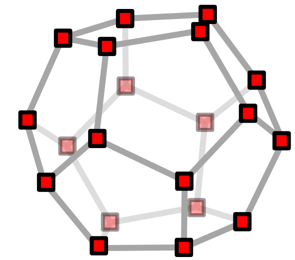
EuMW 2013 NÜRNBERG GERMANY

Maximum Spectral Efficiency Through Parallelized Multiple-Input-Multiple-Output Transmission Using High-Resolution 3D Antenna Topologies (maximumMIMO)



Project of the DFG Priority Programm 1655: Wireless 100Gb/s and beyond

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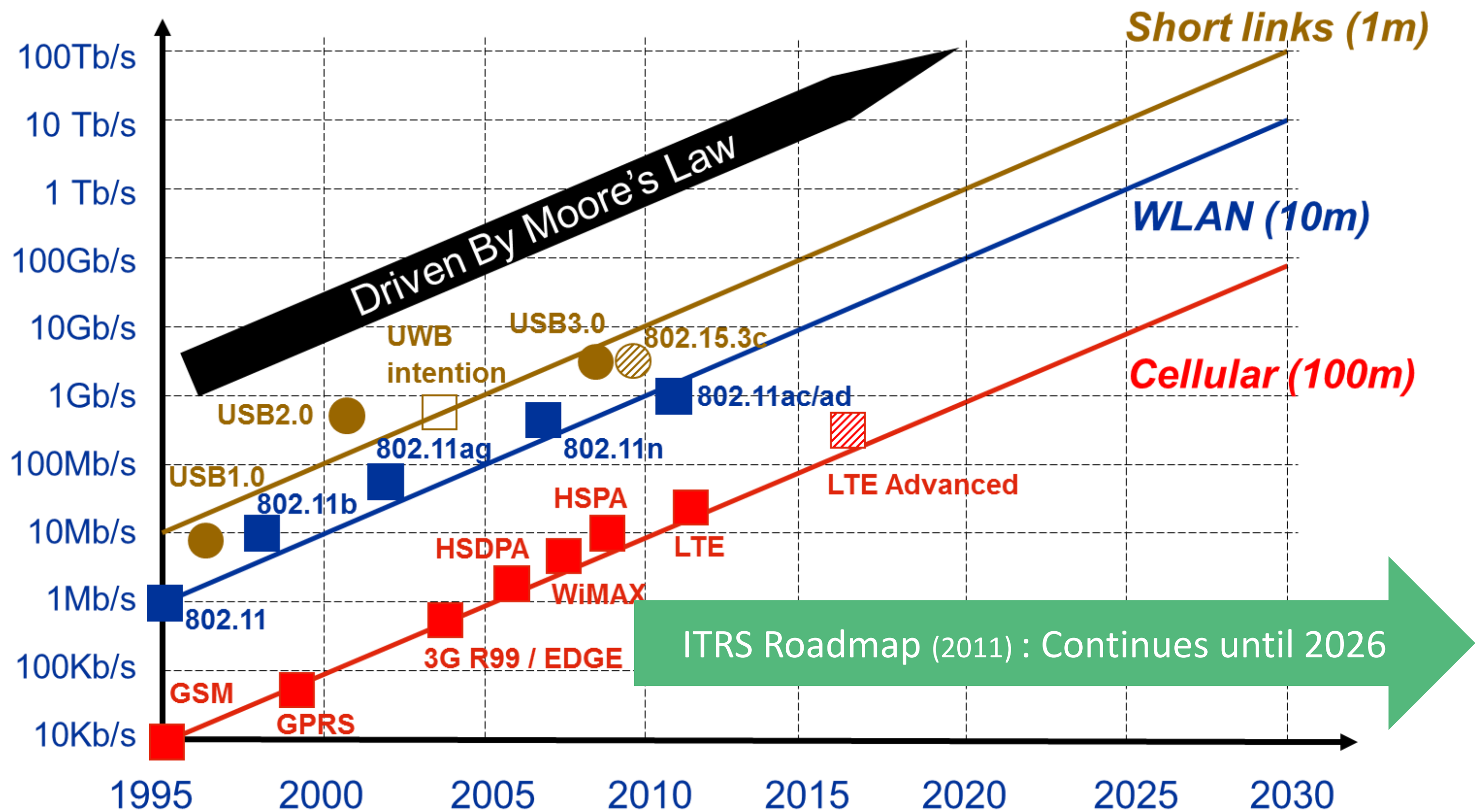
Application Scenarios and Approach

