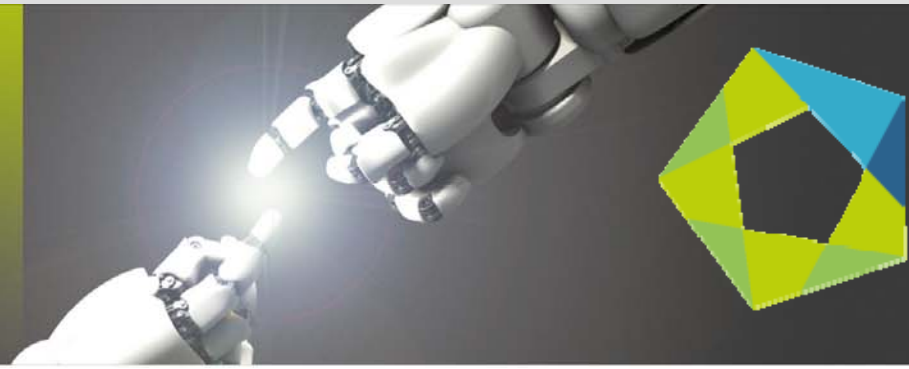
TECHNISCHE UNIVERSITÄT DRESDEN

The Holistic 5G Vision



5G LAB GERMANY

Dr. Rico Radeke

Chair of Communication Networks
Dresden University of Technology

Mobilfunktagung 2015, Osnabrück

vodafone ROHDE&SCHWARZ NATIONAL INSTRUMENTS NOKIA Alcatel·Lucent ERICSSON

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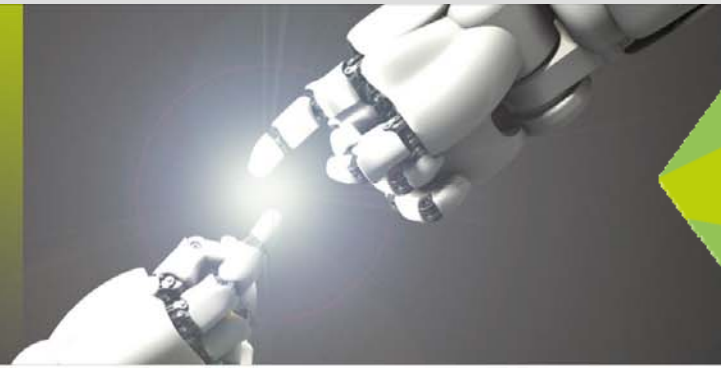
The Holistic 5G Vision



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5G *Use Cases*

5G *Requirements*

5G *Holistic View*

Wireless

Network

Silicon

Cloud

Videos: www.5glab.de

Via Della Conciliazione

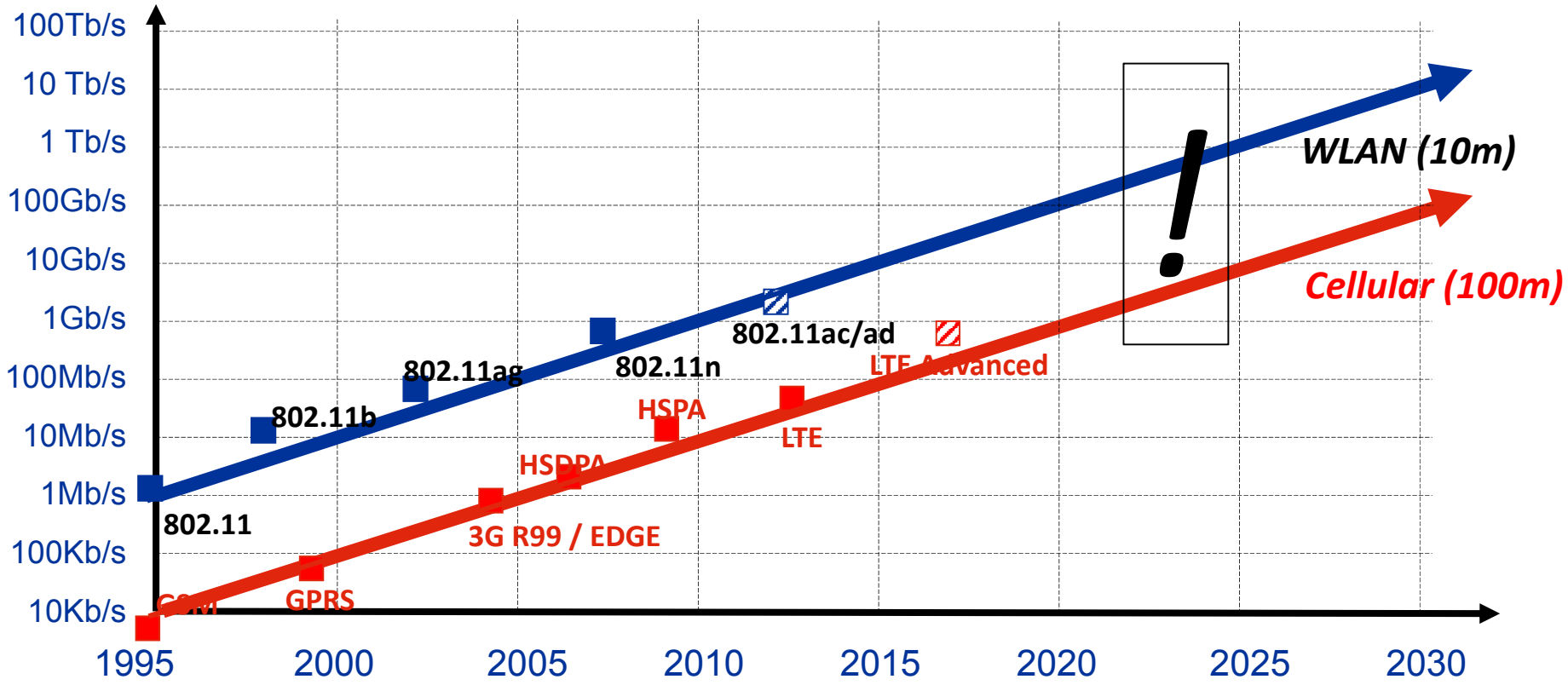
2005/4/4

Source: http://www.spiegel.de/panorama/bild-889031-473266.html

2013/3/12

Source: http://www.spiegel.de/panorama/bild-889031-473242.html

Wireless >2020 Outlook




7
Billion Devices
2014
Throughput
but there is more ....
500
Billion Devices
2022
Quelle: japantimes.co.jp/news/2014/09/30/asia-pacific/hong-kong-democracy-protesters-set-deadline-for-demands/

