5GNOW

5th Generation Non-Orthogonal Waveforms for Asynchronous Signalling

Presenter: **Gerhard Wunder,** gerhard.wunder@hhi.fraunhofer.de

COST Meeting, Ferrara (Italy) 2014

5GNOW

- What is 5GNOW?

  5GNOW (5th Generation Non-Orthogonal Waveforms for Asynchronous Signalling) is an European collaborative research project supported by the European Commission within FP7 ICT Call 8.

- Who is in the consortium?
  - **Fraunhofer HHI (coordinator), Germany, *Dr. Gerhard Wunder***
  - **Alcatel Lucent (technical coord.), Germany, Thorsten Wild**
  - **Technische Universität Dresden, Germany, *Prof. Gerhard Fettweis***
  - **CEA-LETI, France, *Dr. Dimitri Ktenas***
  - **IS-Wireless, Poland, *Dr. Slawomir Pietrzyk***
  - **National Instruments, Hungary, *Dr. Bertalan Eged***

- *Budget: 3.526.991 EURO*

Vision:

- 5GNOW is the physical layer evolution of mobile communication network technology such as LTE-Advanced towards emerging application challenges.

Outline

(1) 5GNOW in a nutshell

(2) 5GNOW Status

- D2.1: Reference Scenarios
- D3.1: Physical Layer Waveforms
- D4.1: Robustness Framework
- D5.1: Demonstrator

(3) Conclusions

5GNOW in a nutshell

4G Situation

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Situation: LTE and LTE-Advanced have been optimized to deliver high bandwidth pipes to wireless users. The transport mechanisms have been tailored to maximize performance by enforcing strict synchronism and orthogonality.
Various emerging trends reveal major shortcomings of those design criteria:

Machine-type-communications (MTC) is growing fast. Transmissions of this kind are suffering from the bulky procedures necessary to ensure strict synchronism

Collaborative schemes have been introduced to boost capacity and coverage (CoMP), and wireless networks are becoming more and more heterogeneous (HetNet) Tremendous efforts must be spent to collect the gains and to manage such systems under the premise of strict synchronism and orthogonality.

The advent of the Digital Agenda and the introduction of carrier aggregation are forcing the transmission systems to deal with fragmented spectrum.

5GNOW Approach

The obedience of LTE and LTE-Advanced to strict synchronism and orthogonality will be challenged.

At the core of this paradigm change we will introduce non-orthogonal waveforms that carry the data on the physical layer:

1) Abandon synchronism and orthogonality altogether, thereby admitting some crosstalk or interference, and to

2) control these impairments by a suitable, most likely, more complex transceiver structure and transmission technique with a boost from Moore's law.

3) Reality check and proof-of-concept with hardware demonstrator

4) 5GNOW will contribute to upcoming 5G standardization.

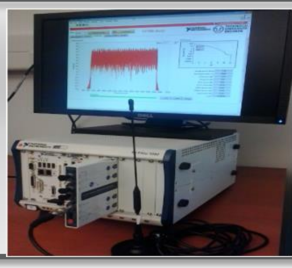
Wireless transmission networks will be better prepared

1) to meet the manifoldness of services, device classes (like in smart cities),

2) to integrate MTC systems, e.g. sensor networks.

3) The per-user experience will be more uniform and satisfying.

5GNOW Architecture



Demonstration

MTC
Enable asynchroneous MTC traffic with drastically reduced signalling

CoMP/ HetNet
Provision of asynchronous CoMP/HetNet concepts

Fragmented Spectrum
Implementation of asynchroneous carrier aggregation concepts

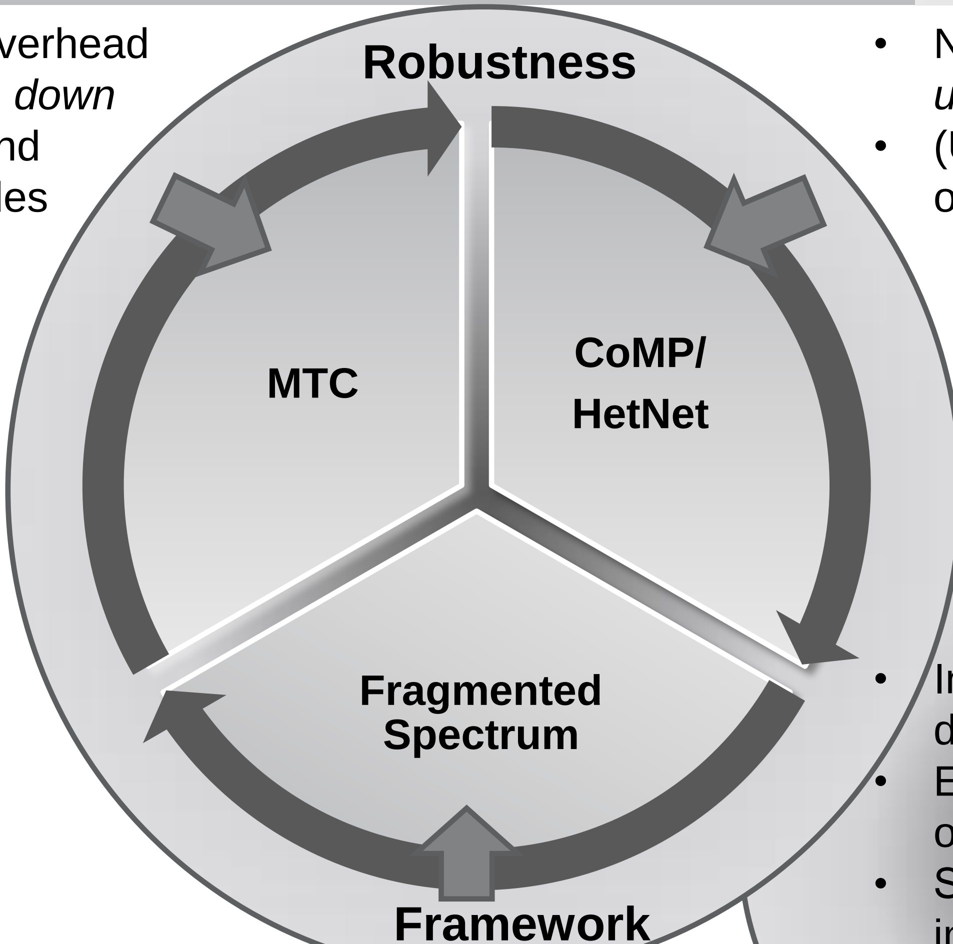
CORE: Re-design of LTE-A PHY Layer based on 5G Non-Orthogonal Waveforms

MAC Design

5GNOW Objectives: Quantitative Measures

- Control signalling overhead per payload *50% down*
- Energy efficiency and lifetime of MTC nodes

- Network capacity *100% up*
- (Uplink) control signalling overhead *25% down*



- Indicators for allowable degree of asynchronism
- Extraction and abstraction of such to upper layers
- System's sensitivity to imperfect network state, mobility etc.