The Wireless Roadmap



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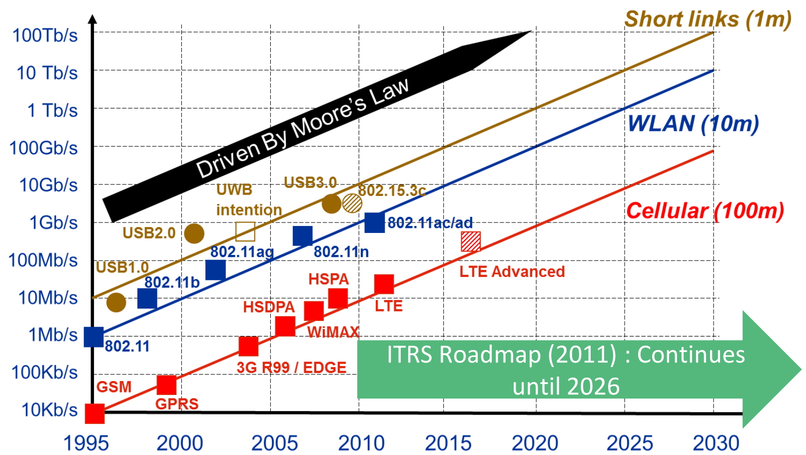
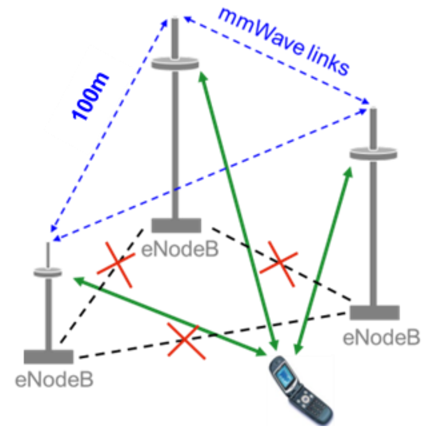
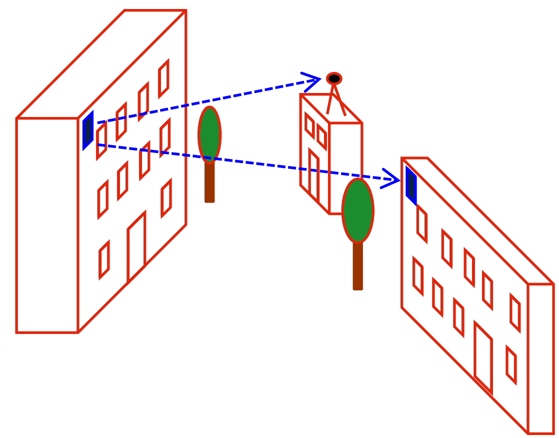


100Gb/s
Wireless Backhaul



100Gb/s
Urban P2P Links



100Gb/s through…

… ultra-large **bandwidth**
- THz carrier frequencies
- Analog frontend bandwidth
- DAC / ADC sampling rate

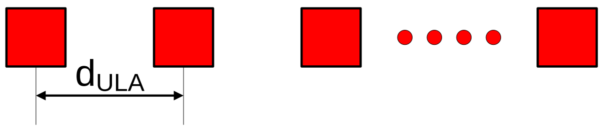
… large
3D-LOS MIMO
Antenna Topologies
&
… parallelized
"Lanes"-Based
MIMO Signal Processing

… high-order **modulation**
- Link budget
- PA output back-off
- DAC / ADC resolution

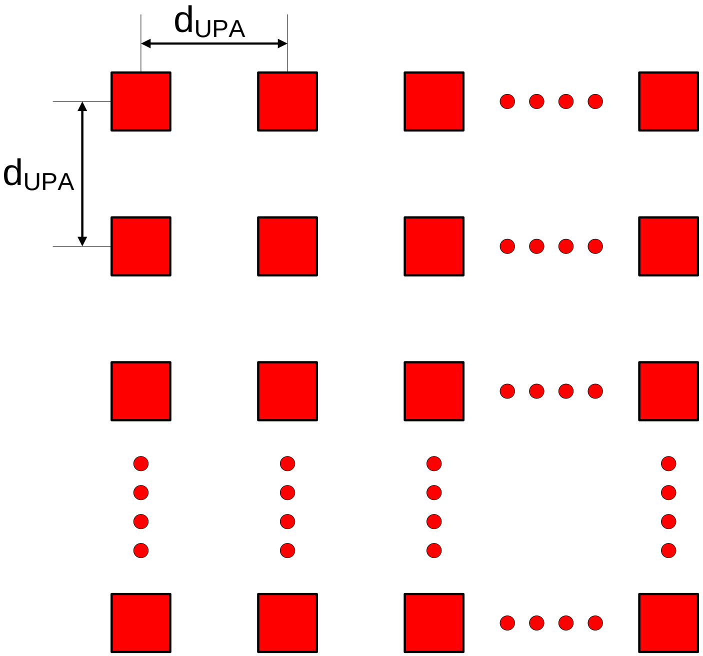
1D / 2D-LOS MIMO Antennas @ 60GHz

1D and 2D topologies (examples): ULA and UPA

$$d_{ULA} = \sqrt{\frac{\lambda \cdot r}{m}} \text{ for } m \text{ antennas}$$



d_{ULA}=17.7 / 7.1cm for 16 / 100 antennas at a distance of 100m for an optimum MIMO capacity (16 / 100 parallel channels)

