack or bicycle rickshaw



Introduction

Hardware features:

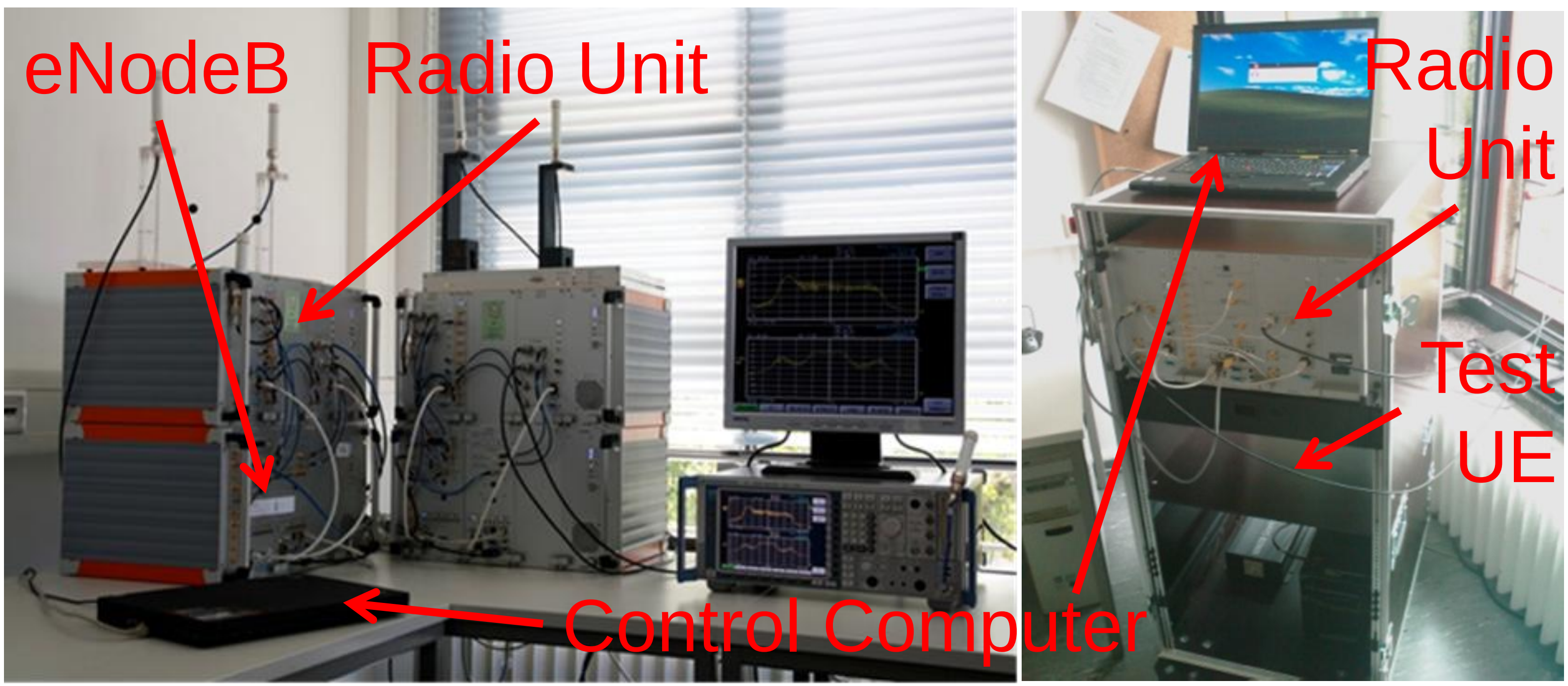
- LTE test equipment from *SIGNALION*
  - UL 1.99 GHz, DL 2.18 GHz
  - 20 MHz bandwidth
  - Supports 2 Tx and 2 Rx channels
  - FPGA based
- Basic operating functionality provided by Hardware (Real-time)
  - Available: RSSI, RSRP, SINR
- Further evaluation of data done in Matlab (Offline)
  - Available: QAM constellations, CSI, BER
  - Link quality metric: BER

base station (eNodeB)

UE (User Equipment)

Available Hardware: Indoor

- **Flexible setup: Tx and Rx antennas can be moved within the lab room**
  - 1 eNBs stationary on the desks
  - 2 UEs on studio racks



Available Hardware: Outdoor

- **Realistic setup: Two sectors on roof of our institute's building; UEs can roam around indoor and outdoor**
  - 2 eNBs on the roof
  - 1 UE on a rickshaw

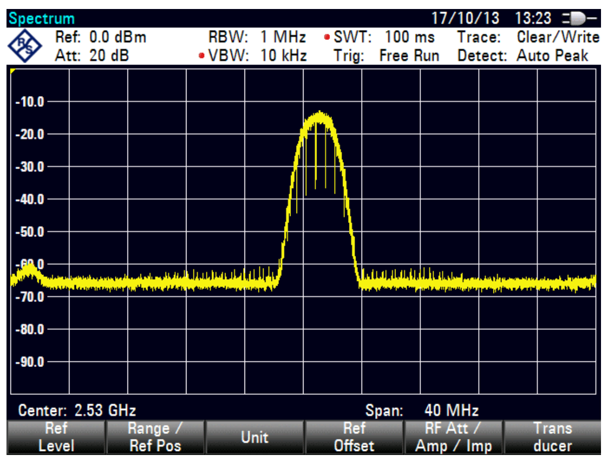
Available Hardware

Hardware for CR:

- *SIGNALION* Hardware-in-the-Loop (HaLo)
- Transmits arbitrary signals
- Different signal wave forms possible (e.g. OFDM, GFDM)
- Signal is generated by Matlab and stored in a Hardware-Buffer

Different parameters controllable

- Bandwidth
- **Frequency**
- Attenuation
- Timing
- Waveform



Secondary system
(transmitting only)

Available Hardware

Hardware for CR:

- *NI* USRP-2920
- Software-programmable radio transceivers designed for wireless communications teaching and research
- Spectrum sensing algorithm for LTE signals from *iMinds*
- Frequency range: 50MHz-2.2GHz
- Instantaneous real-time bandwidth 20MHz (16bit samples), 40MHz (8bit-samples)

Sensing device
(receiving only)