- Bandwidth efficiency in white spaces
- Waveform properties such as peak-to-average power ratio, out-of-band leakage x1*00*

5GNOW Status
Tangible Results

5GNOW Status

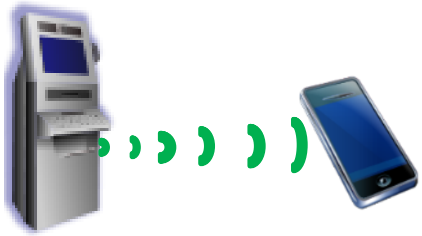
G. Wunder, P. Jung, M. Kasparick, T. Wild, F. Schaich, S. ten Brink, Y. Chen, I. Gaspar, N. Michailow, A. Festtag, G. Fettweis, N. Cassiau, D. Ktenas, M. Dryjanski, S. Pietrzyk, B. Eged, P. Vagp, and F. Wiedmann, **"5GNOW: Non-Orthogonal, Asynchronous Waveforms for Future Mobile Applications"**, to appear in *IEEE Communications Magazine, 5G Special Issue, Feb. 2014*

G. Wunder, H. Boche, T. Strohmer, P. Jung, "**Sparse Signal Processing Concepts for 5G System Design**", IEEE Signal Processing Magazine, 5G Special Issue 2014, accepted white paper

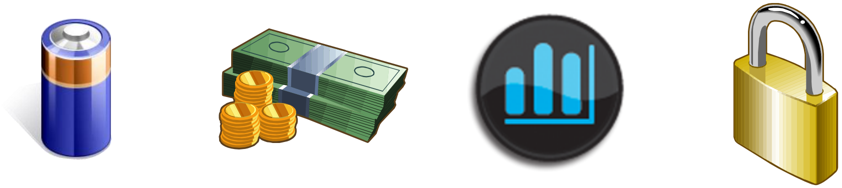
- 5GNOW Webseite (www.5gnow.eu): ~50000 hits
- LinkedIn Group 5GNOW: 173 members
- Deliverables:
  - **D2.1: *Key Performance Indicators and Initial System Concepts***
  - **D3.1: *5G Waveform Candidate Selection***
  - **D4.1: *Intermediate MAC Concept***
  - **D5.1: *Initial Demonstrator Concept***

D2.1: Reference Scenarios

- Gigabit Wireless Connectivity
  - E.g. 3D streaming ~100 Mbit/s, but download is expected 100 times faster: Wireless data kiosk (~ 10Gbit/s) content download

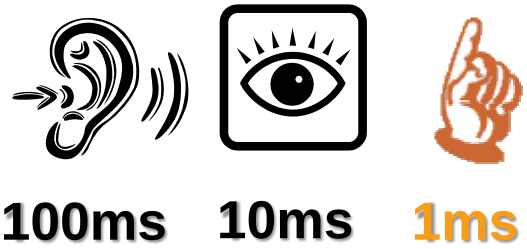


- Internet of Things: *the next killer application*
  - Scalability problem (>100k nodes in a cell):



