System-level interfaces and performance evaluation methodology for 5G physical layer based on non-orthogonal waveforms

Presenter: **Martin Kasparick, Fraunhofer Heinrich Hertz Institute**

Asilomar Conference, Nov. 5th , 2013

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, *Dr. Stephan ten Brink***
  - **Technische Universität Dresden, Germany, *Prof. Gerhard Fettweis***
  - **CEA-LETI, France, *Dimitri Ktenas***
  - **IS-Wireless, Poland, *Dr. Slawomir Pietrzyk***
  - **National Instruments, Hungary, *Dr. Bertalan Eged***

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

Outline

(1) 5GNOW: Why new waveforms?

(2) PHY abstraction fundamentals & challenges

(3) Proposed Link-to-System interface for FBMC

(4) System Simulations: Comparison of FBMC and LTE/OFDMA

Outline

(1) 5GNOW: Why new waveforms?

(2) PHY abstraction fundamentals & challenges

(3) Proposed Link-to-System interface for FBMC

(4) System Simulations: Comparison of FBMC and LTE/OFDMA

Why new waveforms?

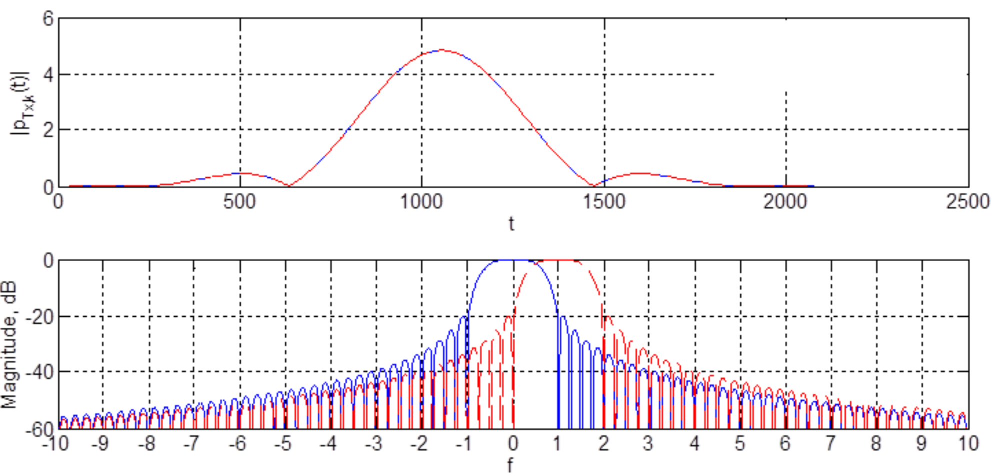
- 5G on the way… intriguing applications
  - Internet of Things
  - Tactile Internet
  - Gigabit Wireless
- Particularly: Fragmented spectrum, spectrum agility

Conclusion: highly flexible robust new waveforms required!

- Several candidate waveforms proposed:
  - Filter Banks Multi-Carrier (**FBMC**)
  - Universal Filtered Multi-Carrier (**UFMC**)
  - Generalized Frequency Division Multiplexing (**GFDM**)
- In this talk we exemplarily focus on FBMC

Why new waveforms?

FBMC Fundamentals



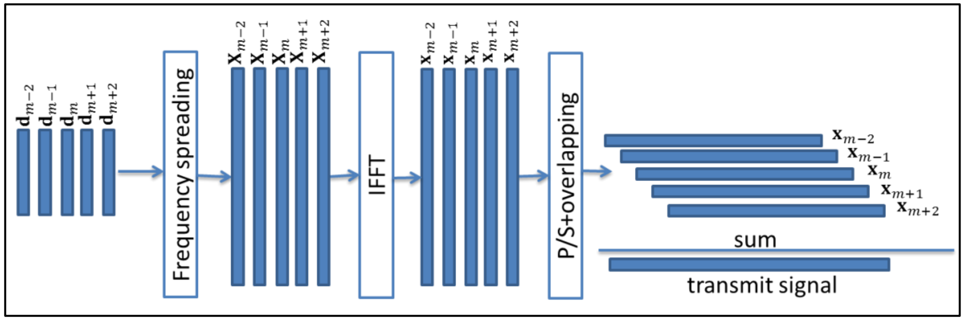
-> Significant Overlap

Features :

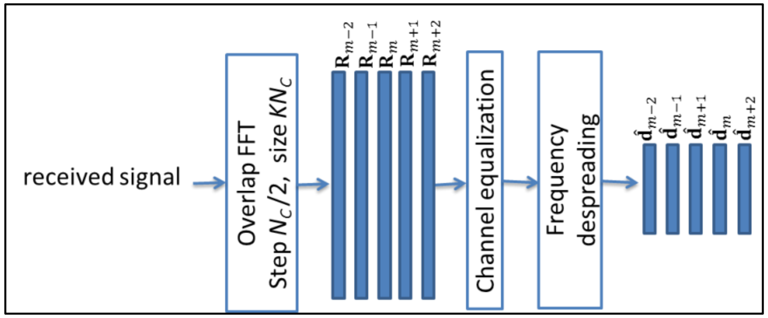
- Spectrally well shaped prototype filter
- Overlapped time symbols

Advantages

- No Cyclic Prefix
- Almost perfect separation of frequency subbands without strict synchronization
- Suitability for fragmented spectrum and for CoMP



FBMC Transmitter



FBMC Receiver

- FBMC well-established waveform but **system-level evaluations** needed

Outline

(1) 5GNOW: Why new waveforms?