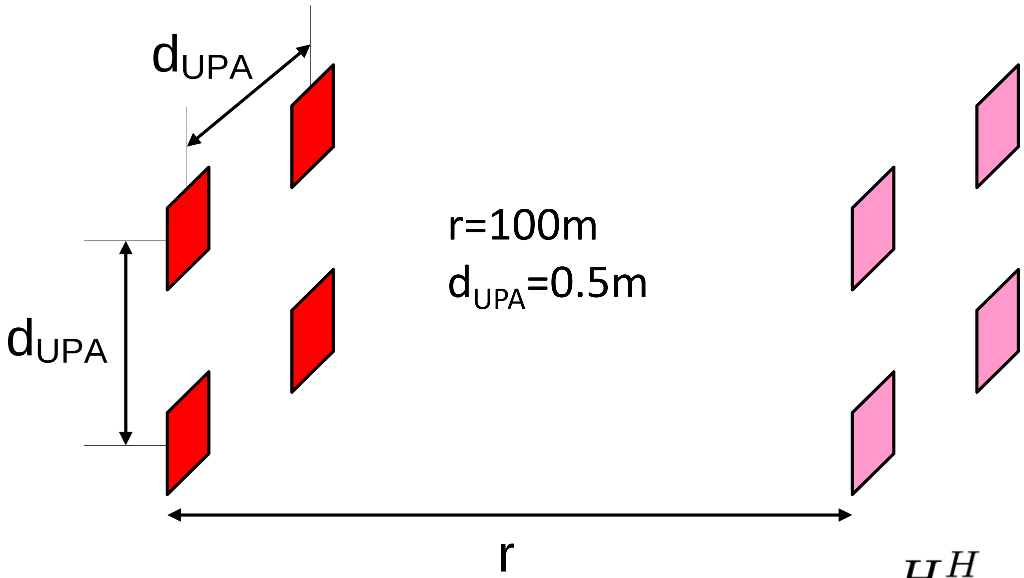


$$d_{UPA} = \sqrt{\frac{\lambda \cdot r}{n}} \text{ for } n \times n \text{ antennas}$$

d_{UPA}=35.4 / 22.4cm for 16 / 100 antennas at a distance of 100m for an optimum MIMO capacity (16 / 100 parallel channels)

2D-LOS MIMO Antennas @ 60GHz

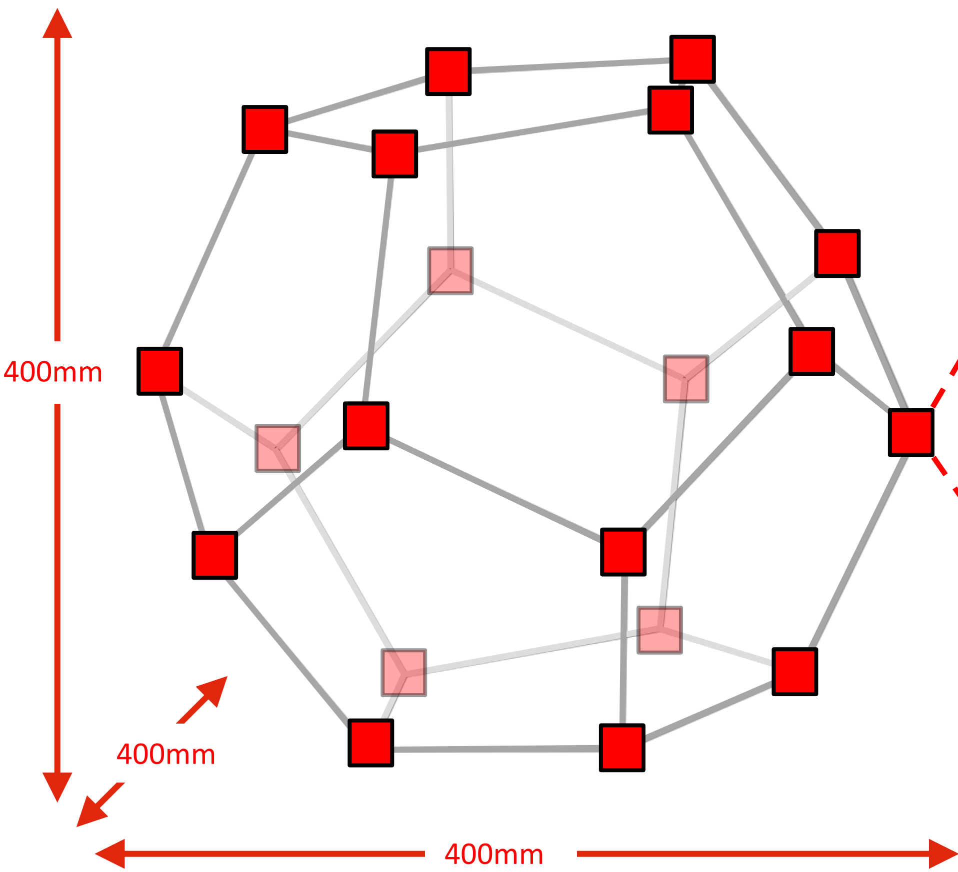
2x2 UPA example with optimal antenna element separation:



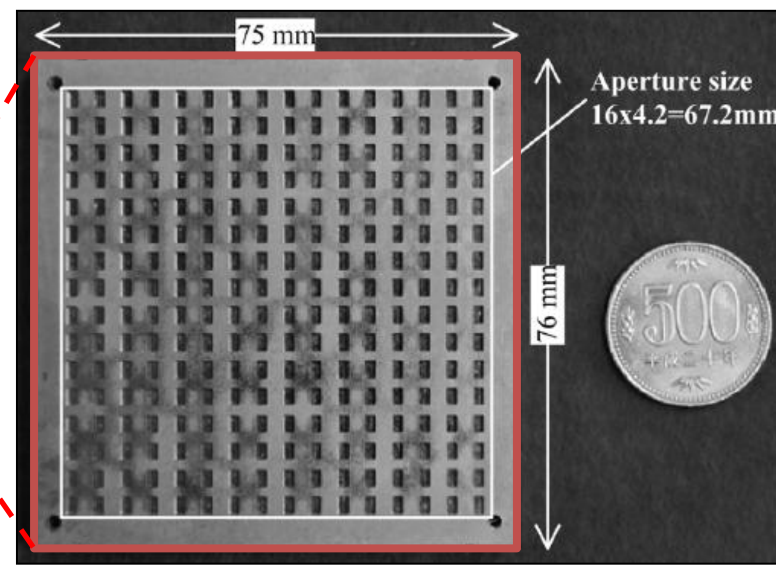
$$
\begin{aligned}
H^H \cdot H &= Q^H \cdot \Lambda \cdot Q \\
\Lambda &= a_F \cdot diag(4,4,4,4) \\
\frac{C}{B} &= \sum_i^4 \log_2 \left(1 + \lambda_i \cdot \frac{S}{4 \cdot N}\right)
\end{aligned}
$$

3D-LOS MIMO Antenna @ 60GHz

3D topology (example): dodecahedron of 20 antenna elements



16 x 16 antenna element: 32dBi gain



Y. Miura, J. Hirokawa, M. Ando, Y. Shibuya, G. Yoshida, "Double-Layer Full-Corporate-Feed Hollow-Waveguide Slot Array Antenna in the 60-GHz Band," IEEE Trans. on Antennas and Propagation, 59(8), 2011.

MIMO Antennas @ 60GHz

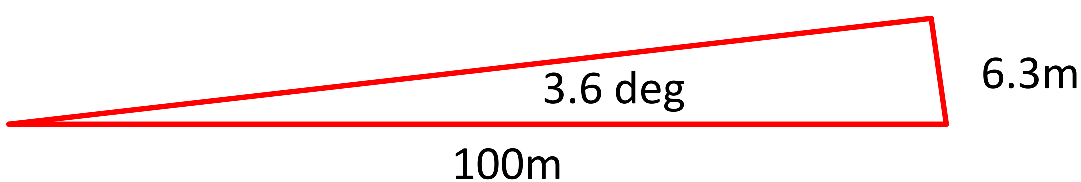
Directivity and antenna effective aperture: $D = \frac{4\pi A_{eff}}{\lambda^2}$