Available hardware

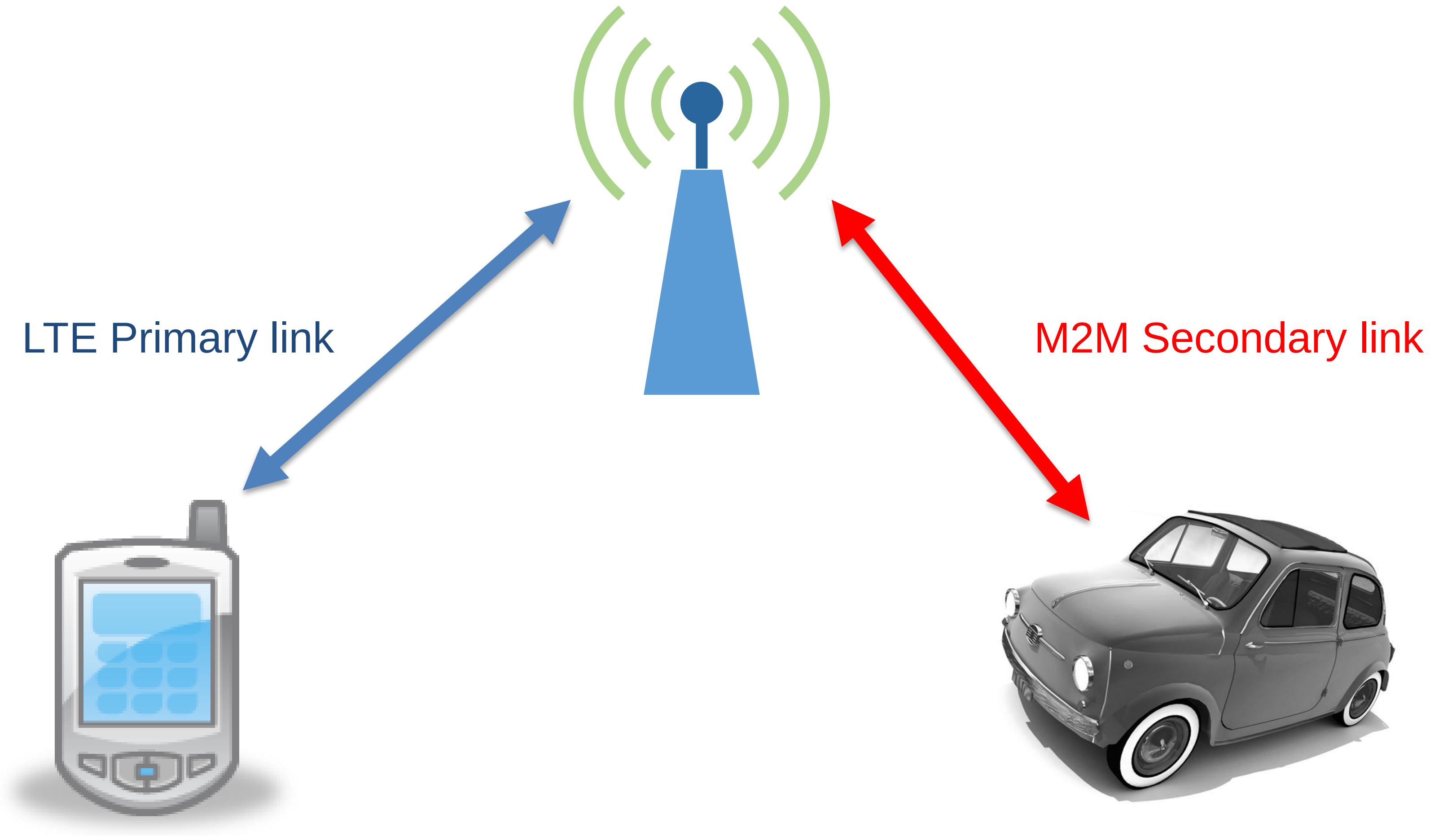
Other

- 3 bicycle rickshaws
  - 110 Ah Battery (can supply an UE for around 2-4 hours)
  - 12 V to 230 V converter (max. load 1 kW)
  - 19” Rack to mount UE’s, HALO, USRP, …
  - Internet access via 3G card or Campus WLAN
- Antennas
  - For UEs and indoor eNBs → omnidirectional *Kathrein* 800 10431
  - For outdoor eNBs → sectorized *Kathrein* 800 10551
- GPS receiver
  - For time synchronization of eNBs
  - For position tracking of UEs
- Various coaxial cables, attenuators, splitters
- Measurement equipment
  - *R&S* FSH4 and FSQ8 spectrum analyzer
  - Signal generator
- Antenna positioning tables (PC controlled stepper motor)

Example scenarios

Real world scenario:

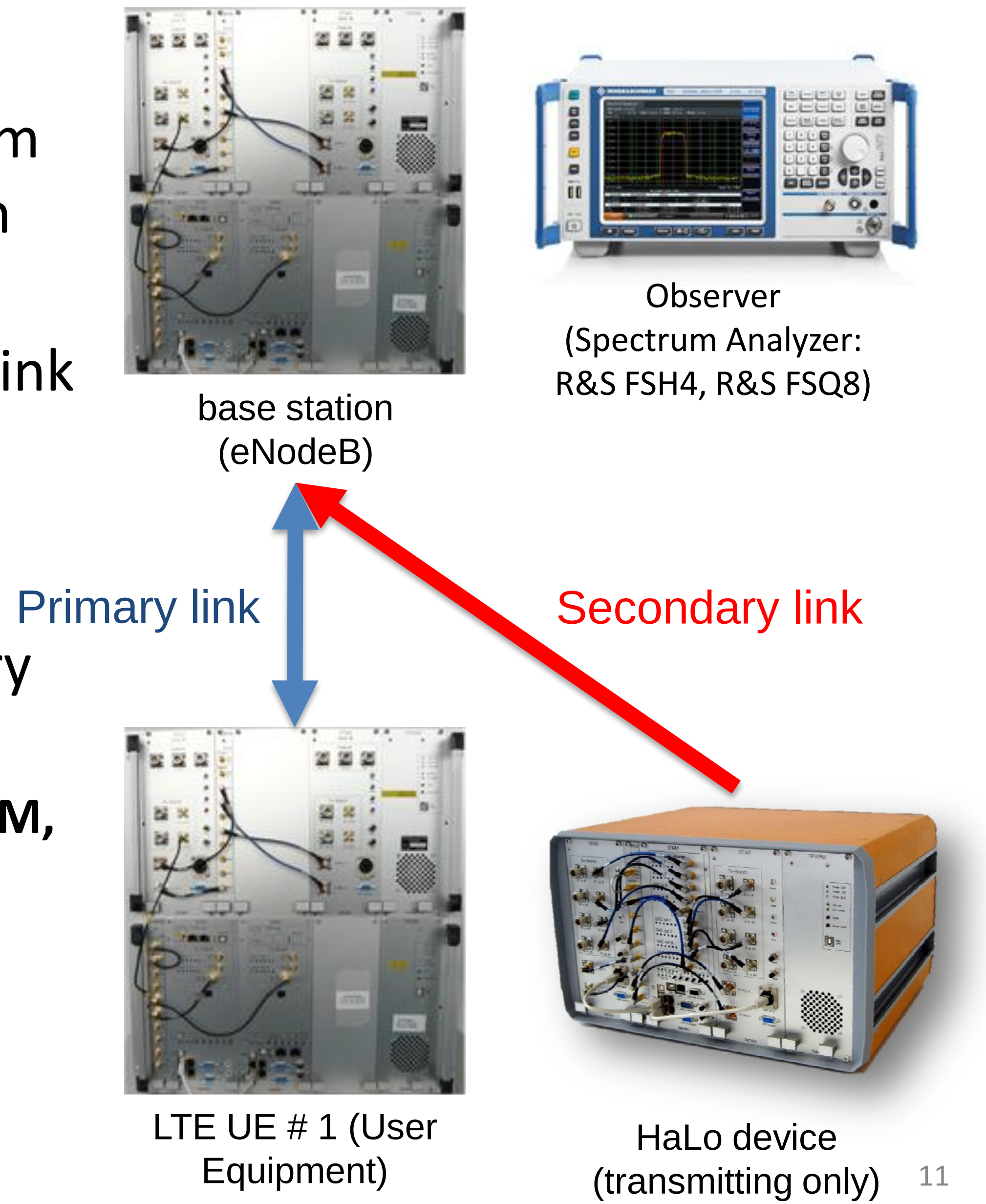
- M2M device uses LTE uplink for communication