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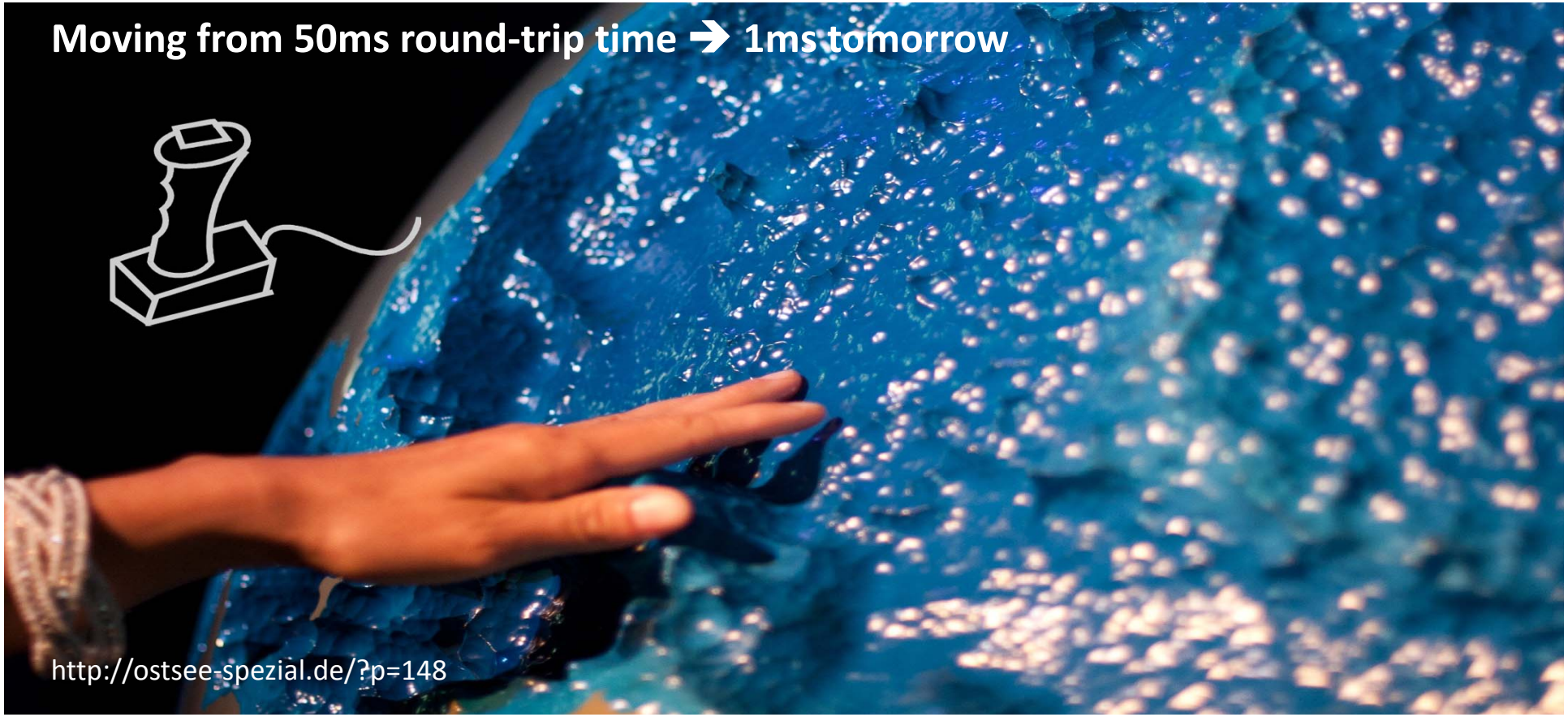
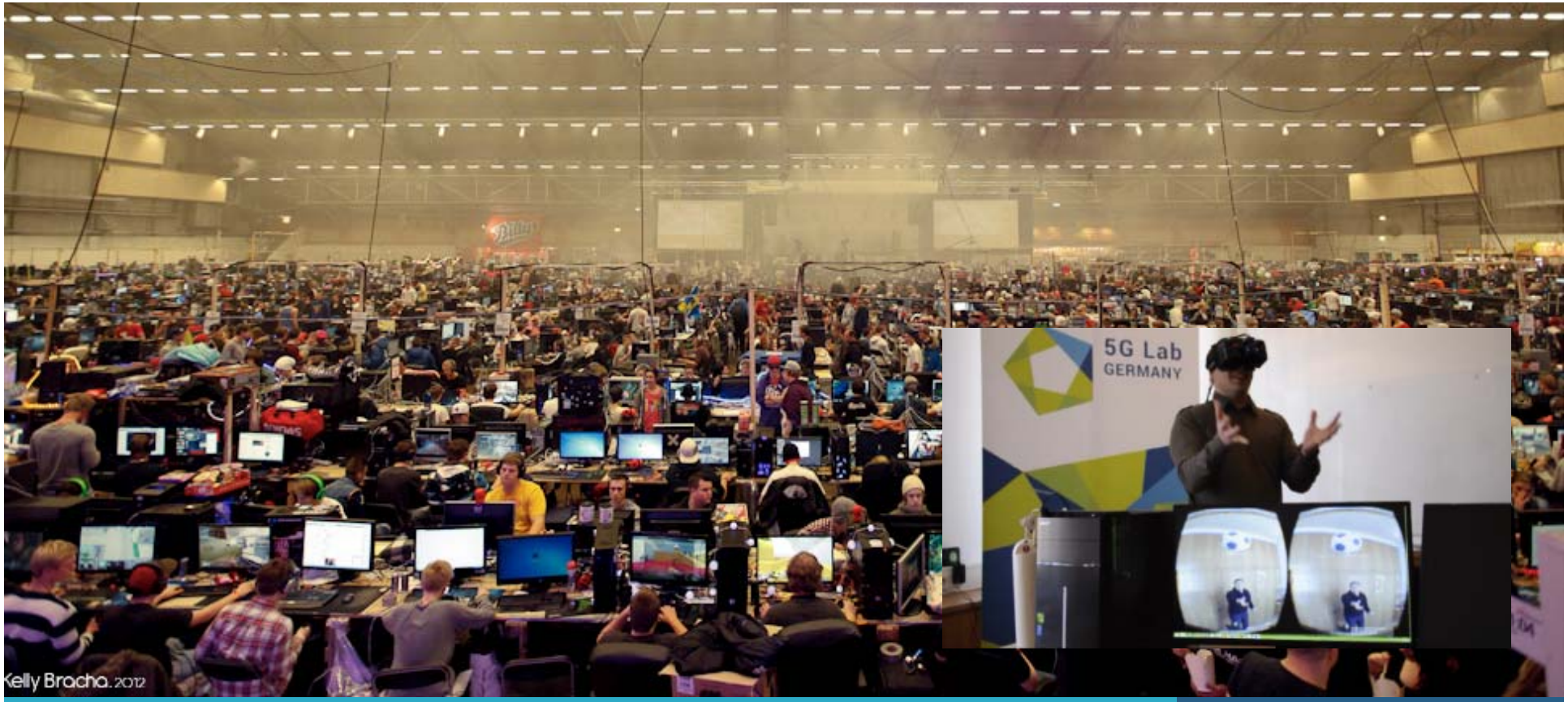
THE TACTILE INTERNET AND ITS MILLISECOND