(2) PHY abstraction fundamentals & challenges

(3) Proposed Link-to-System interface for FBMC

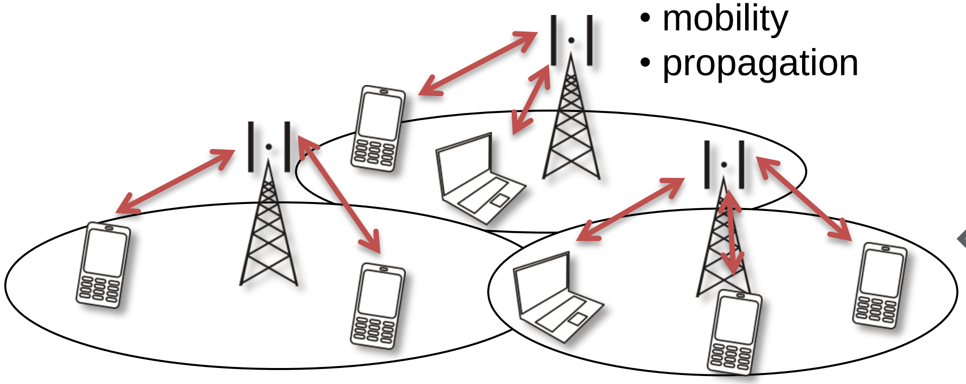
(4) System Simulations: Comparison of FBMC and LTE/OFDMA

PHY Abstraction Fundamentals

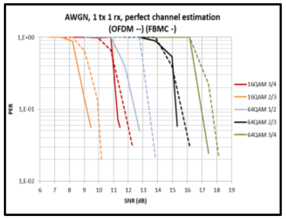
5GNOW

PHY abstraction needed: Obtain *Block Error Rate (BLER) for a transport block*, given particular subcarrier channel realizations, *without* having to carry out real signal processing.

System Simulator
- scheduling
- interference
- mobility
- propagation



Link Level Simulations
- Multiplexing
- Channel Coding, Modulation
- Signal Processing
- Equalization, Detection



Link-To-System Interface

PHY Abstraction Fundamentals
ESM Techniques

5GNOW

- Effective SINR for whole transport block needed
- Challenges:
  - Transport block of bits is spread across (p*ossibly non-orthogonal*) subcarriers and each individual subcarrier may experience different SNIR
  - Interferences from different eNBs may have different influence on different subcarriers
  - Each user may use different BW parts and BLER for each may be calculated separately (the UE may use different MCS on allocated resources)

Effective SINR Mapping (ESM) function $\mathcal{I}(\cdot)$ (e.g. Linear, Logarithmic, Exponential, Mutual Information) needed, such that

$$\gamma_{eff} = \mathcal{I}^{-1}\left(\frac{1}{K}\sum_{k=1}^{K}\mathcal{I}(\gamma_k)\right).$$

PHY Abstraction Fundamentals
Challenges

- To evaluate system-level performance of FBMC , a PHY abstraction that can deal with *non-orthogonal waveforms* and *synchronization errors* is needed.

Elements to consider:
(1) Define suitable quality measure per subcarrier
(2) Derive means to incorporate temporal-spectral asynchronisms
(3) Find suitable effective SINR mapping for whole transmission
(4) Define suitable frame structure and generate AWGN - SNR/BLER tables

Outline

(1) 5GNOW: Why new waveforms?

(2) PHY abstraction fundamentals & challenges

(3) Proposed Link-to-System interface for FBMC

(4) System Simulations: Comparison of FBMC and LTE/OFDMA

PHY Abstraction for FBMC
Information measure

- FBMC induces additional interference from neighboring subcarriers due to non-orthogonality

Use SNIDR model:

$$\mathrm{SNIDR}_k = \frac{P_s}{P_i + P_n + P_d}$$

Residual Distortion

$$P_d(k) = \frac{2P_s}{K^3}\left\|\frac{H_k'(\omega)}{H_k(\omega)}\right\|^2 C_f$$

A. Oborina, C. Ibars, L. Guipponi, F. Bader, "Link Performance Model for System Level Simulations of Filter Bank Multicarrier-Based Systems in PMR Networks", *Proceedings ISWCS 2013,*

- In Rayleigh fading channel: $\frac{H_k'(\omega)}{H_k(\omega)} = \frac{1}{w_k} - \frac{w_k}{\sigma^2}$, with $w_k = \frac{2\pi}{N}(k-1), k = 1,..,N$
  - $H_k(\omega)$, $H_k'(\omega)$:channel frequency response and its derivative evaluated at the $k'th$ subcarrier frequency.
  - P_s, P_i, P_n: signal power, interference power, noise power
  - C_f: first order derivative of receiving prototype pulse. The smoother the filter the lower C_f and the lower is the distortion power.