Example scenarios

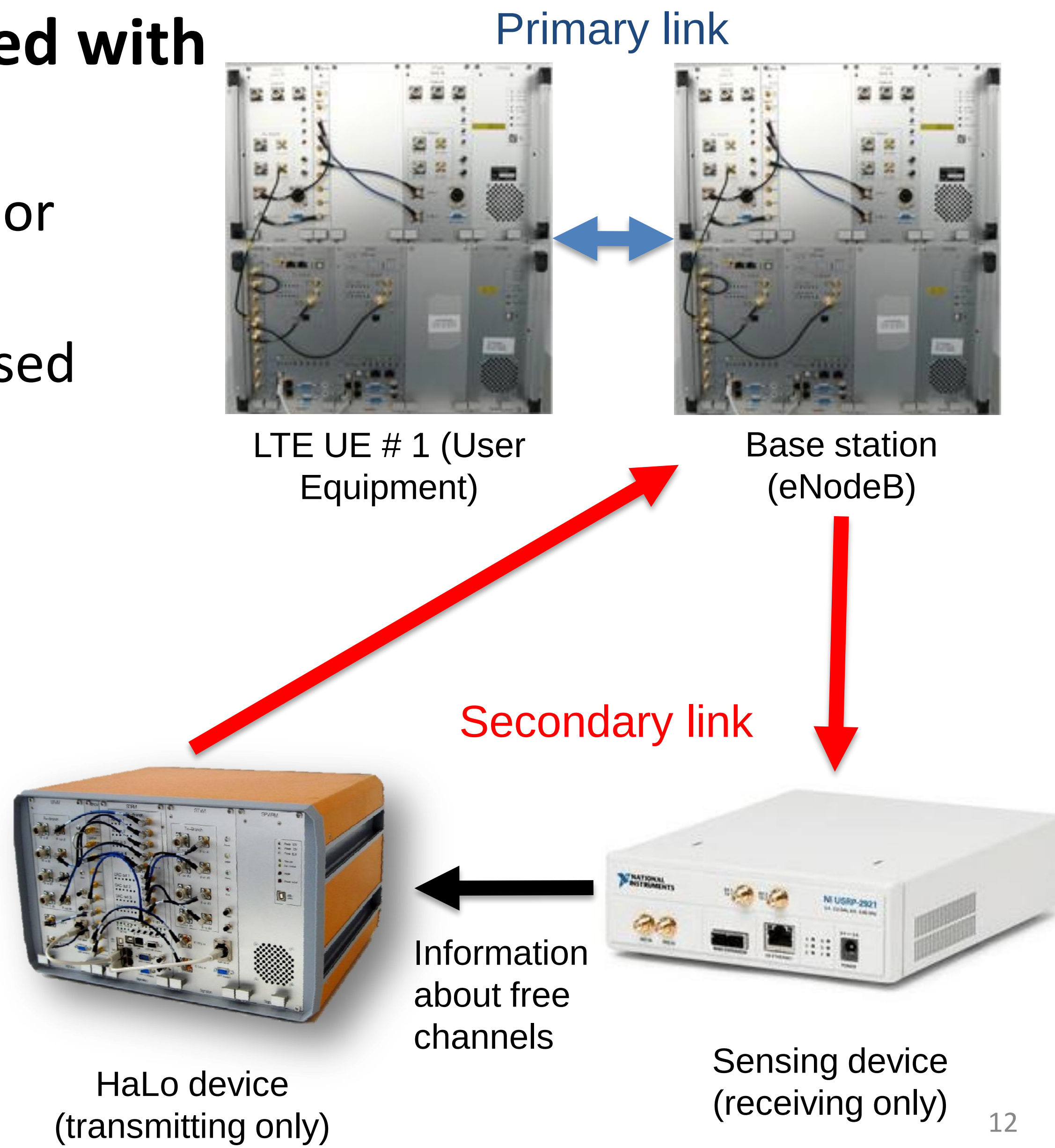
Basic setup

- E.g. to study impact from secondary waveform on primary system
- Parameters of primary link
  - Frequency
  - Attenuation
  - Bandwidth
- Parameters of secondary link
  - **Waveform (OFDM, GFDM, UMTS, …)**
  - Frequency
  - Attenuation
  - Bandwidth



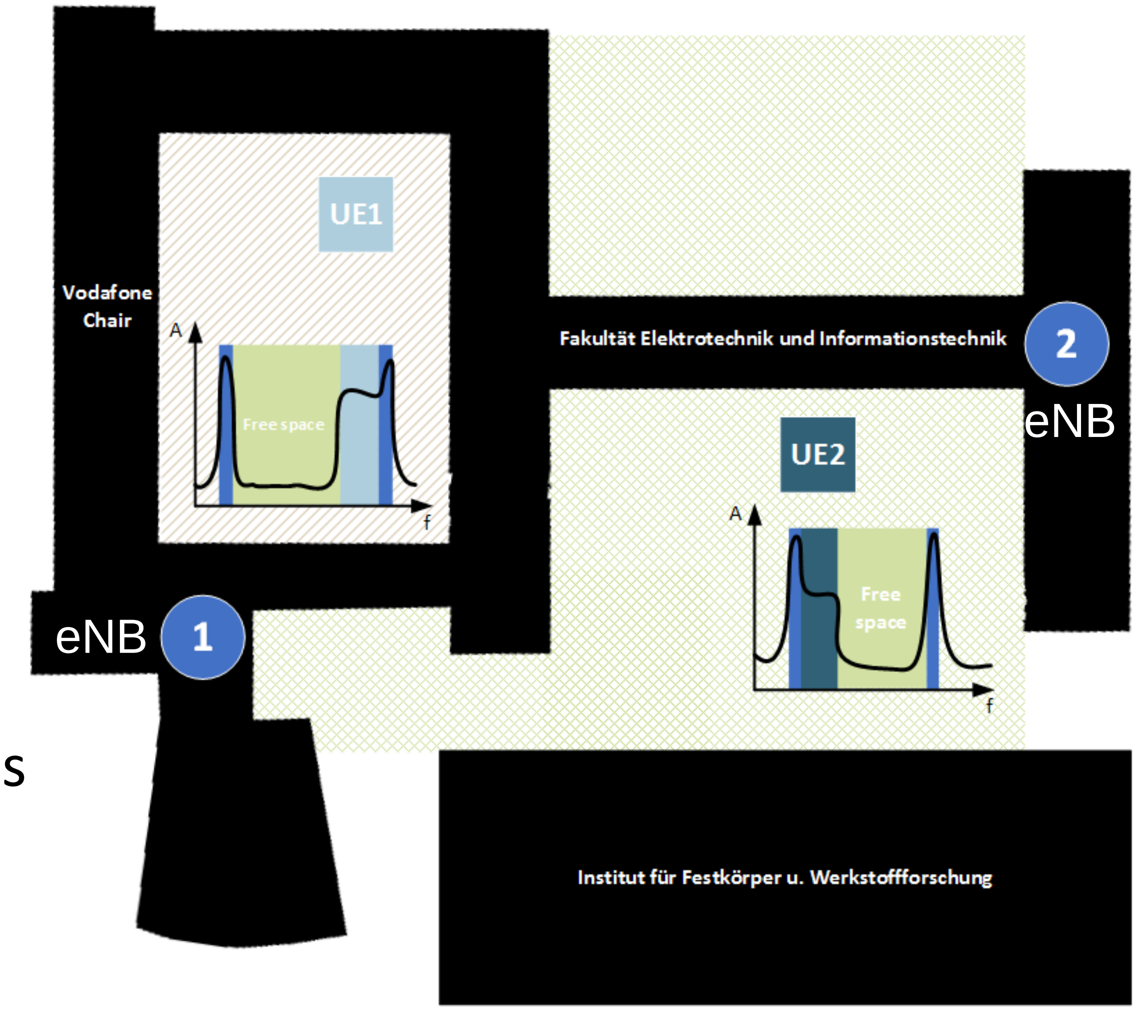
Example scenarios

- **Basic setup extended with sensing device**
  - E.g.: *NI* USRP-2920 or Spectrum Analyzer
  - To study energy based sensing algorithms