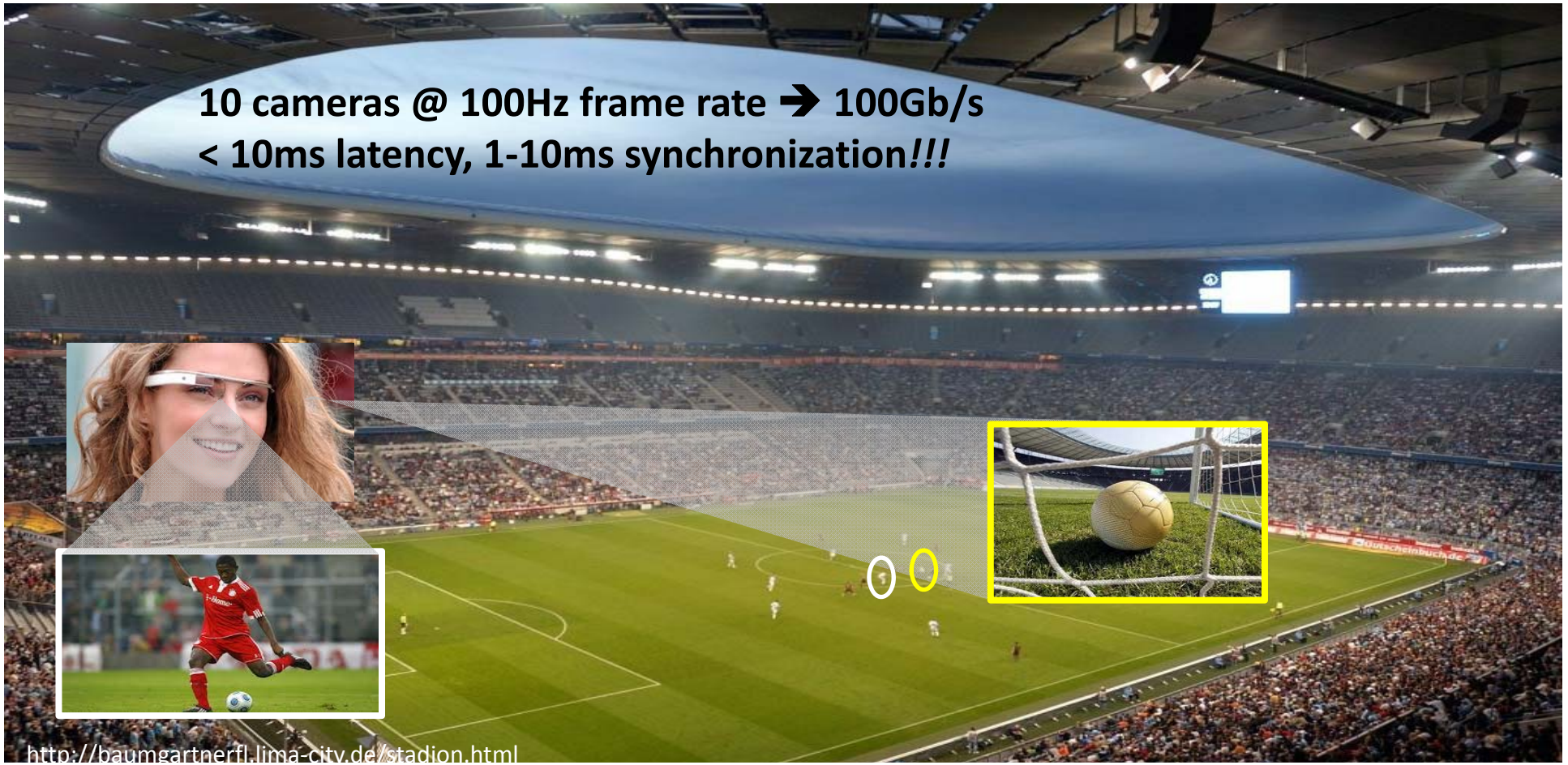
The Tactile Internet



Gaming: They were the first to recognize …

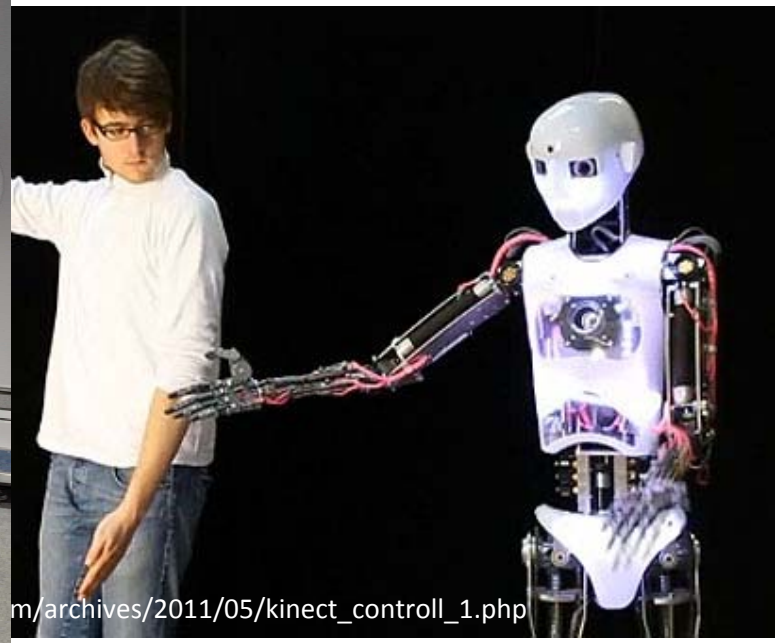


Tactile Internet Killer App: Free Viewpoint Video



The Tactile Internet: Remote Controlled Humanoid Robots

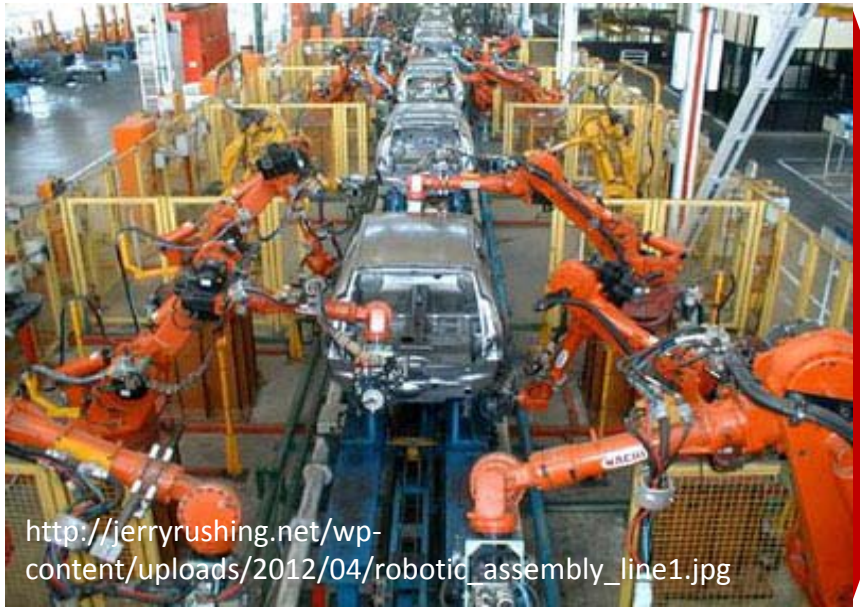
http://images.gizmag.com/hero/8456_512071



m/archives/2011/05/kinect_controll_1.php

Human Touch

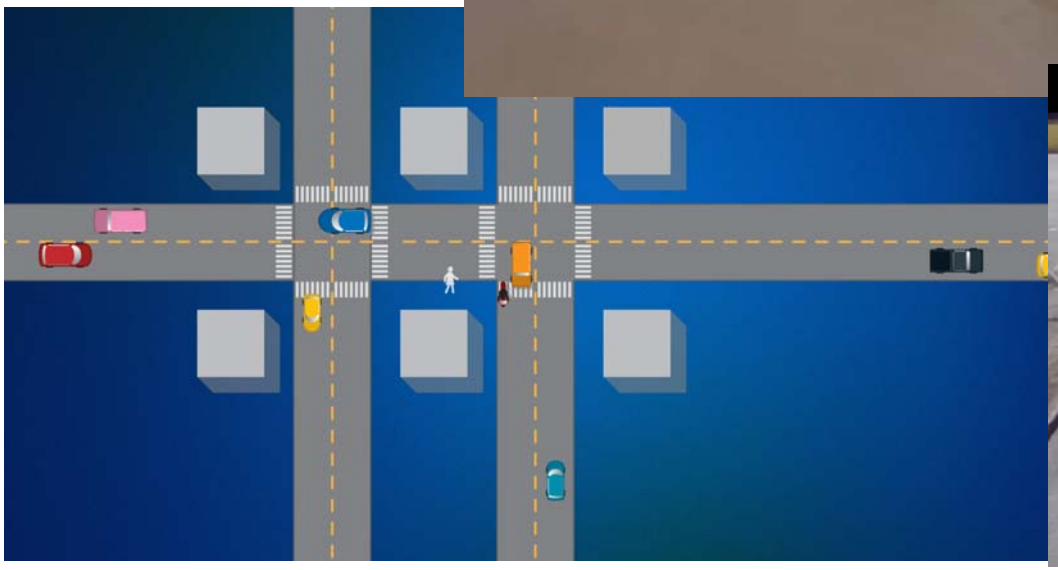
The Tactile Internet
The Manufacturing Revolution Ahead



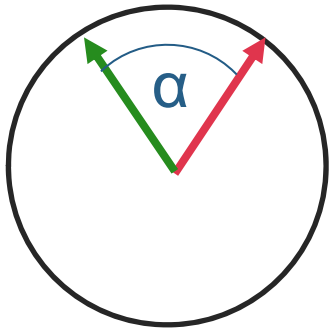
Platooning

1-2 ms examples of today's cars: ESC, ABS

Tomorrow: platooned ESC & ABS