PHY Abstraction for FBMC
Incorporate Time-Frequency Offsets

5GNOW

The following relation holds for non-random time-frequency shifts

$$sinr \geq \frac{\left|A_{h\gamma}(d,\nu)\right|^2}{\frac{1}{SNR} + B_\gamma - \left|A_{h\gamma}(d,\nu)\right|^2}$$

P. Jung, G. Wunder "On Time-Variant Distortions in Multicarrier Transmission With Application to Frequency Offsets and Phase Noise", in *IEEE Transactions on Communications*, Vol. 53, No. 9, pp. 1561-1570, September 2005

- Given a **frequency offset** ν in the OFDM case it holds

$$sinr \geq \frac{\sin^2 \pi\hat{\nu}/(\pi\hat{\nu})^2}{\frac{\sigma^2}{\epsilon\|p_h\|_1} + (1 - \sin^2 \pi\hat{\nu}/(\pi\hat{\nu})^2)} \quad \text{with} \quad \hat{\nu} = \frac{\nu}{F}$$

- In FBMC case we get :

$$sinr \geq \frac{|A_{hh}(0,\tilde{\nu})|^2}{\frac{1}{SNR} + 1 - |A_{hh}(0,\tilde{\nu})|^2}$$

- FBMC case (only frequency shift): ambiguity function given by

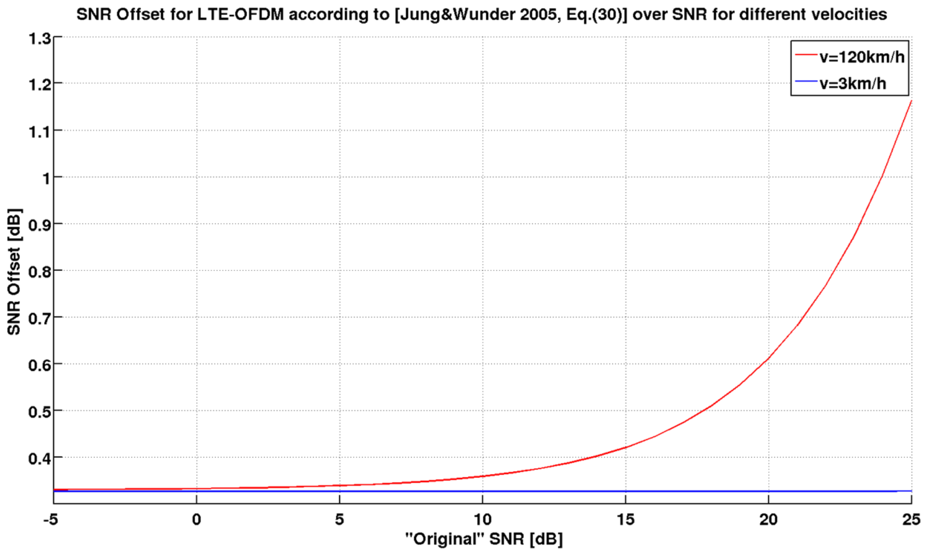
$$A_{hh}(0,\nu) = \int_{-\infty}^{\infty} \left|\tilde{h}(t)\right|^2 e^{j2\pi\nu t} dt \quad \text{with} \quad \tilde{h}(t) = \frac{1}{\|h(t)\|_2} h(t).$$

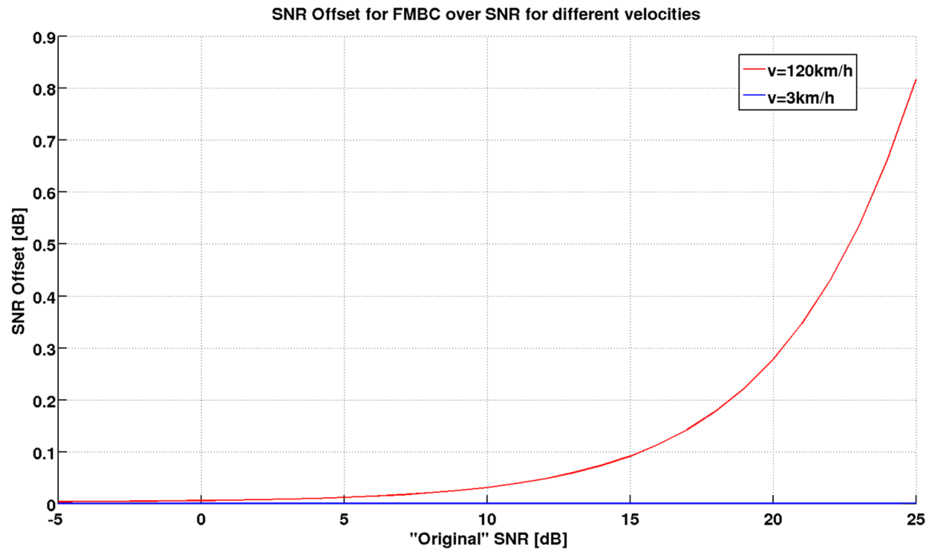
- Transmit (and receive) filter:

$$h(t) = P_0 + 2\sum_{k=1}^{K-1} (-1)^k P_k \cos\left(\frac{2\pi k}{K N_c}(t+1)\right), t = 0{:}\, K N_c - 2$$