Directivity and beam width: $D \approx \frac{4\pi}{\Phi_{HP} \cdot \theta_{HP}}$

Example for a 35dBi antenna at 60GHz:

$$A_{eff} = 6.3 \cdot 10^{-3} m^2 \quad \hat{=} \quad 8 \times 8cm$$

$$\Phi_{HP} = \theta_{HP} = 6.3 \cdot 10^{-2} rad \quad \hat{=} \quad 3.6 deg$$



Link Budget: 100Gb/s LOS MIMO @ 60GHz

Systen parameters	Modulation alphabet	-	4-QAM	4-QAM	4-QAM	4-QAM	4-QAM
	Modulation raw spectral efficiency	**bpcu**	**2**	**2**	**2**	**2**	**2**
	Number of spatial streams	**-**	**41**	**55**	**82**	**163**	**325**
	Channel bandwidth	GHz	2,16	1,62	1,08	0,54	0,27
	Symbol rate	GHz	1,728	1,296	0,864	0,432	0,216
	Code rate	-	3/4	3/4	3/4	3/4	3/4
	Frame overhead (preamble, pilots, etc.)	%	*5,0*	*5,0*	*5,0*	*5,0*	*5,0*
	Effective data rate	**Gb/s**	***100,96***	***101,57***	***100,96***	***100,34***	***100,04***
	Spectral efficiency	bit/s/Hz	*46,74*	*62,70*	*93,48*	*185,82*	*370,50*
Ant. Gain	Tx Antenna element gain	dBi	35	35	35	35	35
	Rx Antenna element gain	dBi	35	35	35	35	35
Tx Power	Ouput power of the amplifier	dBm	-11,1	-12,4	-14,1	-17,1	-20,1
	Tx power (EIRP) per stream	dBm	23,9	22,6	20,9	17,9	14,9
	Tx power density (EIRP) per stream	dBm/MHz	-9,1	-10,4	-12,1	-15,1	-18,1
	Tx power (EIRP) <= 40 dBm !	**dBm**	**40,0**	**40,0**	**40,0**	**40,0**	**40,0**
Path loss	Reference distance	m	0,10	0,10	0,10	0,10	0,10
	Path loss at ref. distance	dB	47	47	47	47	47
	Path loss exponent		2	2	2	2	2
	Margin for rain attenuation	dB	3	3	3	3	3
Noise and impl. losses	Thermal noise power (-174dBm/Hz)	dBm	-81	-82	-84	-87	-90
	Rx noise figure	dB	8	8	8	8	8
	Average noise power	**dBm**	**-73**	**-74**	**-76**	**-79**	**-82**
	Analog losses (fronted, antenna)	dB	**6**	**6**	**6**	**6**	**6**
	Digital losses (sync, channel estimation, etc.)	dB	**3**	**3**	**3**	**3**	**3**
BER 10^{-4}	Required SNR (AWGN channel)	dB	11,4	11,4	11,4	11,4	11,4
	Operating range	**m**	**114,23**	**113,56**	**114,36**	**114,50**	**114,64**

← 40 … 400 antenna elements

← 2 … 0.2GHz bandwidth

← 100Gb/s PHY throughput

← min. 35dBi ant. element gain
(German regulation for 60 GHz outdoor P2P links)

← max. 40dBm EIRP
(German regulation for 60 GHz outdoor P2P links)

m parallel SISO channels assumed

← 100m range

	Parameter	Unit					
System parameters	Modulation alphabet	-	4-QAM	4-QAM	4-QAM	4-QAM	4-QAM
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Path loss	Reference distance	m	0,10	0,10	0,10	0,10	0,10
	Path loss at ref. distance	dB	47	47	47	47	47
	Path loss exponent		2	2	2	2	2
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	Analog losses (fronted, antenna)	dB	**6**	**6**	**6**	**6**	**6**
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BER 10^{-4}	Required SNR (AWGN channel)	dB	11,4	11,4	11,4	11,4	11,4
	Operating range	**m**	**114,23**	**113,56**	**114,36**	**114,50**	**114,64**