Smart Grids ➔ Minimizing Reactive Power



1ms

18°

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5G REQUIREMENTS

5G – “Massive” Requirements

State of the art

- Massive throughput
- Massive low latency
- Massive sensing
- Massive resilience
- Massive safety and security
- Massive fractal heterogenity

5G

The Tactile Internet

> 10Gbit/s per user

< 1ms RTT

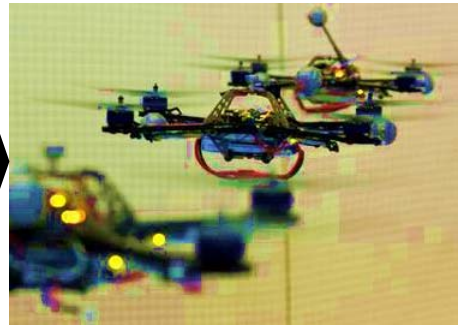
> 10k sensors per cell

< 10^{-8} outage

< 10^{-12} security

10x10 heterogeneity

Revolution Ahead: The Tactile Internet



5G:

Ubiquitous

Steering & Control
Communications

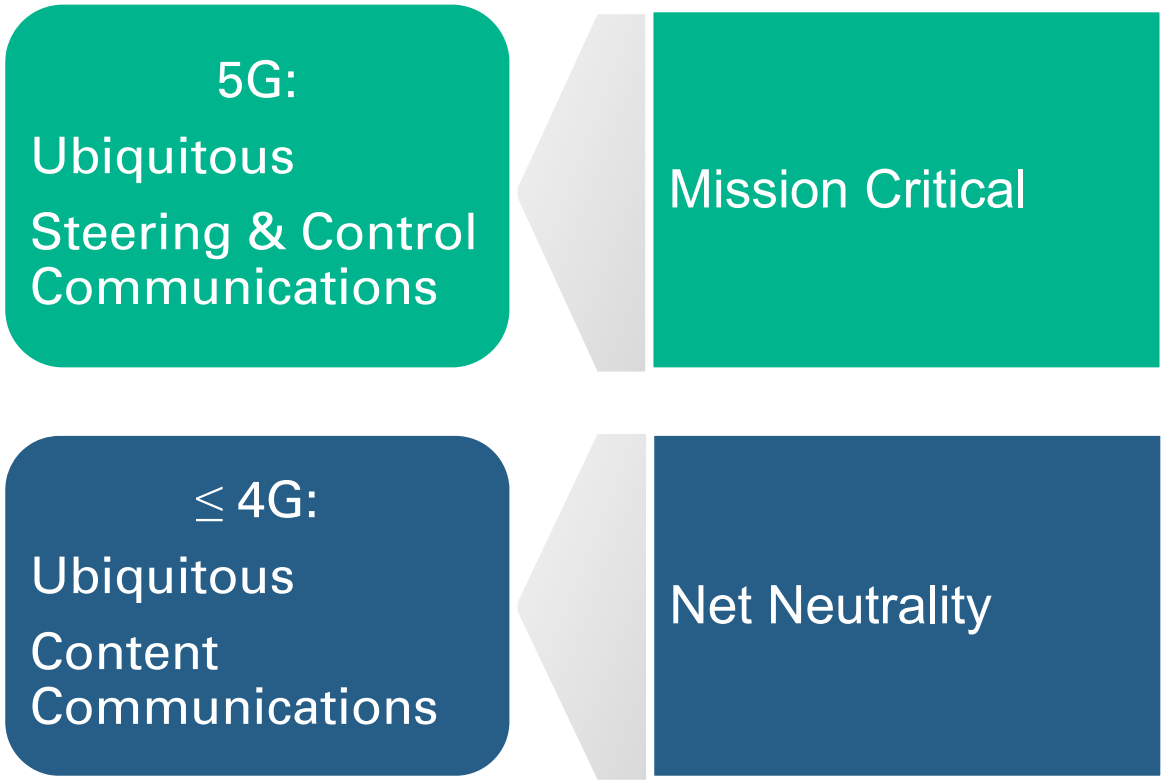
≤ 4G:

Ubiquitous

Content
Communications

Health & Care
Traffic & Mobility
Sports & Gym
Edutainment
Manufacturing
Smart Grid
...

Revolution Ahead: The Tactile Internet



Cellular Roadmap of USPs

5G – 2022
+ Tactile Internet

4G – 2012
+ Video everything
+ 3D Graphics

3G – 2002
+ Data
+ Positioning

2G – 1992
Voice
Messages

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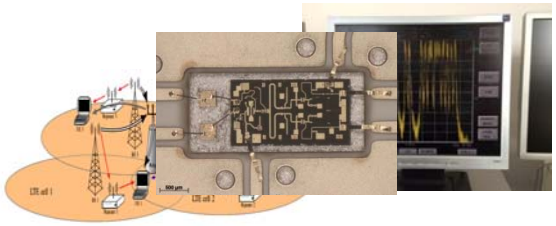
5G Research on four Tracks



Wireless & Network

Tactile Internet applications

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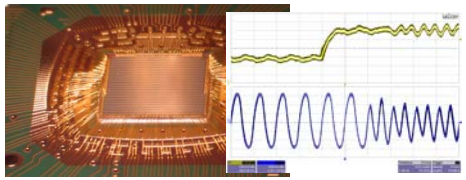


Silicon systems

vodafone

fast

ROHDE&SCHWARZ

NOKIA

Alcatel·Lucent

NATIONAL INSTRUMENTS

ERICSSON

Mobile edge cloud

Members on Tracks

5G LAB GERMANY

Silicon systems track


Rene Schüffny


Frank Ellinger


Dirk Plettemeier


Michael Schröter

Wireless & Networking track


Gerhard Fettweis


Eduard Jorswieck


Christof Fetzer


Frank Fitzek


Thorsten Strufe


Silvia Santini

Mobile edge cloud track


Wolfgang Nagel


Wolfgang Lehner


Hermann Härtig


Christel Baier

Tactile Internet application track


Leon Urbas


Uwe Aßmann

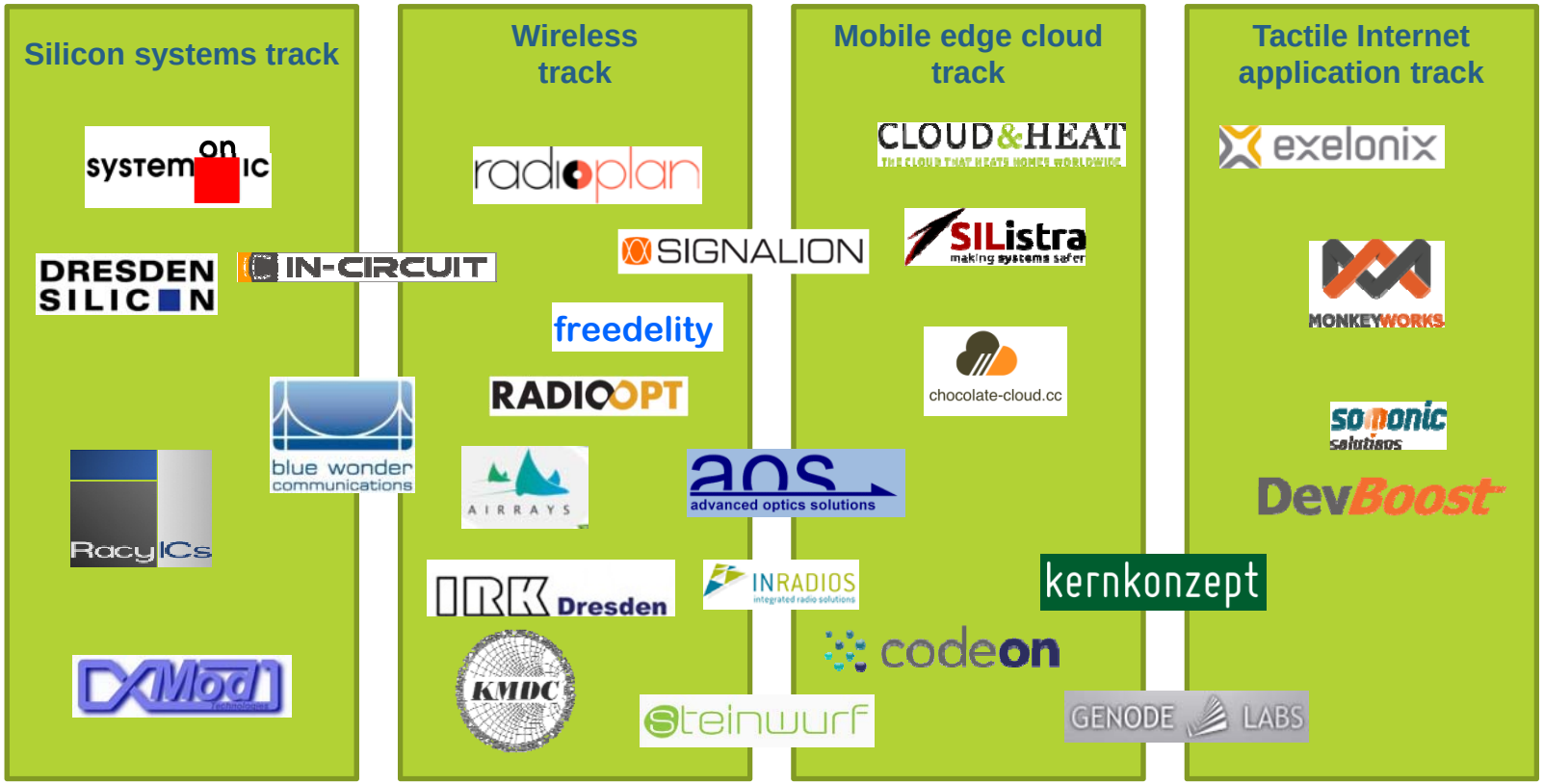

Ercan Altinsoy


Klaus Janschek


Thomas Herlitzius

Team of 500+ Researchers *!!!*

Relevant Startups Generated by Team



Connected industry partners

Mission Statement

We will address the massive requirements

by an holistic approach

tackling the wireless and the fix domain.