Example scenarios

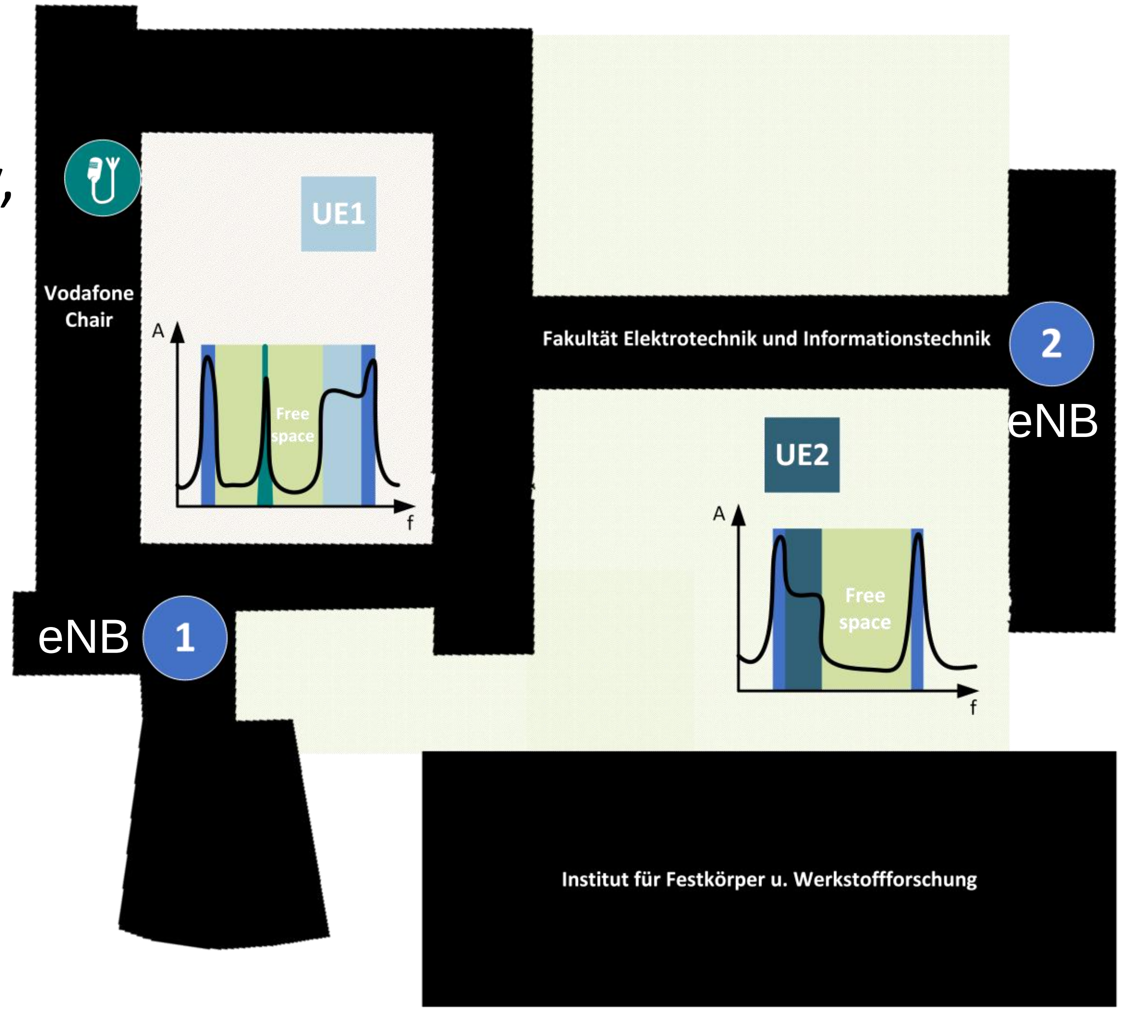
- **Basic setup in outdoor use**
- **Possible scenarios:**
  - Study differences compared to indoor environment
  - Evaluate sensing algorithms
  - Test GPS location based spectrum management systems (in combination with sensing)



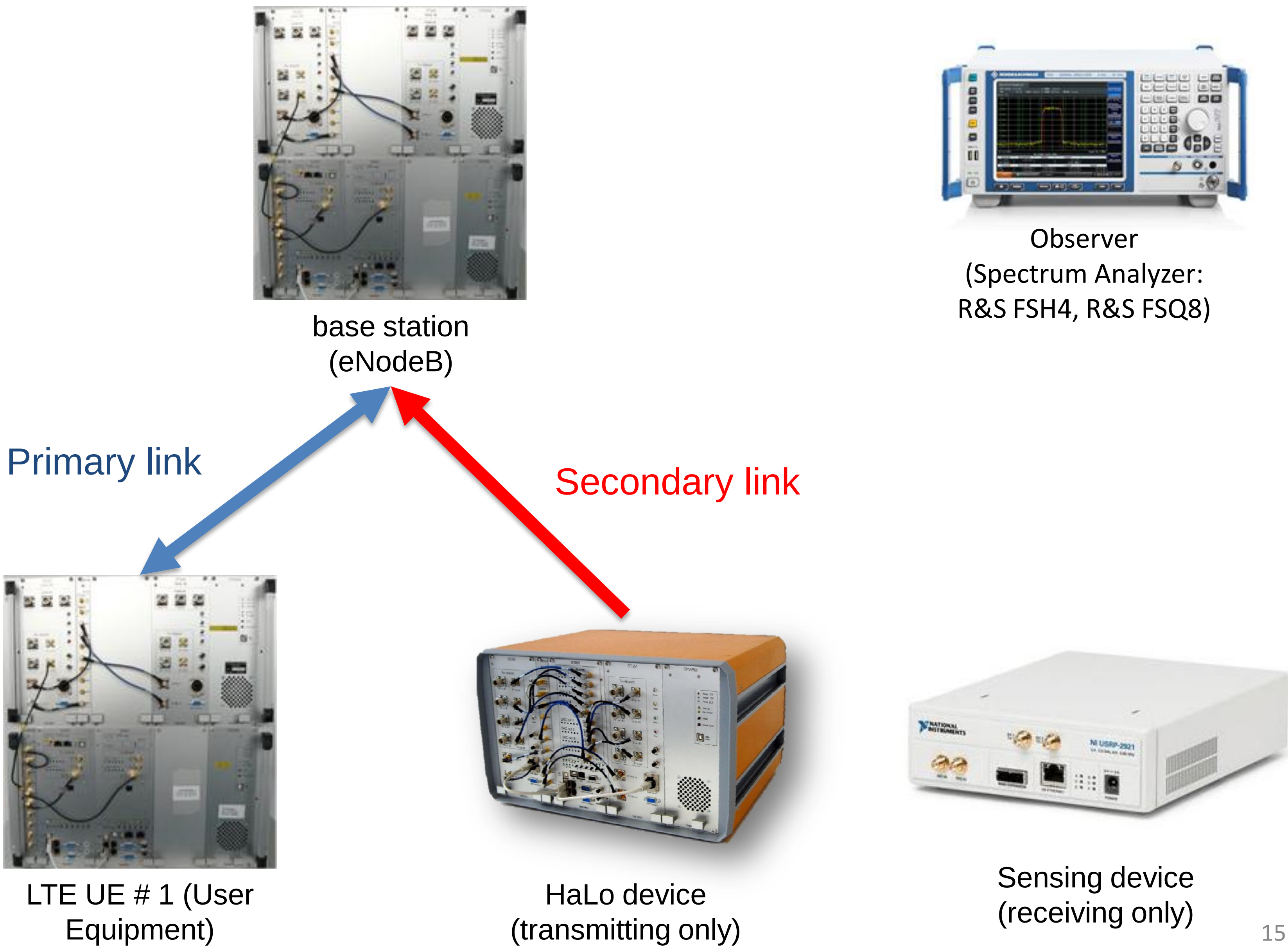
Example scenarios

Possible extensions

- Static or dynamic configuration of UE's in terms of frequency, attenuation, position…)
- Signal generator simulates small bandwidth spectrum application (wireless microphone, smart meter, …)



Setup


base station
(eNodeB)
Observer
(Spectrum Analyzer:
R&S FSH4, R&S FSQ8)
Primary link
Secondary link
LTE UE # 1 (User
Equipment)
HaLo device
(transmitting only)
Sensing device
(receiving only)

1. Start base station

Configuration file must be prepared.

1 Select config file

2 eNB reset

3 Config

2. Start UE

App controls a *SIGNALION* program, which is very sensitive to IP changes.