← 40…400 antenna elements

← 2 … 0.2GHz bandwidth

← 100Gb/s PHY throughput

← min. 35dBi ant. element gain
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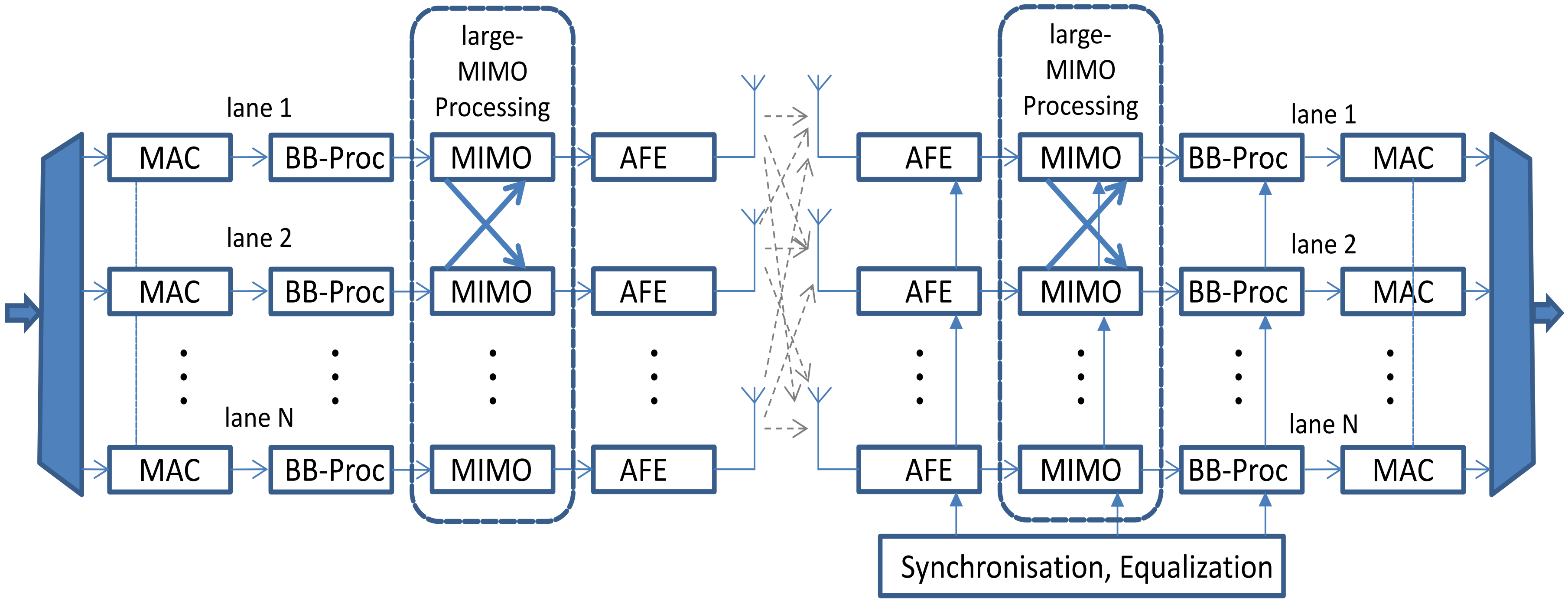
← max. 40dBm EIRP
(German regulation for 60 GHz outdoor P2P links)

m parallel SISO channels assumed

← 100 m range

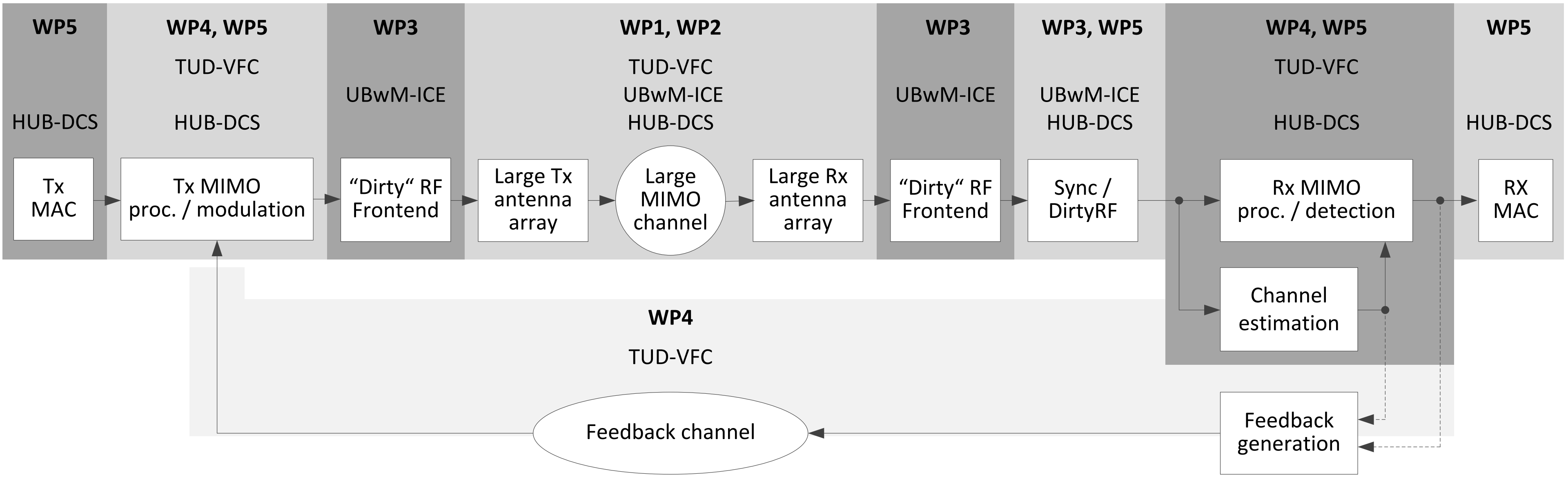
Architecture of the maximumMIMO System



Challenges:

- Antenna design and optimization (partitioning)
- Channel characterization (for LOS-MIMO + 3D Antennas)
- massive MIMO processing (algorithms + implementation)
- Scalable parallel implementation of BB-processor and MAC,…

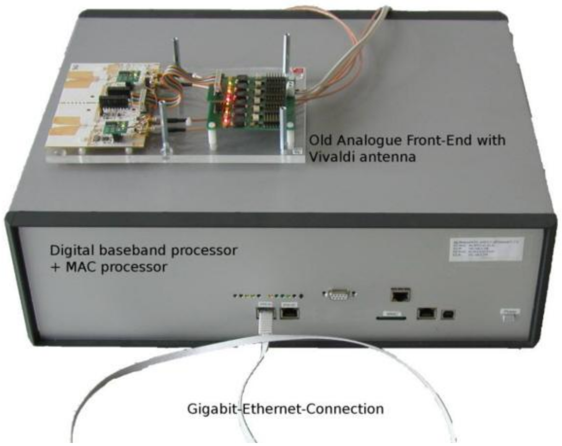
Work split in the maximumMIMO Project

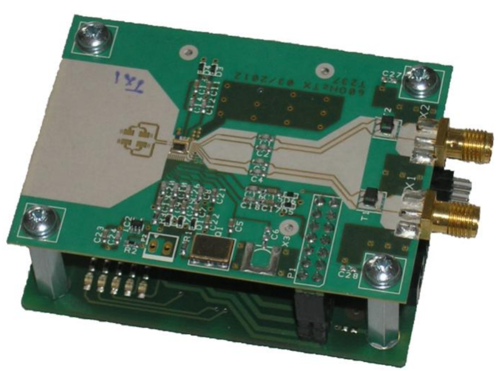


Challenges:

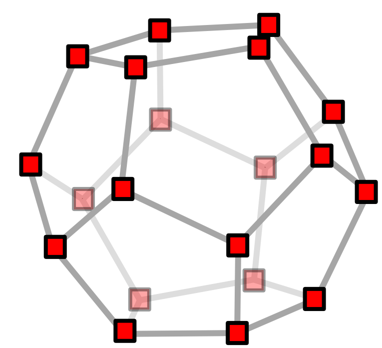
- Dirty RF frontend and related signal processing algorithms
- Synchronization concepts
- Optimized low effort MIMO processing
- Scalable parallel implementation of BB-processor and MAC,…