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THE MILLISECOND - CHALLENGES

fast actuators sensors & transceivers

Coordinators: Frank Ellinger, (Gerhard Fettweis), TU Dresden
Starting 2014, appox. €75M project size, 60+ partners

Bundesministerium für Bildung und Forschung

fast value chain
sales & service
systems, networks, software
circuits
components
semi-conductors

fast network of states
Berlin
Brandenburg
Mecklenburg Vorpommern
Saxony-Anhalt
Saxony
Thuringia
Baden-Württ.
Lower Saxony
Bavaria

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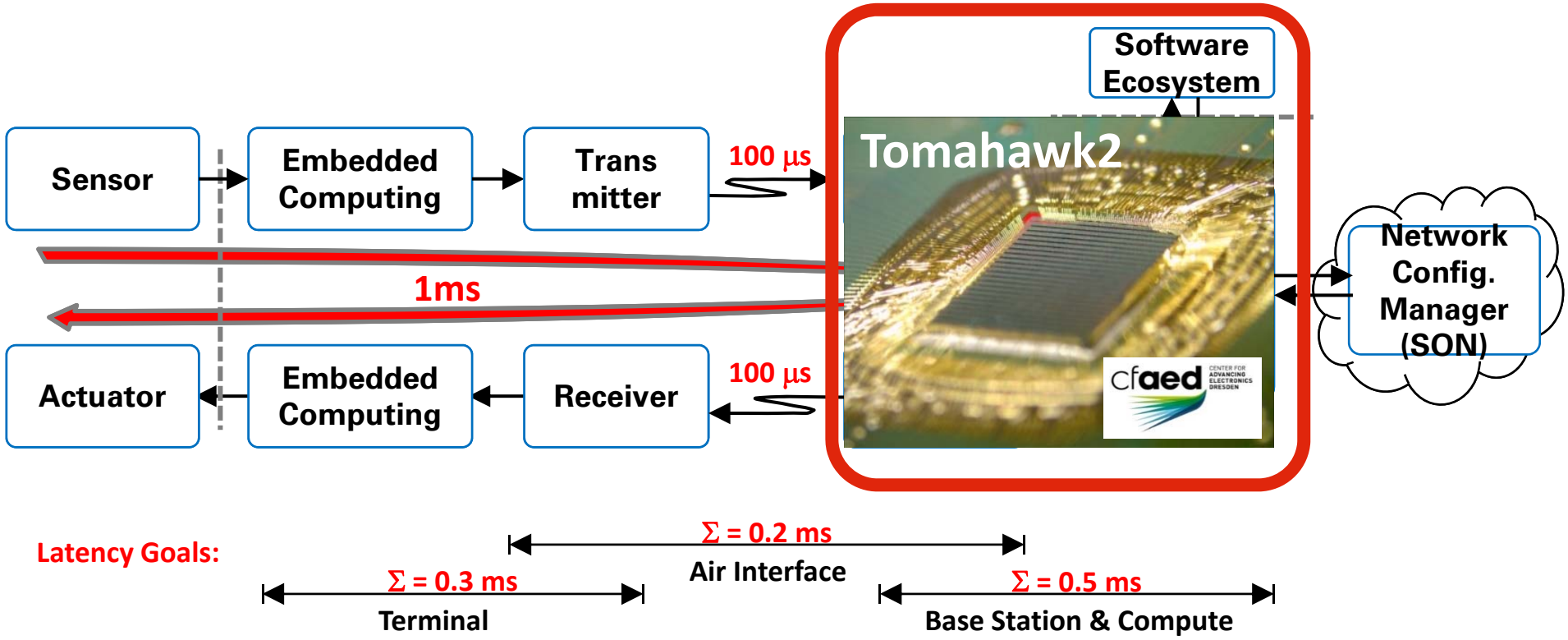
THE MILLISECOND - FROM SENSOR TO ACTOR

1ms Impact


Sensor
Embedded Computing
Trans mitter
100 µs
Software Ecosystem
Tomahawk2
Network Config. Manager (SON)
1ms
Actuator
Embedded Computing
Receiver
100 µs
Latency Goals:
Σ = 0.2 ms
Air Interface
Σ = 0.3 ms
Terminal
Σ = 0.5 ms
Base Station & Compute

1 ms Showcase at Cebit 2015

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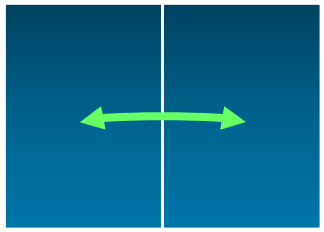
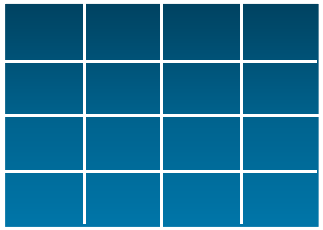
COMUPTATIONAL POWER

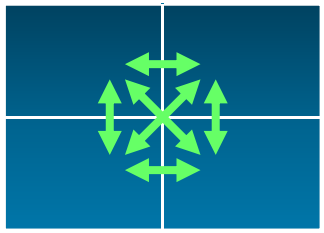
The Communication Bottleneck of Parallel Computing