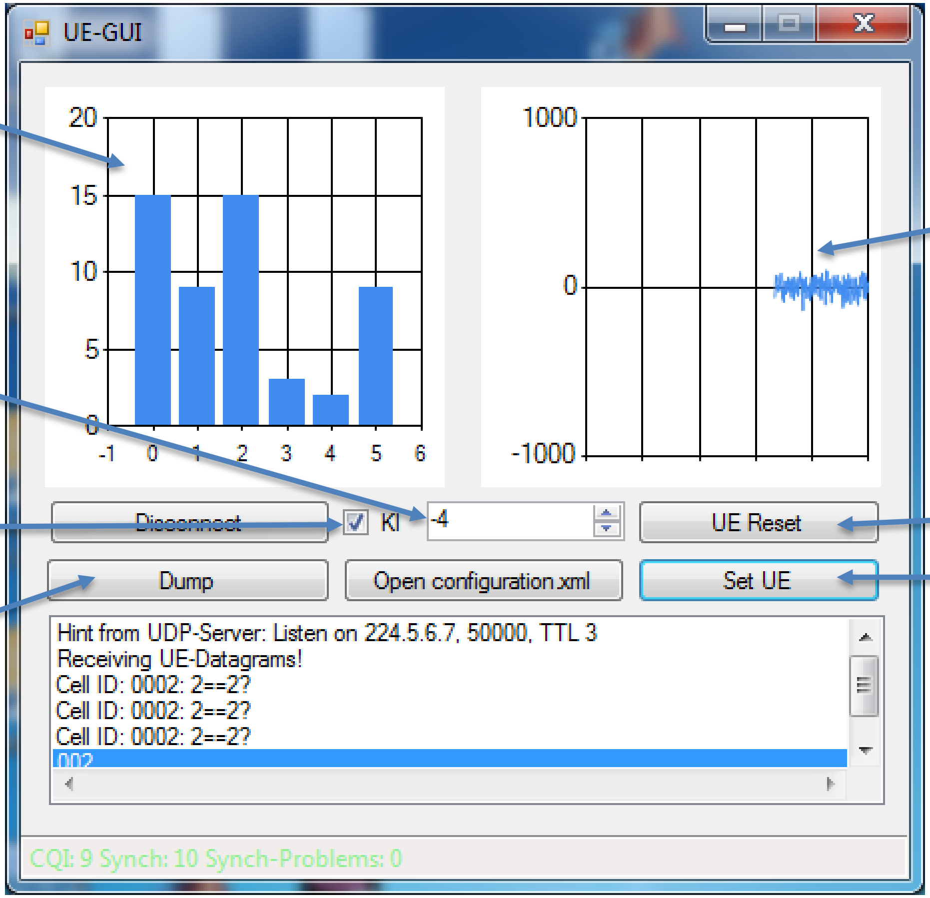
Configuration file must be prepared and loaded into *SIGNALION* program before.

Receive signal strength

Manual TX power

Restarts UE if CFO is too bad

DL dump



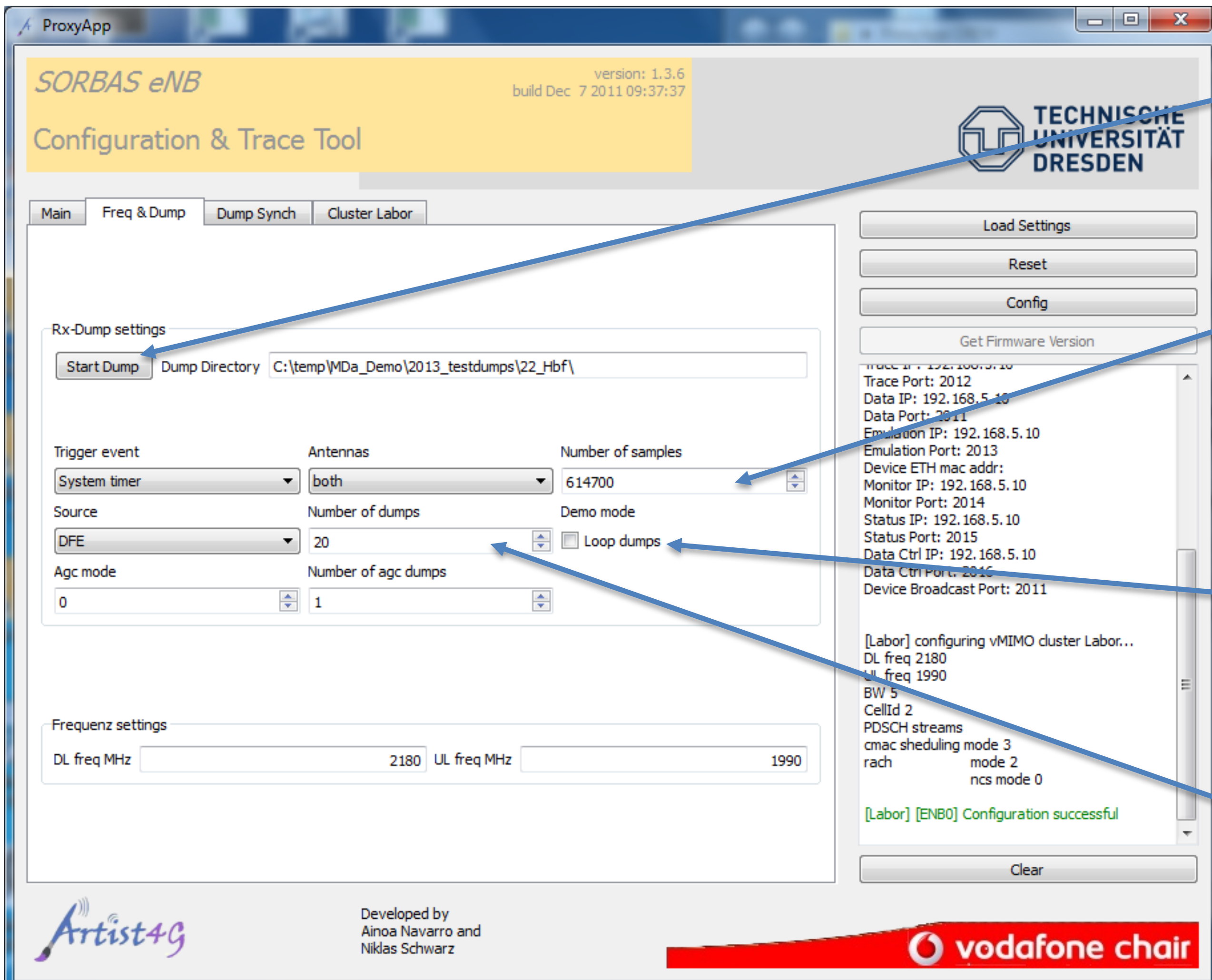
Carrier frequency offset (CFO) → DL is very sensitive

1 UE reset

2 Set UE

3. Dump signals at base station

Configuration file must be prepared.