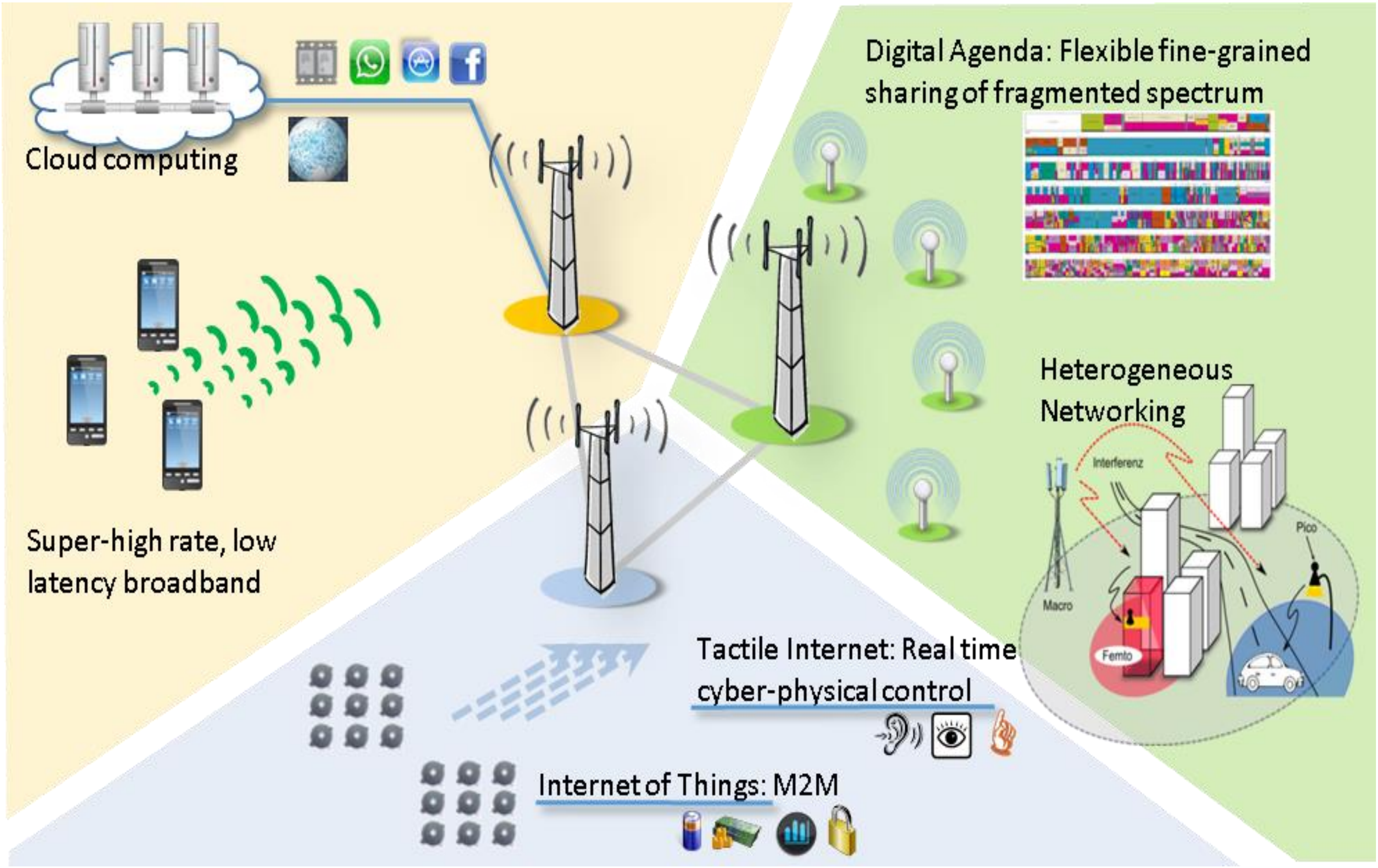
D2.1: Reference Scenarios

- Fragmented Spectrum and the *spectrum paradox*:
  - Spectrum scarce and expensive but underutilized
  - White Spaces communication: 100x better localization, PAPR issues



- Tactile Internet (Real-time *cyber-physical tactile control*)
  - Toughtest constraint: human tactile sensing (distinguishes latencies in the order of 1ms)
  - 1ms round-trip: time budget on PHY: **max 100µs**

D2.1: Reference Scenarios



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Wireless Access:

- flexible
- scalable
- content aware
- robust
- reliable
- efficient (energy, spectrum)

5GNOW has taken a big step towards these requirements …

(CommMag-Paper, Feb. 14)

D3.1: Unified Frame Structure

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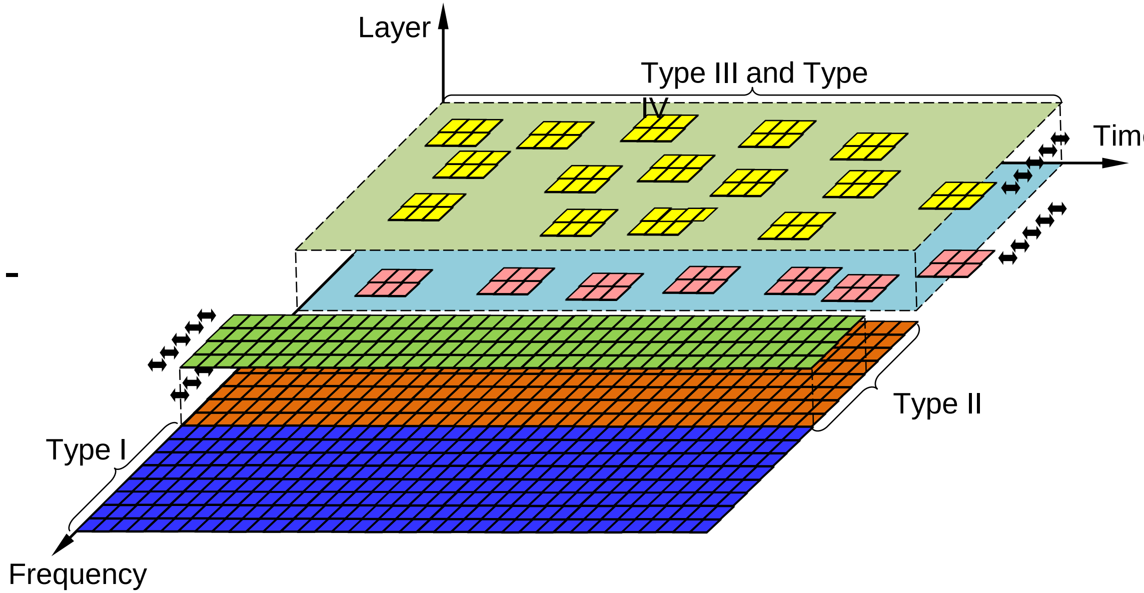
Target:
Efficiently combine various types of service and performance classes within a common radio frame (from small packet service - types III and IV - to high rate ‘bit-pipe’ – types I and II) for scalability.

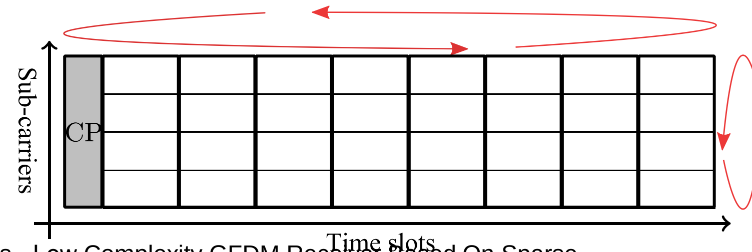


Traffic Type	Synch?	Access Type	Properties
I	closed-loop	scheduled	classical high volume data services
II	open-loop	scheduled	HetNet and/or cell edge multi-layered high data traffic
III	open-loop	sporadic, contention-based	few bits, supporting low latency, *e.g. smartphone apps*
IV	open-loop/none*	contention-based	energy-efficient, high latency, few bits

D3.1: Waveform Approaches

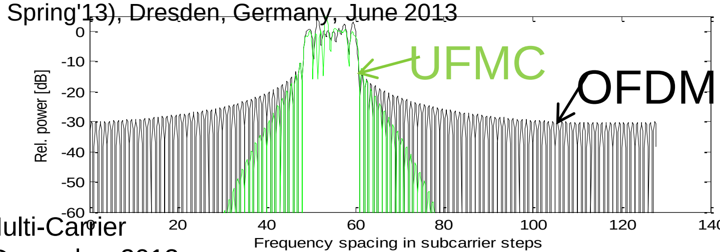
Considered waveform approaches:

- Generalized Frequency Division Multiplexing (GFDM)