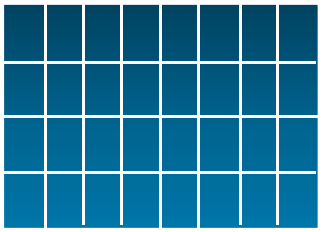
Parallelism = 2
Comm. Links = 1



P = 16
C = 120

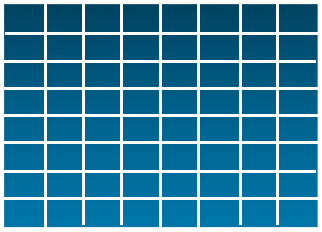


P = 4
C = 6



P = 32
C = 496

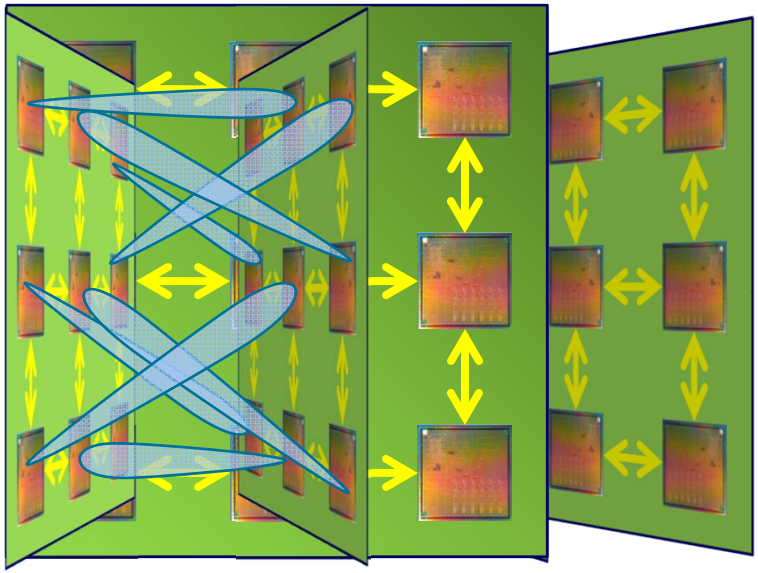
P = 8
C = 28



P = 64
C = 2016

Highly Adaptive Energy-Efficient Computing

High-Rate Inter-Chip Communications



Optical Interconnect

- adaptive analog/digital circuits for e/o transceiver
- embedded polymer waveguide
- packaging technologies (e.g. 3D stacking of Si/III-V hybrids)
- 90° coupling of laser

Radio Interconnect

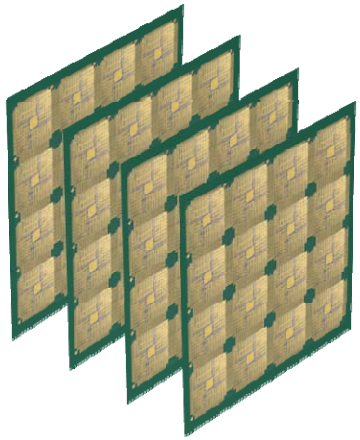
- Top-of-3D-stack antenna arrays
- analog/digital beam steering and interference minimization
- 100Gb/s – 1Tb/s
- 25 GHz channel @ 200GHz carrier
- 3D routing & flow management