Start dumping

Number of samples per file (should be a multiple of 30720 (1 TTI)

For live demo (dump files older than 1 min are deleted)

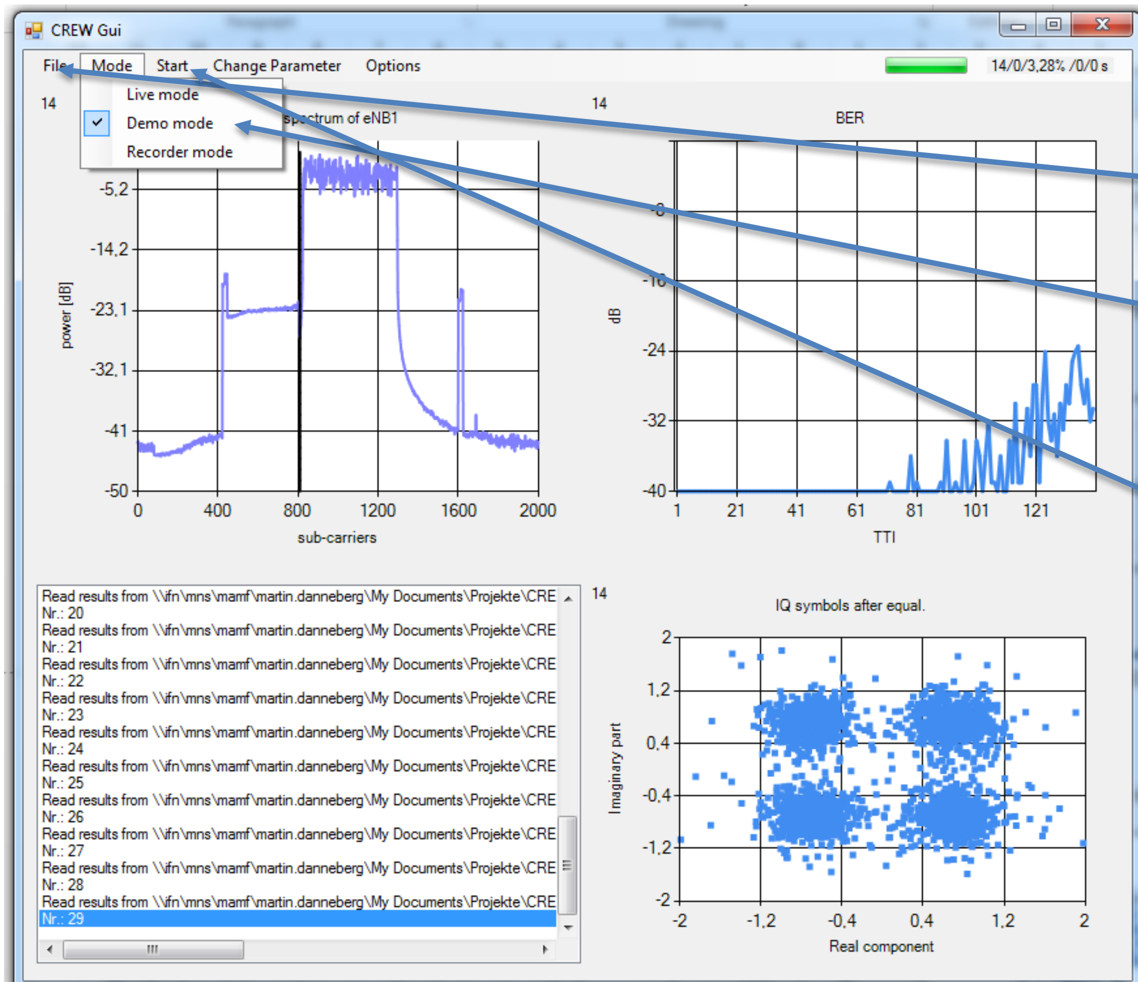
Number of dump files

Setup

4. Evaluate dump files

Dump files have to be copied in a special folder structure.

MATLAB 2013b 32bit Runtime must be installed. App uses a DLL with a MATLAB script.



1 Select dump dir

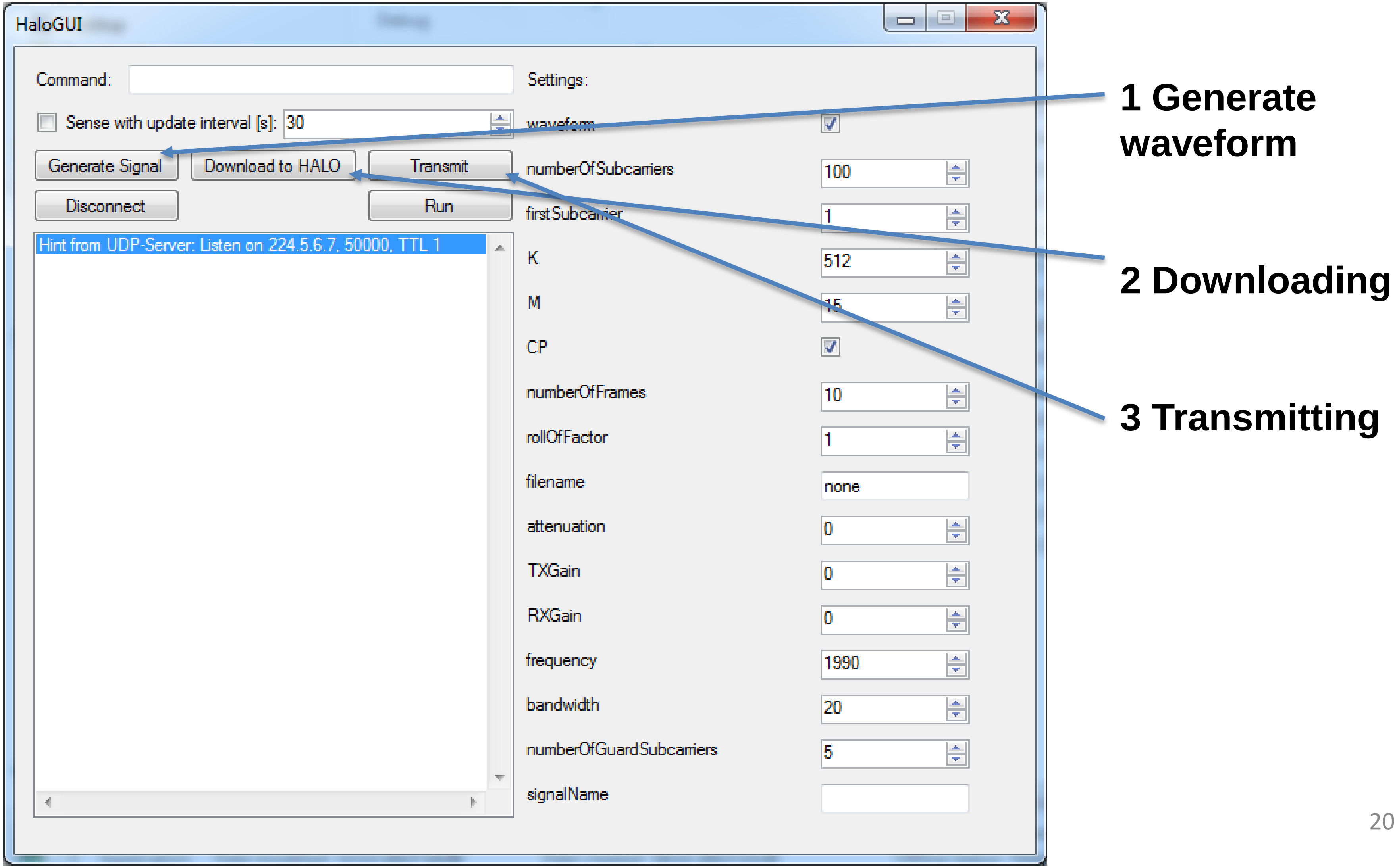
2 Select mode

Demo mode → evaluates all dump files
Live mode → evaluates only the newest file

3 Start

Controlling the secondary waveform parameters

MATLAB 2013b 32bit Runtime must be installed. App uses a DLL with a MATLAB script.