PHY Abstraction for FBMC
Frequency offsets due to user velocity

5GNOW





- Example: Frequency offset induced by user velocity (Doppler shift)
- So far influence of user velocity in system simulator not sufficienty considered

Result:
- Influence of frequency offsets in FBMC much lower
- However small offsets for the considered velocities

PHY Abstraction for FBMC
Effective SINR Mapping

Two main challenges:

(1) Get average quality measure for resource block

- Use ESM or simple averaging of subcarrier SNIDRs (same as OFDM)

(2) Get overall effective SNIR for whole transmission: ESM needed

- Popular method: EESM, but difficult to configure
- MIESM: Use mutual information as information measure function $\mathcal{I}(\cdot)$

MIESM mapping:

- Good match with AGWN curves without specific parameter optimization.
- A polynomial approximation of mutual information is given by:

$$MI(SINR, m) = \frac{1}{\left([s \cdot MI_{Shannon}(SINR)]^{-w} + m^{-w}\right)^{\frac{1}{w}}}$$

R. Schoenen, C. Teijeiro and D. Bültmann "System Level Performance Evaluation of LTE with MIMO and Relays in Reuse-1 IMT-Advanced Scenarios", in International Conference on Wireless Communications, Networking and Mobile Computing – WiCom, 2010

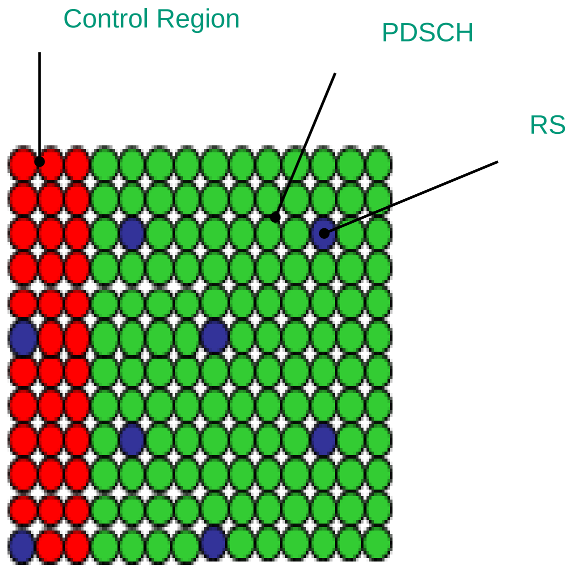
$$MI_{shannon}(SINR) = \log_2(1 + 10^{\frac{SINR}{10dB}}), \qquad s = s(m) = 0.95 - 0.08 \cdot (m \bmod 2), w = w(m) = 2 \cdot m + 1$$