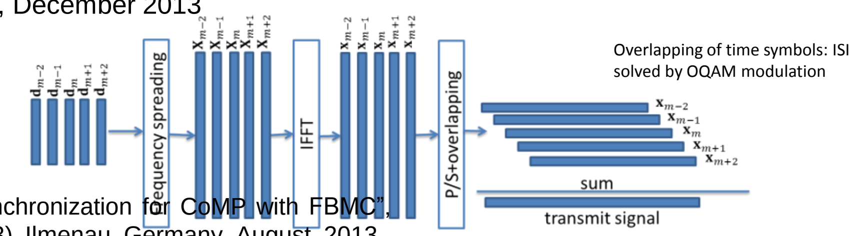
I. Gaspar, N. Michailow, A. Navarro Caldevilla, E. Ohlmer, S. Krone and G. Fettweis, „Low Complexity GFDM Receiver Based On Sparse Frequency Domain Processing“, 77th IEEE Vehicular Technology Conference (VTC Spring'13), Dresden, Germany, June 2013

- Universal Filtered Multicarrier (UFMC)



V. Vakilian, T. Wild, F. Schaich, S.t. Brink, J.-F. Frigon, "Universal-Filtered Multi-Carrier Technique for Wireless Systems Beyond LTE", IEEE Globecom'13, Atlanta, December 2013

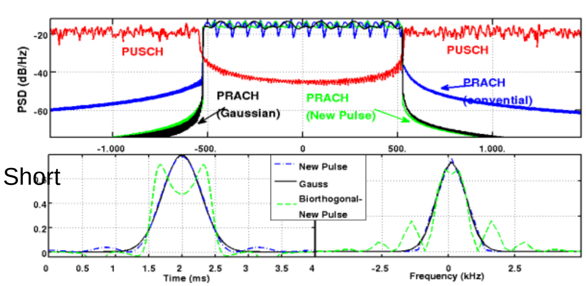
- Filter Bank Multicarrier (FBMC)



FBMC transmitter with filtering in the frequency domain

Nicolas Cassiau, Dimitri Kténas, Jean Baptiste Doré, “Time and frequency synchronization for CoMP with FBMC”, Tenth International Symposium on Wireless Communication Systems (ISWCS’13), Ilmenau, Germany, August, 2013

- Bi-orthogonal Frequency Division Multiplexing (BFDM)



G. Wunder, M. Kasparick, P. Jung, “Bi-orthognal Waveforms for 5G Random Access with Short Message Support”, IEEE European Wireless, 2014, invited paper

D3.1: Random Access

Observation: Many traffic classes require **very fast acquisition** and therefore an **efficient common control signalling channel!**

Elements of 5G random access

- Many users can potentially access the resource; resource is not designed to accomodate all users
- Data and control in the same resource („one shot“); control cannot be fully separated from data
- Sparsity of user activity, message sizes, and channel profiles is expected
- Asynchronous user access in many small frequency slots required