Setup

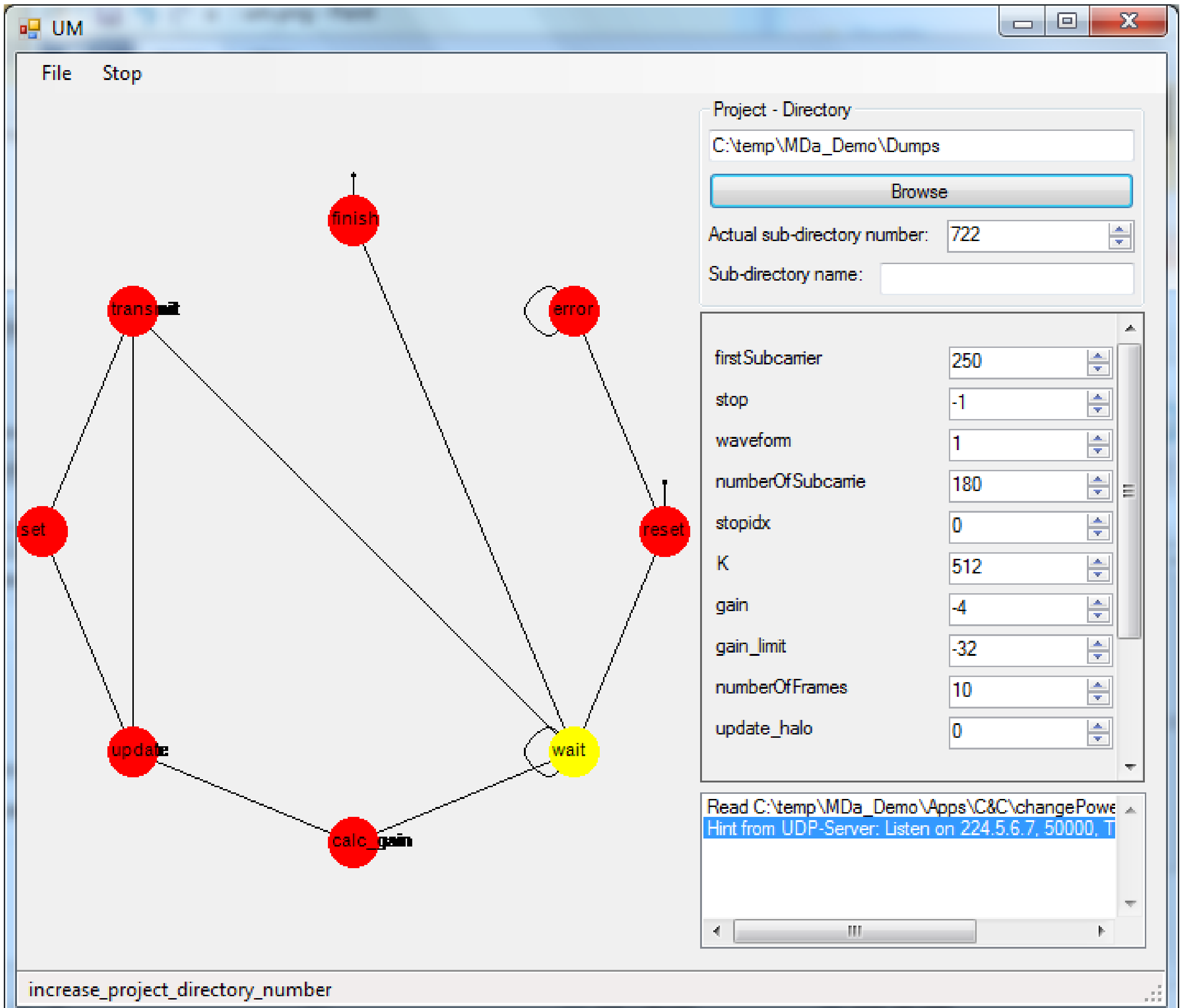
Advanced measurements

- Parameter via UDP from C&C-Server changeable
- Script controlled measurements possible
- C# based application suite
  - Created with Visual Studio
  - Working under Win XP, Vista, 7 and Linux
  - Only requirement: .NET 4 or MONO installed
- Remote controllable Applications available for:
  - UE, GPS tracking, Antenna positioning devices, HALO, Matlab, R&S spectrum analyzer, serial console based devices (e.g.: eNB’s power amplifiers), file management
  - *iMinds* USRP sensing software is currently under work
- With a little effort, every device can be added
  - Network communication in separate class available

Setup

Advanced measurements

Finite state machine based. Simple programming language using XML.




```xml
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<body>
    <variables>
        <integer>
            <idx>0</idx>
            <stop>0</stop>
        </integer>
        <string>
            <Anzeige> </Anzeige>
        </string>
        <udp>
            <IP>224.5.6.7</IP>
            <Port>50000</Port>
            <TTL>3</TTL>
            <ID>1</ID>
            <Type>1</Type>
        </udp>
    </variables>
    <fsm>
        <reset>
            <action>idx = 1;
            stop = 0;
            Anzeige = 'Bereit';</action>
            <nextState>dump</nextState>
        </reset>
        <dump>
            <action>command 'changeHaloStartIdx' 'value' idx ;
            command 'generateSignal';
            sleep 500;
            command 'DownloadToHalo';
            sleep 500;
            command 'Transmit';
            sleep 1000;</action>
            <nextState>wait</nextState>
        </dump>
        <wait>
            <action>idx = idx + 100;</action>
            <condition>idx lt 2048 then dump;
            stop eq 1 then finish;</condition>
            <nextState>wait</nextState>
        </wait>
        <finish>
            <action>Anzeige = ' Fertig! ';</action>
            <nextState>stop_fsm</nextState>
        </finish>
    </fsm>
</body>
```

Requirements for 3rd party usage

Aspects to consider

- **Scenario description**
  - Indoor, outdoor
- **Hardware requirements**
  - Size
  - Power supply
- **Software requirements**
  - Windows, Linux
  - Internet access
  - Script controlled measurements with own devices
    - → Test bed uses MATLAB & C# .NET
- **Parameters and metrics**

Available support

- **Preparing indoor/outdoor measurement**
- **Setting LTE test equipment up**
- **Applying new waveforms to the HALO-Box (time signal is needed)**
- **Assisting to prepare script controlled measurements**
- **Documentation of test bed facilities**
  - Overview *SIGNALION* SORBAS and HALO test equipment
  - Datasheet of *R&S* spectrum analyzers

Contact

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Outlook

- **Migrate to new hardware platform**
  - *NI* PXI System with Labview software environment
  - FPGA-based
- **Implementation of a GFDM Transceiver**

RF Transceiver module 5791, 5781

NI FlexRIO FPGA-module 7965

PXI 1082 Chassis

Thank you!

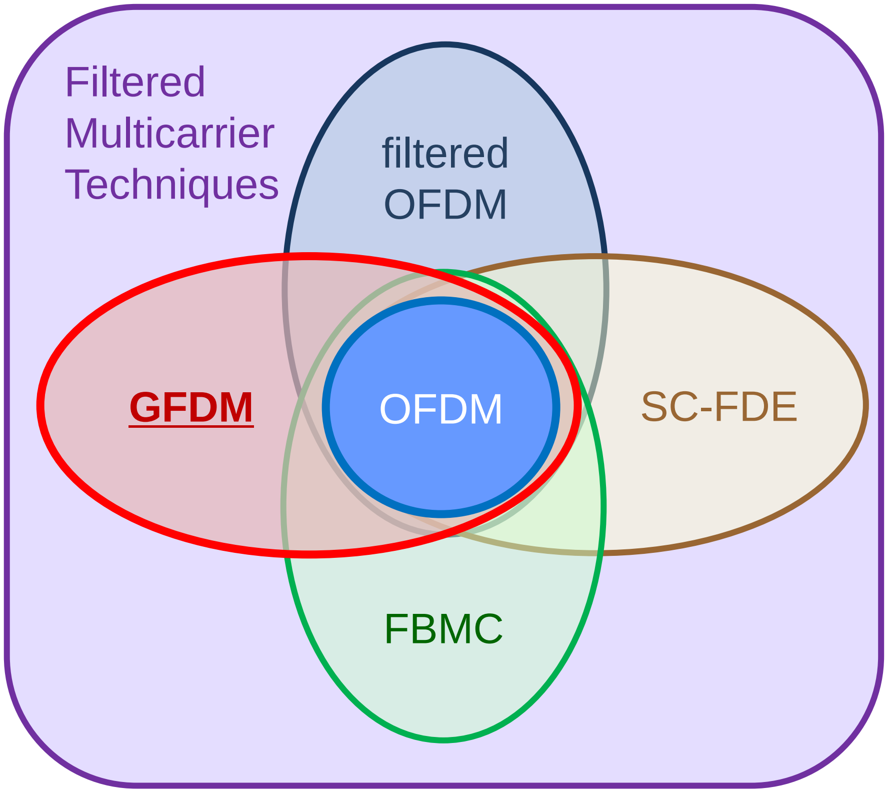
The research leading to these results has received funding from the European Union's
Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 258301 (CREW project).