PHY Abstraction for FBMC
Frame Structure

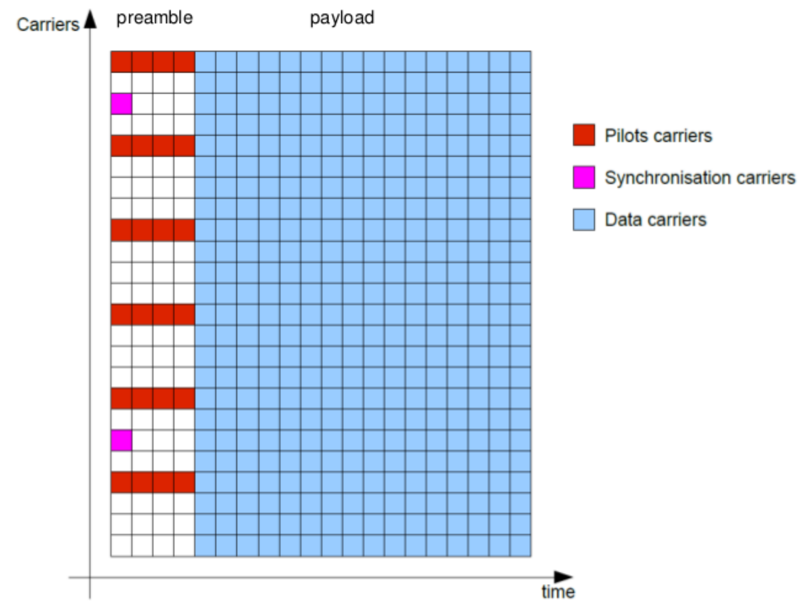
5GNOW

LTE / OFDM

Subframe structure



FBMC



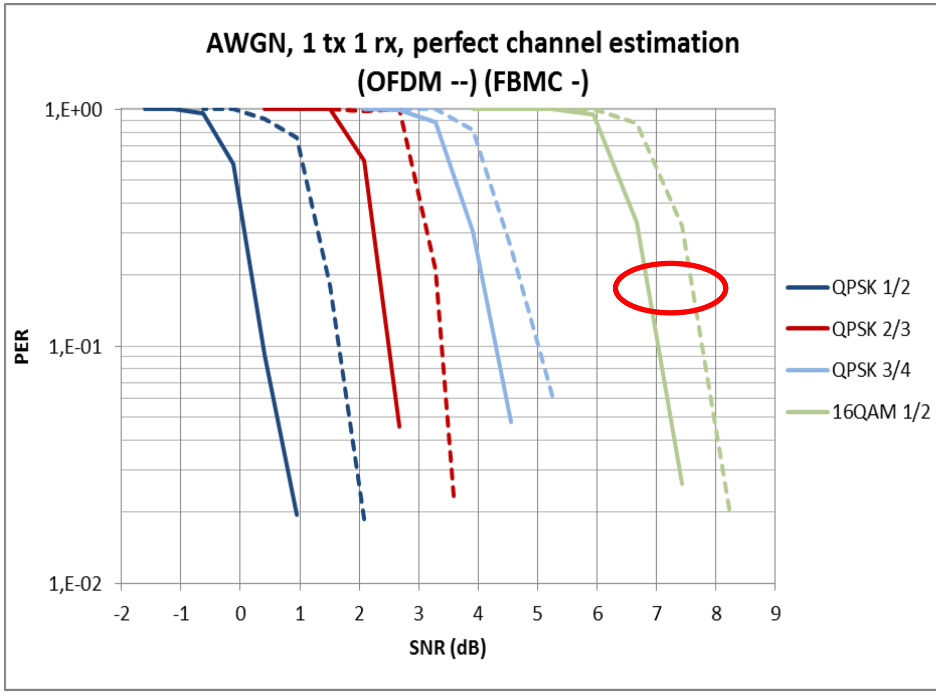
	LTE / OFDM	FBMC
Quality measure per subcarrier	SNIR per subcarrier	**SNIDR** per subcarrier
Effective SNIR Mapping	MIESM	MIESM

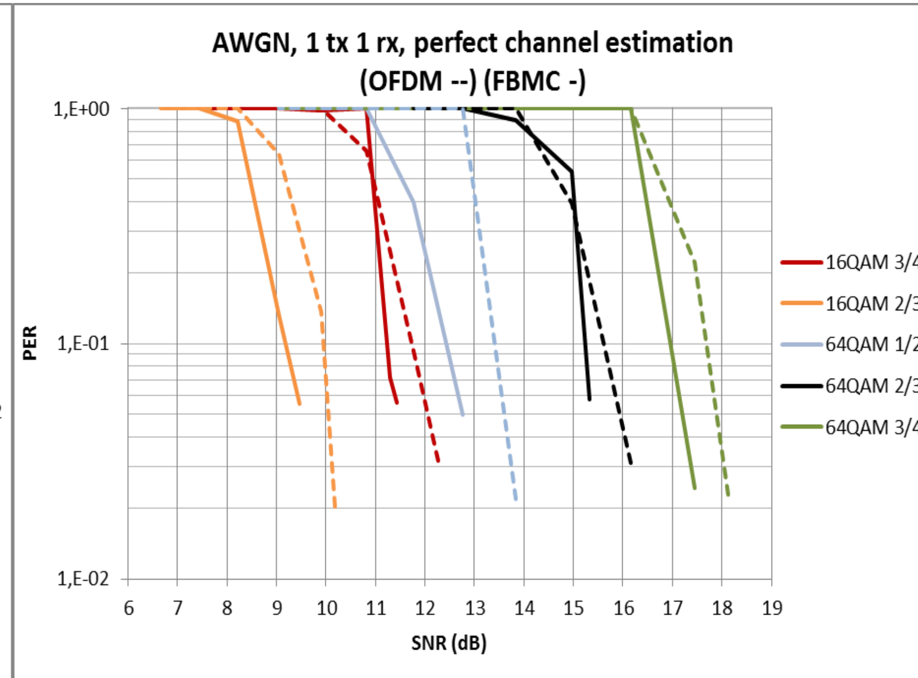
- Frame structure matched to enable fair comparison (to have same throughput)
  - OFDM: 9 data and 4 signaling/control/... symbols, subframe duration: 0.93 ms, cyclic prefix: 72 carriers
  - FBMC: 16 data and 4 signaling/control/... symbols, subframe duration: 1.63 ms

PHY Abstraction for FBMC
Parameters and SNR – BLER curves

5GNOW

Resulting SNR/BLER curves:





- Convolutional encoder / Viterbi decoder
- Gain through cyclic prefix

Outline

(1) 5GNOW: Why new waveforms?