HHI approach: **Non-orthogonal Pulse Shaped Compressive Random Access**

D3.1: Random Access

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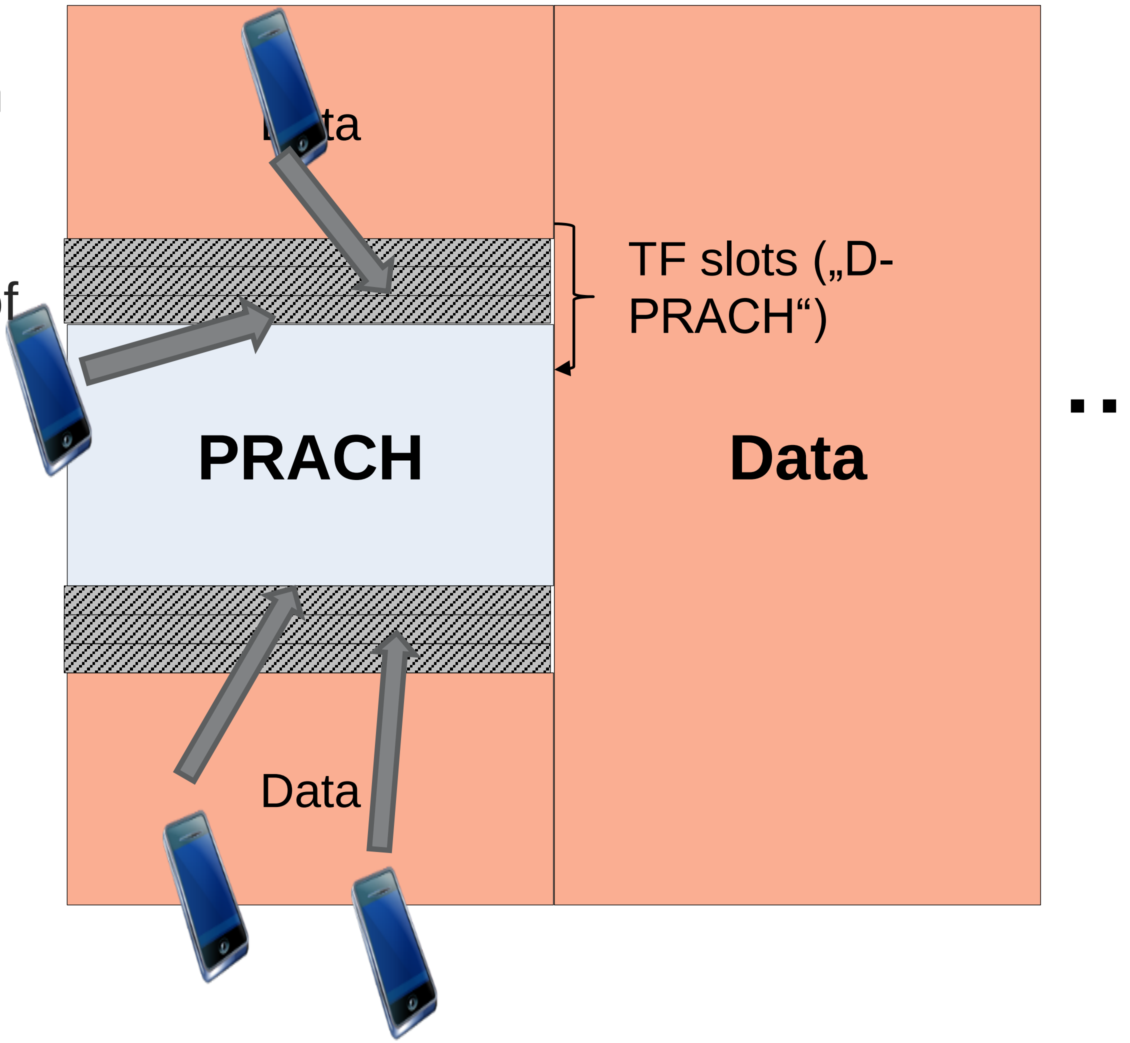
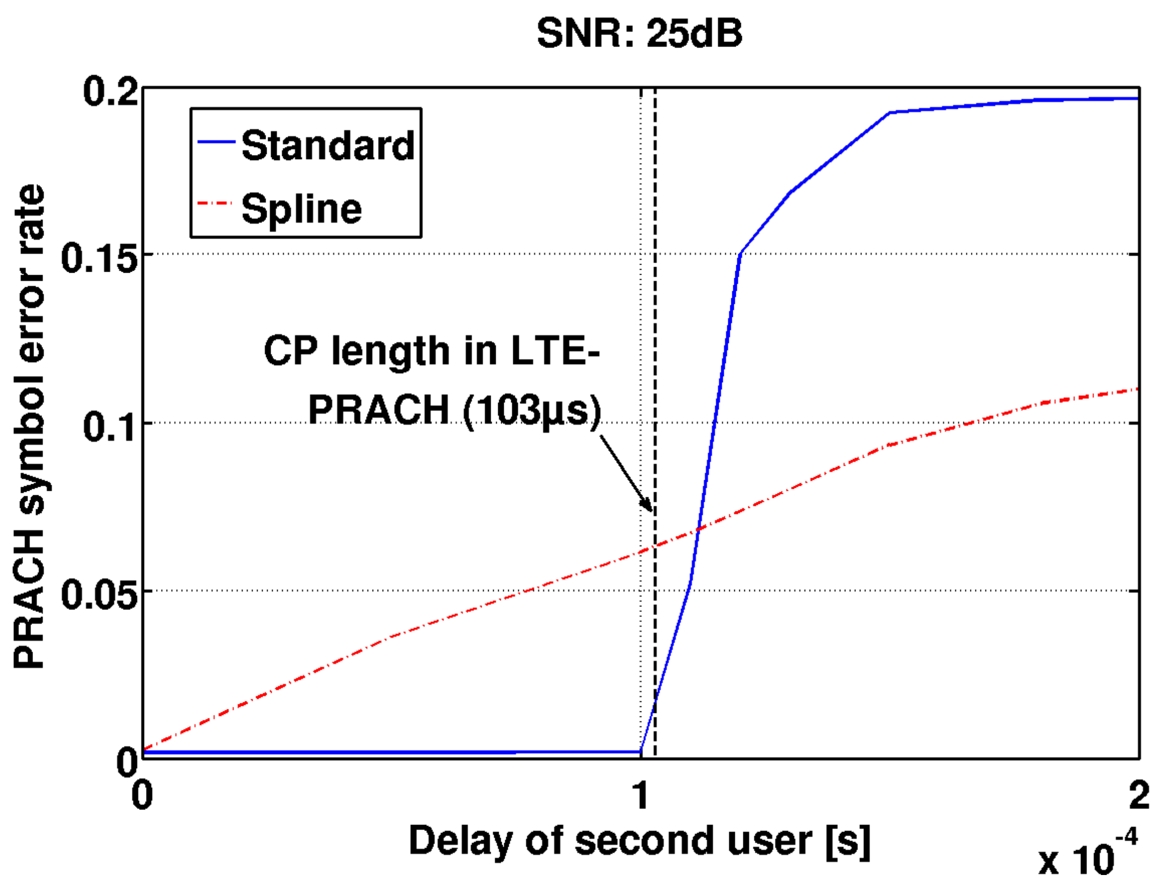
- **4G Orthogonal design**: Unused guard band between different TF slots
- **5GNOW non-orthogonal design**: Allow transmission of small data packets in a number of adjacent subcarriers
- Completely asynchronous user access: **non-orthogonal waveforms needed due to bad localization and spectral efficiency**



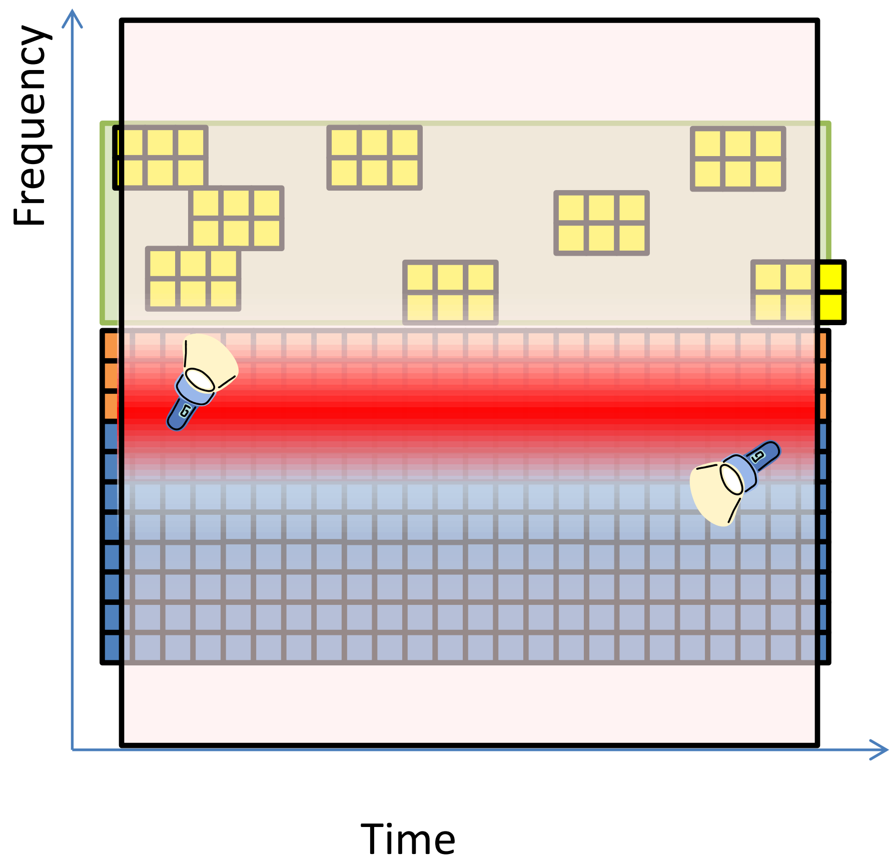
D3.1: Random Access



Symbol error rate in D-PRACH averaged over 10 out of 20 subcarriers available for data transmission vs. the time offset of a second user. The other 10 subcarriers are used by the second (asynchronous) user. The black line indicates the cyclic prefix length in LTE PRACH.