Background: Cellular Networks

- Todays 4G cellular networks (LTE-Advanced) are based on Orthogonal Frequency-Division Multiplexing (OFDM)
- For future 5G cellular network, new waveforms are considered

Candidate filtered multi-carrier techniques for 5G:

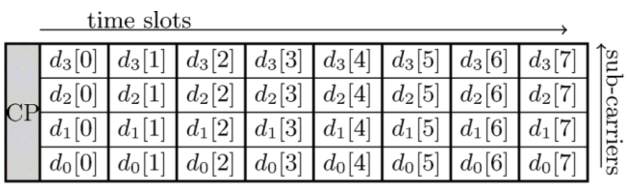
- OFDM
- filtered OFDM
- SC-FDE
- FBMC
- <u>**GFDM**</u>



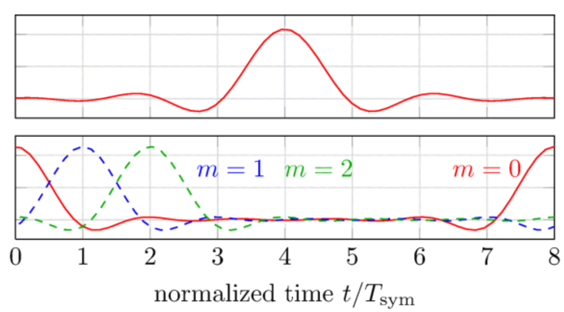
Background: Cellular Networks

- GFDM: Generalized Frequency Division Multiplexing
  - Non-orthogonal multi carrier scheme with pulse shaping
  - Data is spread on time-frequency grid
- GFDM main benefits compared to OFDM
  - Relaxed requirements on orthogonality and synchronism
  - Less out-of-band interference and lower peak-to-average power ratio
  - Time-frequency resource grid enables flexible resource assignment
  - Accommodate low-rate and high-rate users
- GFDM potential issues (being increasingly alleviated by ongoing research)
  - Self-interference and higher complexity

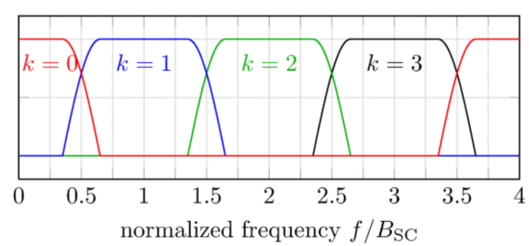
GFDM resource grid



Circular sub-carrier pulse shape



Non-orthogonal sub-carriers

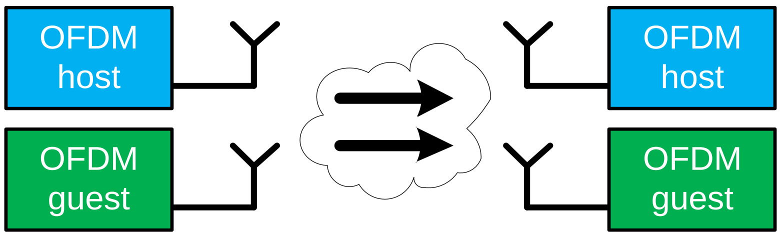


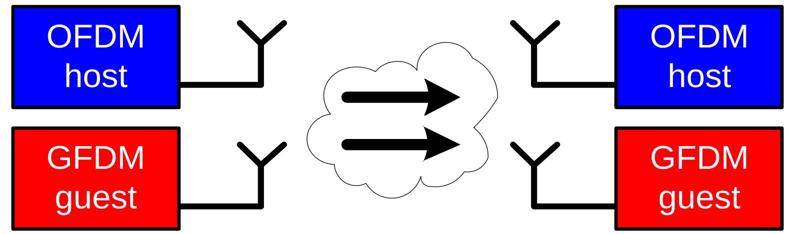
Background: Cellular Networks

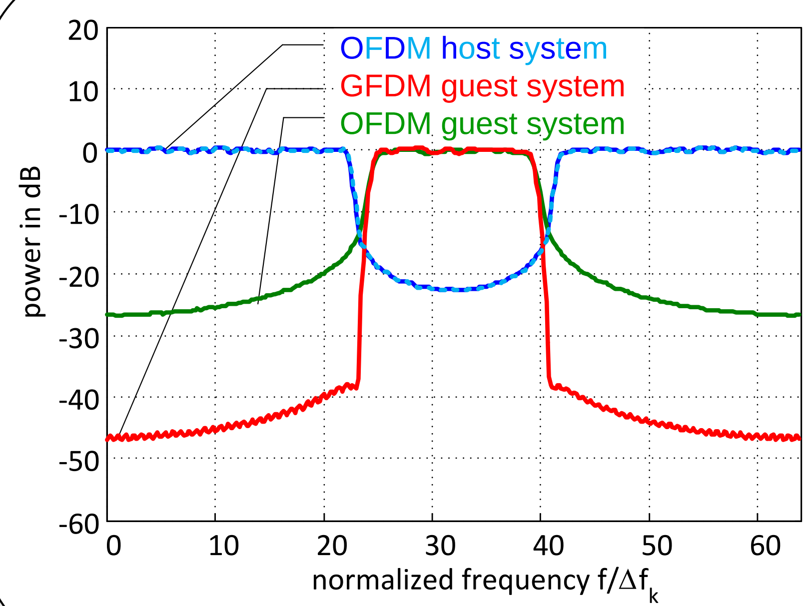
- For future coexistence of 4G and 5G networks, GFMD has favorable features
  - Spectrally shaped sub-carriers
  - Flexible resource grid
- Coexistence scenario
  - *Host system* is OFDM with a number of silenced subcarriers
  - *Guest system* is designed to match the created white space
- GFDM as guest system
  - creates less interference to host system
  - causes lower BER in host system

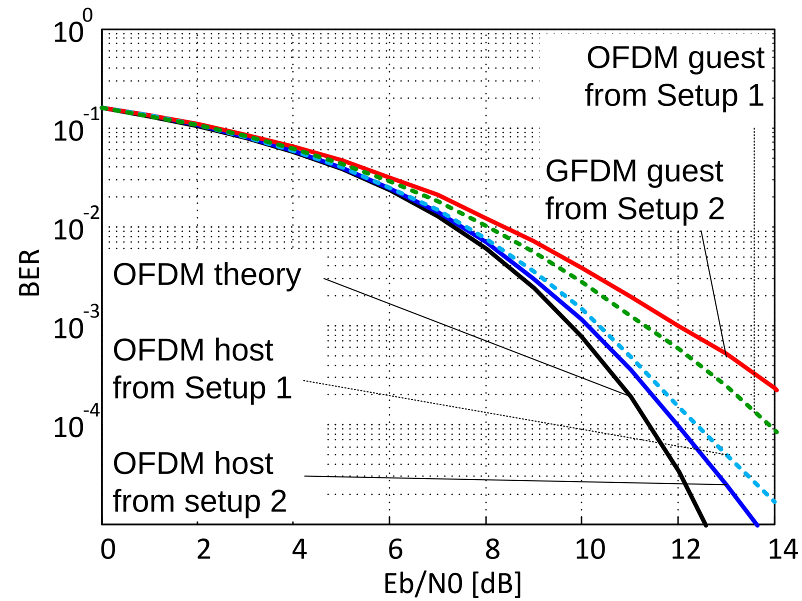
→ see next slide

Background: Cellular Networks









N. Michailow et al. *"Integration of a GFDM secondary system in an OFDM primary system"*, Proc. FNMS 2011