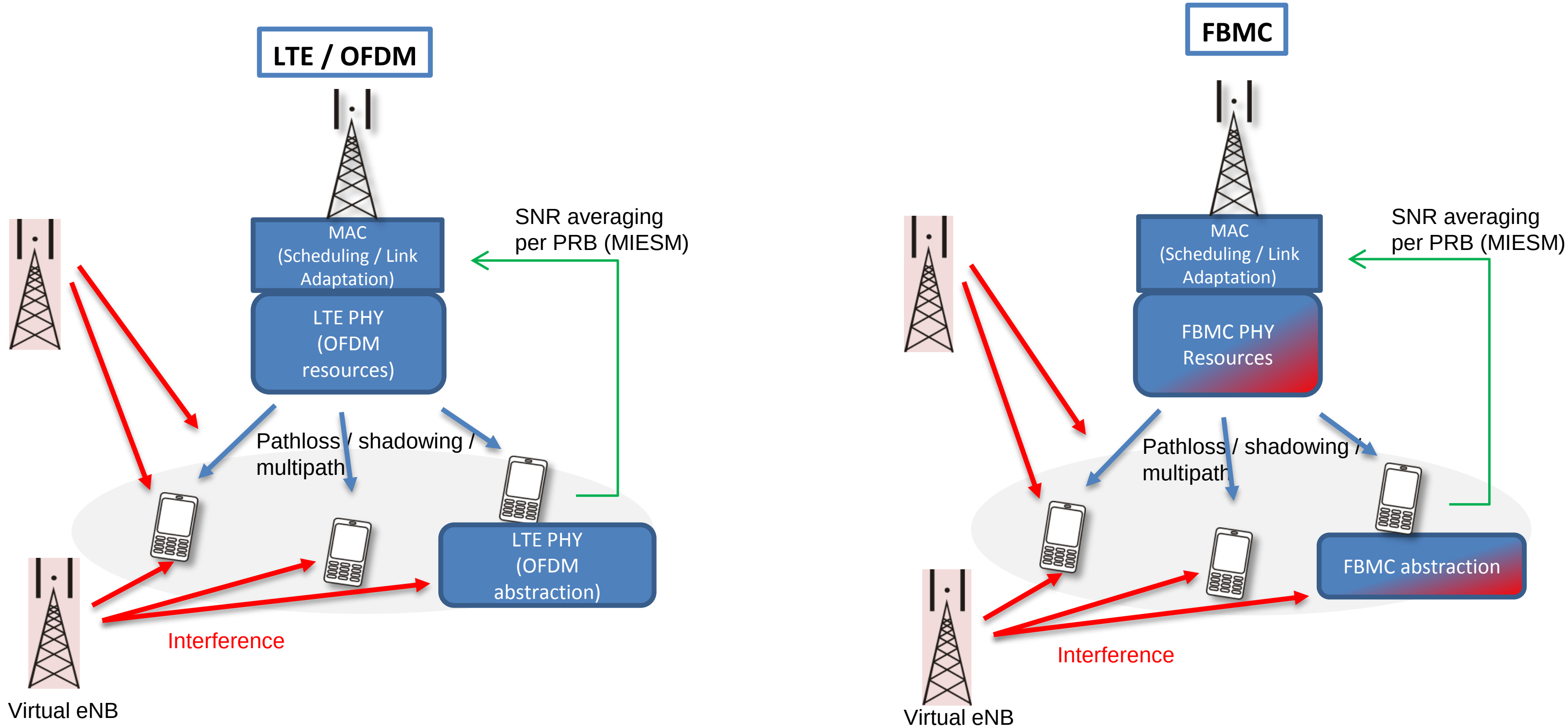
(2) PHY abstraction fundamentals & challenges

(3) Proposed Link-to-System interface for FBMC

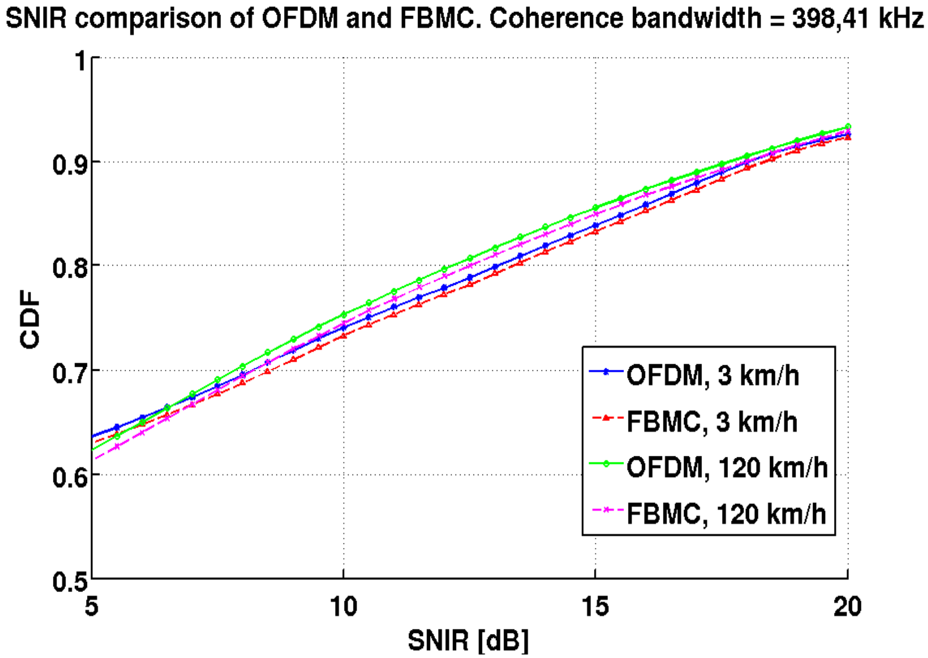
(4) System Simulations: Comparison of FBMC and LTE/OFDMA