D4.1: Compressive Random Access

1) Compressive measurements in a dedicated channel
2) Underlay signalling
3) 5G-RACH illuminates the whole bandwidth
4) Payload outside dedicated channel



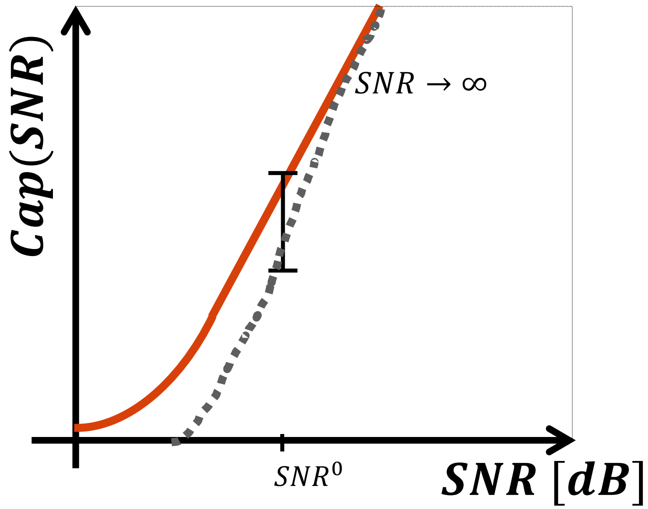
D4.1: Robustness Framework

Why robustness?

- CoMP promises vast gains, however disappointing results in practice
- Literature: Analysis based on DoF
- Limited feedback results fragile

J. Schreck, G. Wunder, and P. Jung, “Distributed Interference Alignment with Limited Feedback for Cellular Networks", Accepted for International Workshop on Emerging Technologies for LTE-Advanced and Beyond-4G, IEEE Globecom'13, Atlanta, GA, USA, December 2013

- Solution: New metrics needed!



5GNOW claim: <u>limited feedback</u> in multiuser multicell networks is not properly addressed so far!

Erroneous information from terminals can lead to wrong decisions

Ideal link adaptation is assumed

Direct link often neglected

D4.1: Robustness Framework

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- New: per-user metric

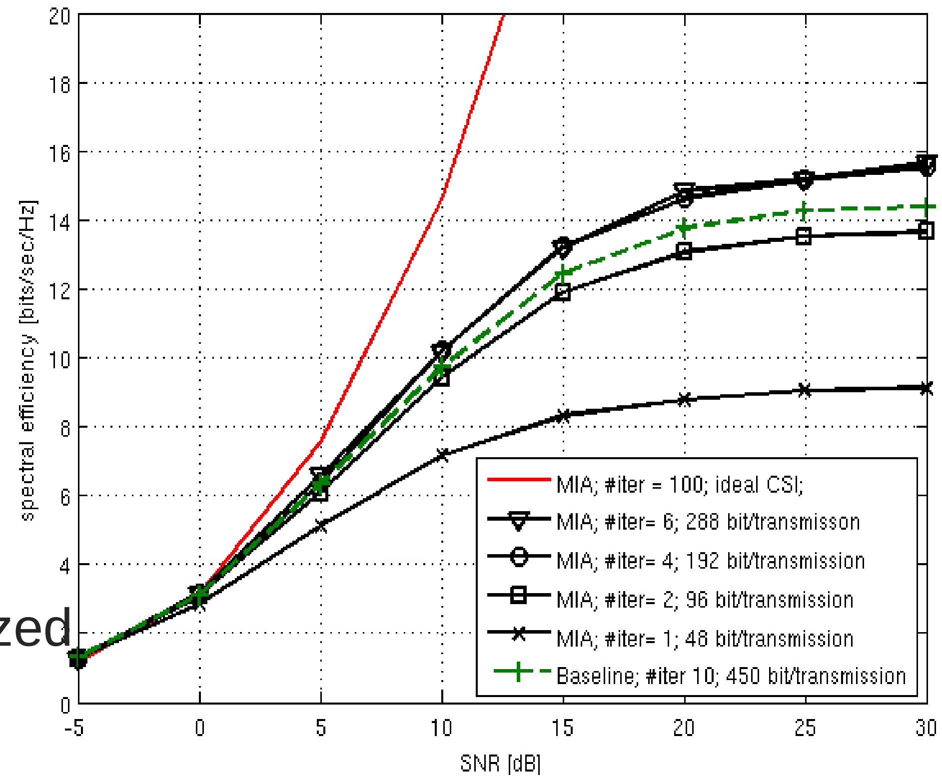
standard metric: rate loss with suboptimal scheduling applied to actual channel

take real link adaptation into account: rate loss with suboptimal scheduling applied to reported channel

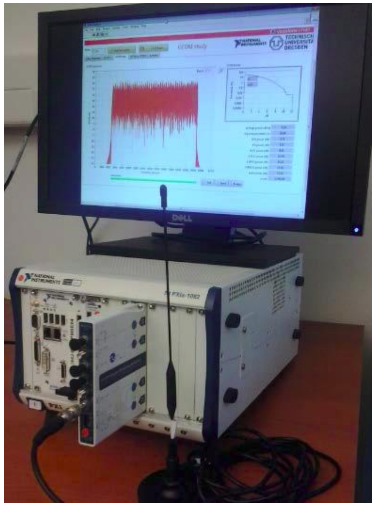
$$r_m(\pi_H, \pi_V) := \max\{r_m(\pi_H, S_H; H) - r_m(\pi_V, S_V; H), r_m(\pi_H, S_H; H) - r_m(\pi_V, S_V; V)\}$$