Planned Demonstrator using 60 GHz Analog Front Ends



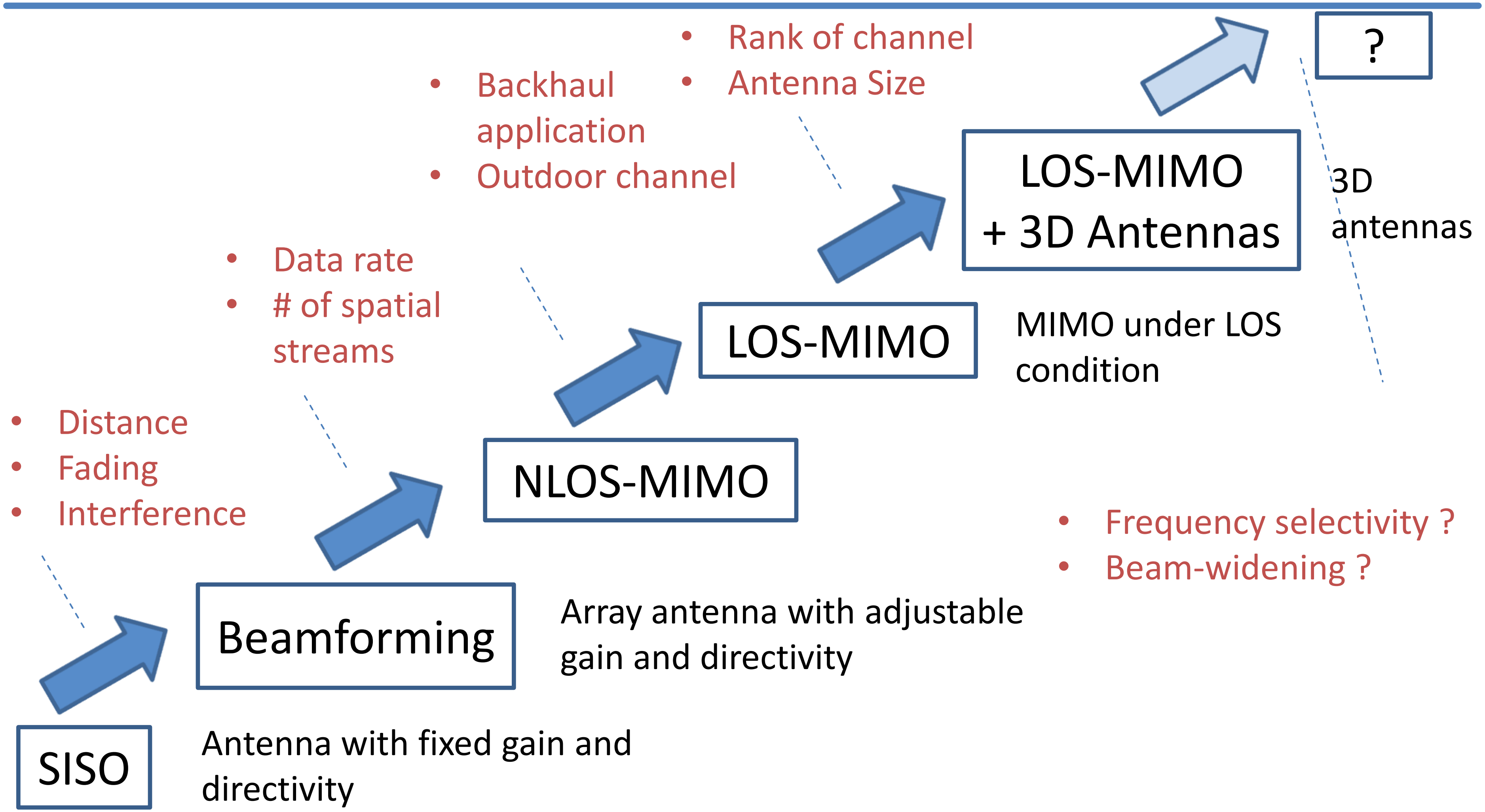


Available compact 60 GHz frontend module with patch array antenna and power supply



Planned small scale Demonstrator using 60 GHz technology and 4…8 antennas

Trends: Transmission Schemes



Target outcome: maximumMIMO will…

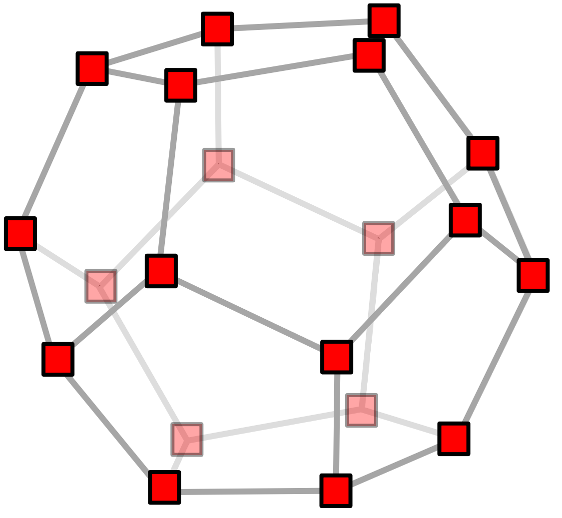
…identify fundamental design paradigms for wireless communication systems that use very large antenna arrays with 3D topology at the transmitter and receiver to maximize the bandwidth efficiency

…derive information-theoretic concepts for robust 3D antenna topologies and highly-parallelized MIMO processing schemes, focusing on the fundamental limit for an arbitrary number of antenna elements.

…validate the theoretical concepts for practical applications, i.e., for antennas with 50 to1000 elements.

…consider LOS transmission at 60GHz as an application example, which will be extended to non-LOS transmission, e.g., for 100 Gb/s cellular communications, in the second phase of the project.

maximumMIMO



Thank you!

MIMO Basics

SISO channel with power S: $\frac{C}{B} = \log_2\left(1 + \frac{S}{N}\right)$

m parallel SISO channels with power $\frac{S}{m}$ each: $\frac{C}{B} = m\log_2\left(1 + \frac{S}{mN}\right)$

MIMO case parallel channels (m Tx and m RX ant.): $\frac{C}{B} = m\log_2\left(1 + \frac{S}{N}\right)$

MIMO case keyhole (m TX and m RX ant.): $\frac{C}{B} = \log_2\left(1 + \frac{mS}{N}\right)$