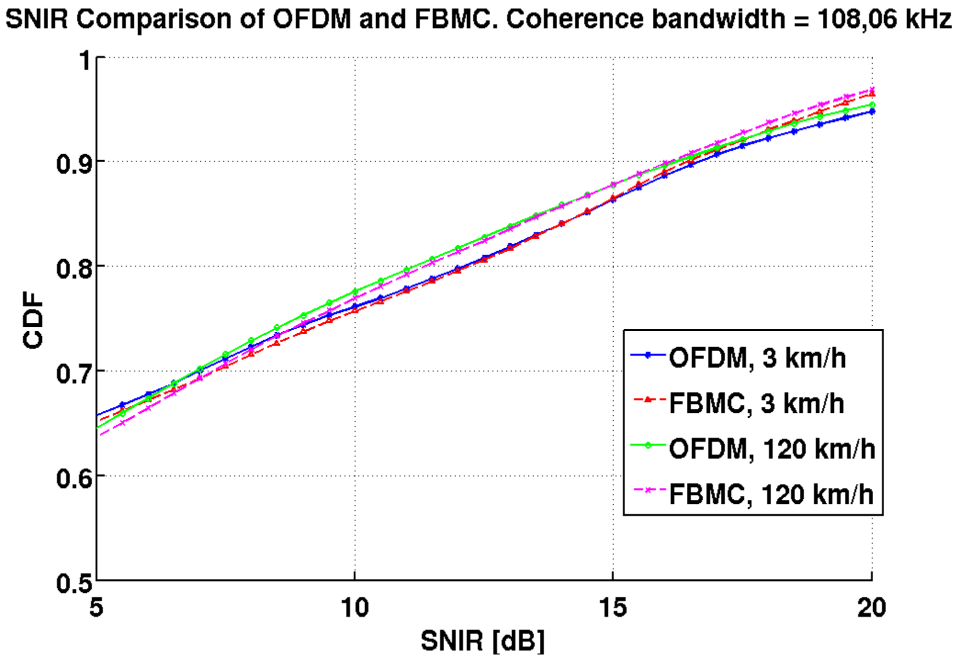
System Simulations

- System simulations of OFDM vs. FBMC downlink using *LTE MAC Lab* software
  - Number of users: 50, user velocities: 3km/h and 120 km/h, Max-SINR scheduler
  - Duration: 2000/3260 TTIs for FBMC/OFDM, average 6 simulation runs
  - System bandwidth: 10MHz, System band: 2GHz, Ideal feedback