- Baseline: centralized algorithm
- 3 bits/scalar, 3 BS, 5x5 MIMO

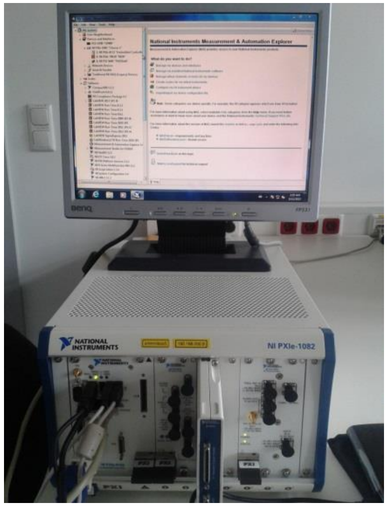
  → 450 bits/msg
- New: Iterative distributed algorithm interference alignment scheme
- Results: Already with 2 iterations and 16bit codebook very close to centralized solution



D5.1: Demonstrator



GFDM Demo platform



FBMC Demo platform

5GNOW Booth VTC

5GNOW Booth FuNeMS

Conclusions

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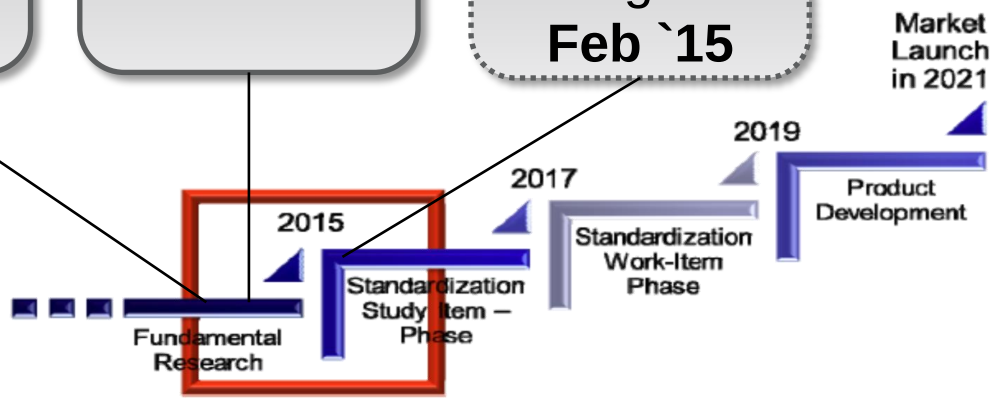
Window of opportunity 2014/2015 for launching a study item for non-orthogonal wave forms and transmission schemes

- Initiating new standardisation process towards 5th Generation mobile networks
- 5GNOW explicitly named by several EU officials to have fostered 5GPPP

VTC booth and special session **June `13**

Globecom **Dec`14**

Mobile World Congress **Feb `15**



Thank you for your attention!

www.5gnow.eu

Contact

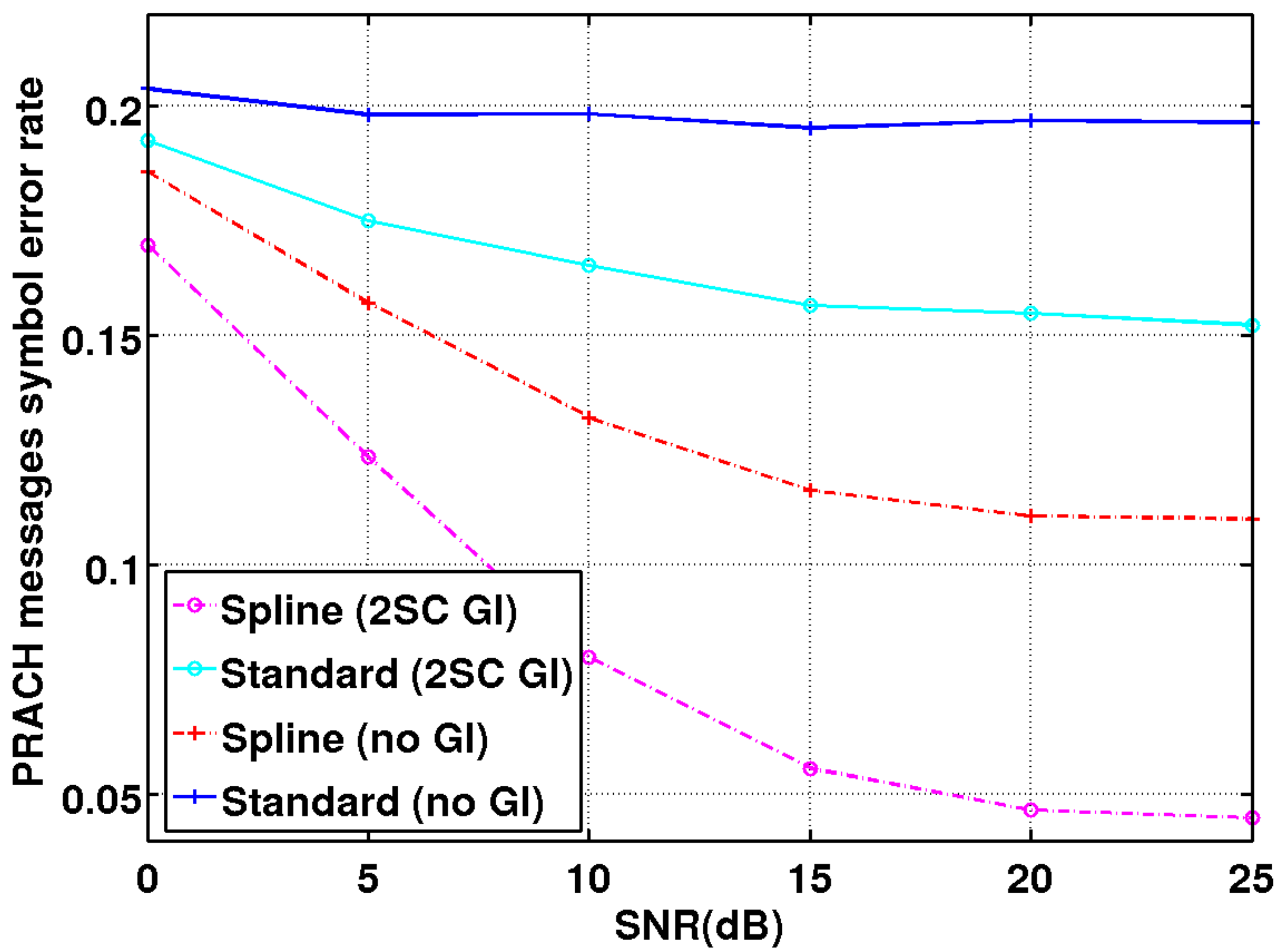
Dr. Gerhard Wunder – gerhard.wunder@hhi.fraunhofer,de

www.hhi.fraunhofer.de/wn

Fraunhofer Heinrich Hertz Institute

Berlin, Germany

Backup



PRACH messages symbol error rate
0.2
0.15
0.1
0.05
0
5
10
15
20
25
SNR(dB)
Spline (2SC GI)
Standard (2SC GI)
Spline (no GI)
Standard (no GI)

Backup

Kasten: 5GNOW adresses sporadic traffic as an enabler of the ‚Internet of Thing

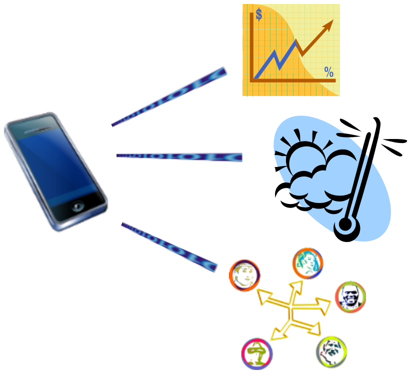
Sources for sporadic traffic

Smartphone short message delivery

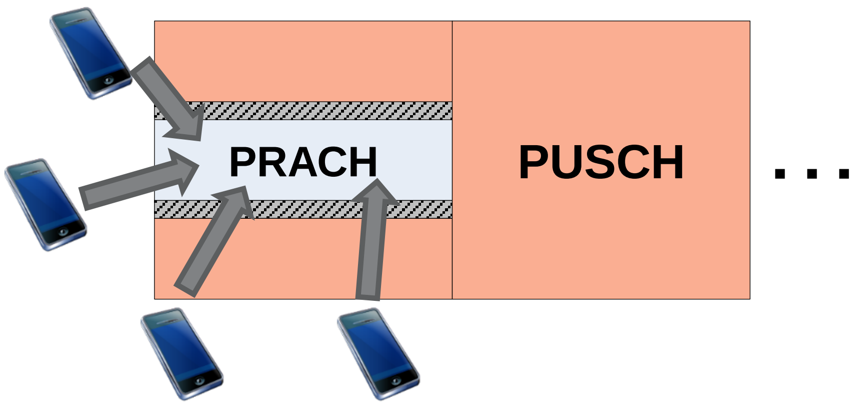
Machine-type communications (MTC)

Approach:

Waveform design, sparse signal processing



- Link acquisition and payload in **pulse-shaped PRACH**
- **Non-orthogonal design**: interference between PUSCH and PRACH
- 5GNOW PRACH: Asynchronous non-orthogonal multi-user access under sparsity constraints



Joint acquisition, channel estimation, and demodulation by iterative multi-user sparse detection!

Backup

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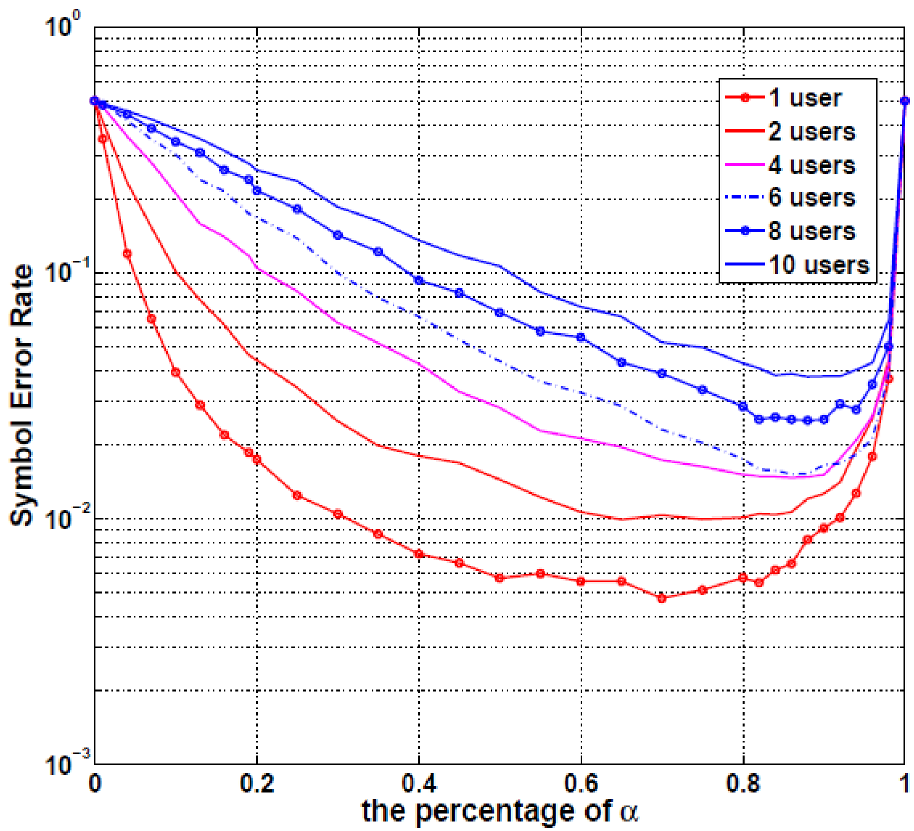
5GNOW RACH Example:

- Up to 10 users/devices out of 100 can be identified with high probability in 1ms
- 10 MHz bandwidth for data
- Channel estimation, channel equalization and decoding in 1ms shot in parallel
- They can transmit over the LTA-A bandwidth with symbol error rate below 0.1
- Control effort roughly 3.5%
- Channel delay spread must be <10µs delay with max. 6 paths



$$R(\alpha) \geq \log\big(1 + \mathrm{SNR} \cdot (1-\alpha)\big) - \log\left(1 + m \cdot \left(\frac{4\sqrt{1+\delta_{2k}}}{1-(1+\sqrt{2})\delta_{2k}}\right)^2 \cdot \left(\mathrm{SNR} \cdot \frac{1-\alpha}{\alpha} + \frac{1}{\alpha}\right)\right)$$