Simulation Results
SNIR comparison

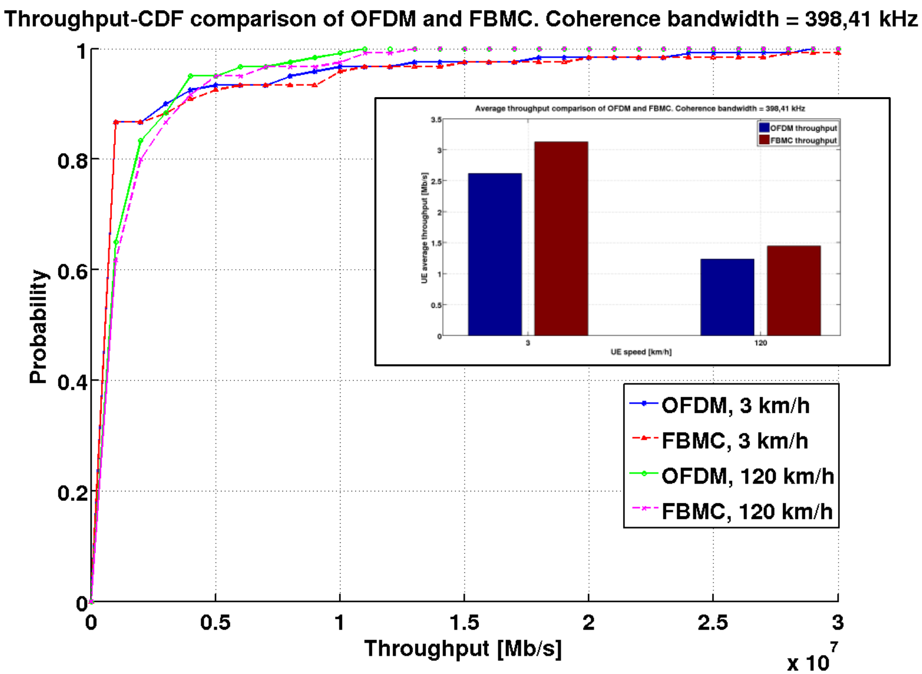


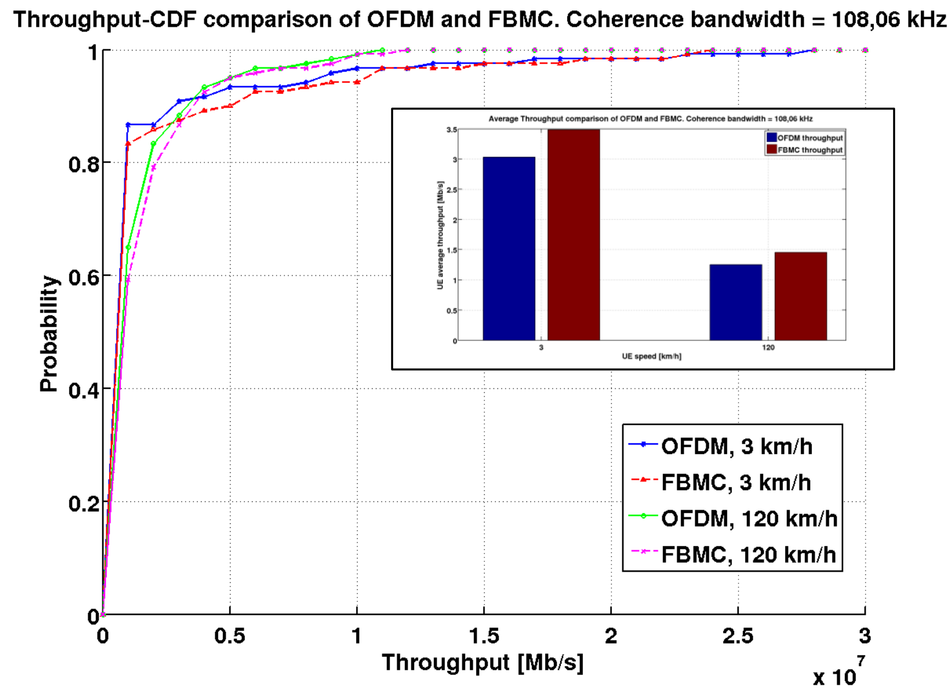


- Difference between the two considered channels : 3GPP EVA (coh.-BW: 398.41 kHz) and (modified) 3GPP ETU (coh.-BW: 108.06 kHz)
- Additional distortion term in FBMC has only influence when coherence bandwidth is smaller than the filter response in frequency domain
- Influence of frequency offsets leads to gain of FBMC at large coherence bandwidth

Simulation Results
Throughput Comparison

5GNOW





- Despite the additional distortion throughput gains through FBMC can be observed in both cases
- Gain through FBMC becomes smaller in ‘frequency selective‘ channel

Conclusions

- First steps towards **system level simulations of non-orthogonal waveforms**
  - Quality measure and corresponding effective SNR mapping
  - FBMC frame structure proposed
  - Methods to incorporate frequency offsets

- Incoporate frequency offsets
  - Impact not strong enough to significantly change the performance
  - Time offsets most likely have more significant impact

- FBMC turns out to be more efficient with small frequency selectivity
  - Here the gain of the removed cyclic prefix takes the full effect
  - With larger frequency selectivity the gain decreases.

Thank you for your attention!
www.5gnow.eu

Contact

Martin Kasparick – martin.kasparick@hhi.fraunhofer,de

www.hhi.fraunhofer.de/wn

Fraunhofer Heinrich Hertz Institute

Berlin, Germany

Appendix

Parameter	Value FBMC	Value OFDM	Unit	Abreviation
Usefull bandwidth	10^7	10^7	Hz	B
Number of carriers	1024	1024		N_C
Number of active carriers	601	601		N_{ac}
Cyclic Prefix	N/A	72	carriers	
Carrier spacing	$15\text{x}10^3$	$15\text{x}10^3$	Hz	Δ_f
Sampling rate	$15.36\text{x}10^6$	$15.36\text{x}10^6$	Hz	f_S
Sampling period	$65.1\text{x}10^{-9}$	$65.1\text{x}10^{-9}$	s	$T_S = 1/f_S$
Number of preamble symb. in the subframe	4	4		
Number of data symbols in the subframe	16	9		L
Subframe duration	$1.63\text{x}10^{-3}$	$0.93\text{x}10^{-3}$	s	L_{frame}
Overlapping factor	4	N/A		K
Number of Resource Blocks	50	50		