GLOBALFOUNDRIES IBM amazon web services

The Outlook: The HAECBox in 2030+

Assume 64K processors per chip — 4x4 chip-stacks, double-sided board

160x chips stacked in 3D — 4x boards in a box



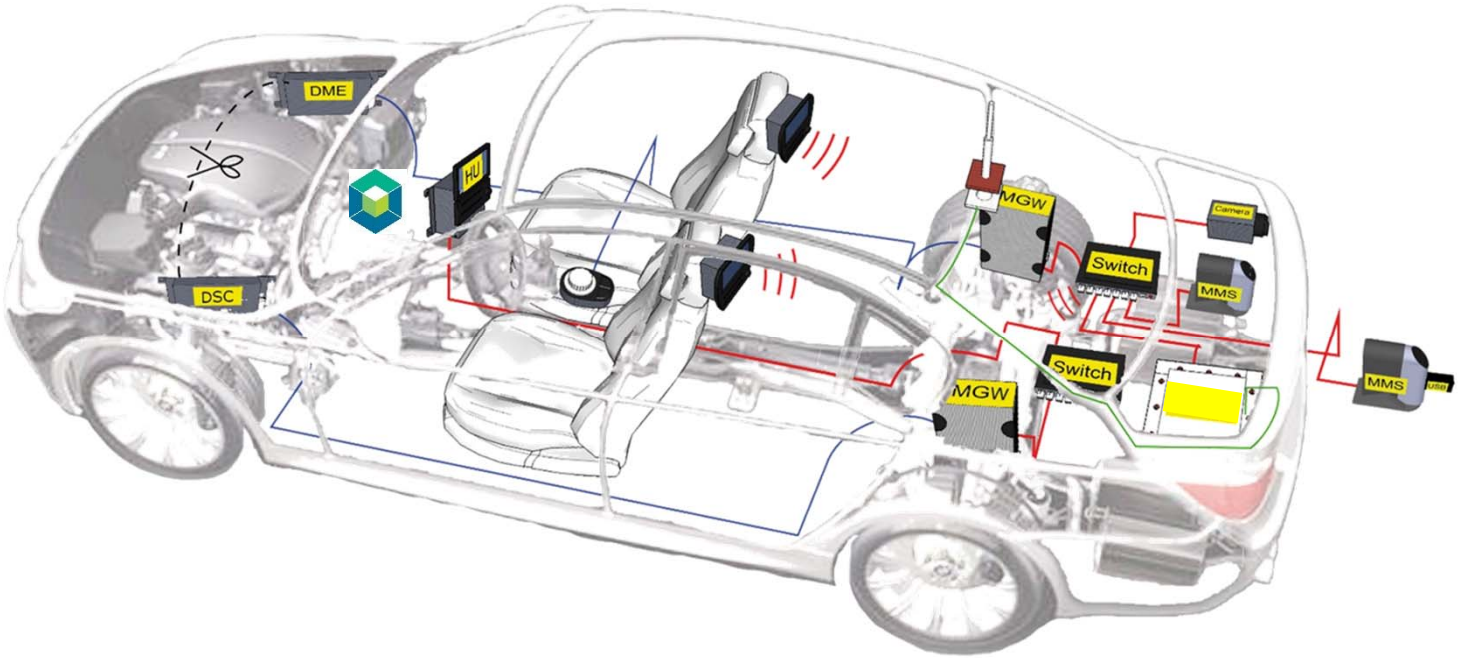
HAECBox

$10m^2$ Si

in 10x10x10 cm^3 (1 liter) → **10^8 processors!**

1.6K processor + 16K memory chips → **10^4x performance of today!**

HAEC Box Embedded Everywhere



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RESILIENCE

Carrier Grade Wireless: Use cases

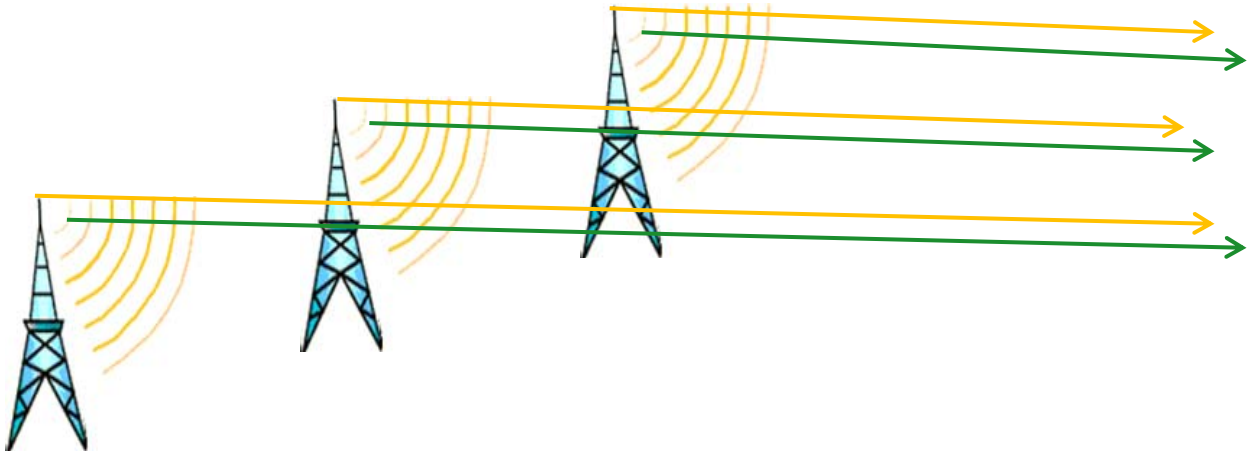
		Availability (time)	Latency	Coverage/ Availability (space)	Speed
Traffic safety & efficiency		> 99.999%	< 1ms	≈100%	< 500kmh
Industrial automation (Motion control)		> 99.999999%	< 1ms	≈100%	n/a
Tele surgery		> 99.999%	< 1ms	n/a	n/a
Emergency Communication		> 99.999%	n/a	≈100%	n/a

Others: Power Networks / Smart Grid, Real-Time Remote Computing, Platooning, ESP, Exoskeleton [1]

[1] Fettweis, G., "The Tactile Internet: Applications and Challenges," *Vehicular Technology Magazine, IEEE* , vol.9, no.1, pp.64,70, March 2014.

Serious Carrier Grade: 10^{-x} via Diversity

# indep. channels	1	2	3	4	5	6
outage	3%	10^{-3}	3×10^{-5}	10^{-6}	2×10^{-8}	7×10^{-10}



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MODULATION FOR CM-WAVES

Gerhard Fettweis

Realtime 5G Research Testbed: GFDM With -45dB to -65dB Notches *!*

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NATIONAL INSTRUMENTS

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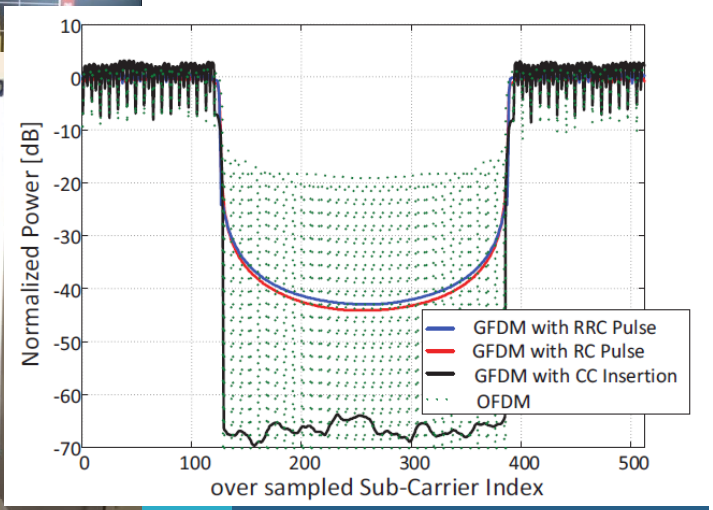
vodafone chair



10 Gbit/s Showcase at Cebit 2015

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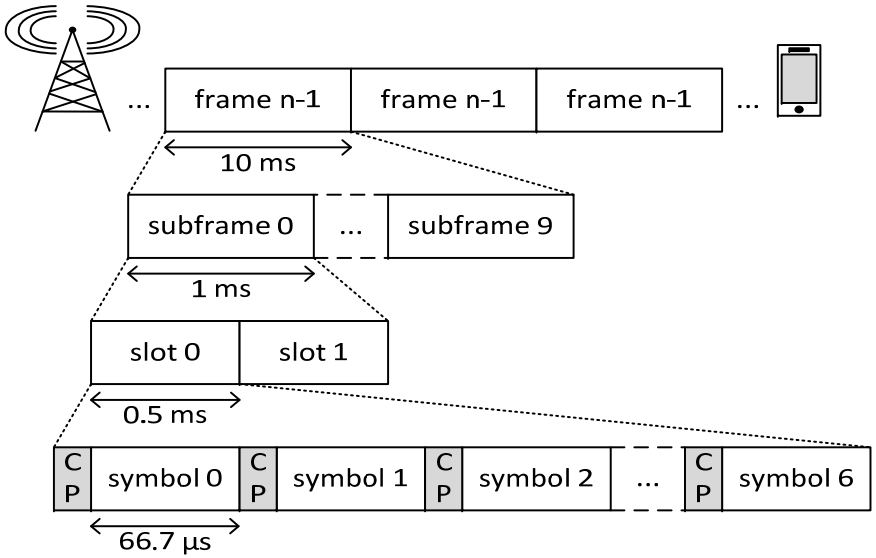
LTE COMPATIBILITY

The LTE Frame Structure



LTE parameters for the FDD mode.

Parameter	Normal mode	Extended mode
Frame duration	10 ms or 307.200 samples	
Subframe duration	1 ms or 30.720 samples	
Slot duration	0.5 ms or 15.360 samples	
Subcarrier spacing	15 kHz	
Subcarrier bandwidth	15 kHz	
Sampling freq. (clock)	30.72 MHz	
# of subcarriers	2048	
# of active subcarriers	1200	
Resource block	12 subcarriers of one slot	
Number of OFDM per slot	7	6
CP length (samples)	160 or 144	512

LTE is clearly one order of magnitude above the target latency.

The 5G goal:
Reduce the 1 ms based frame structure to something in the order of 50-100 µs.

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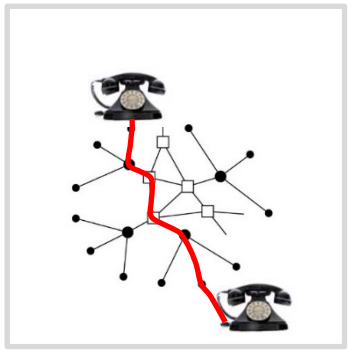
THE NETWORK

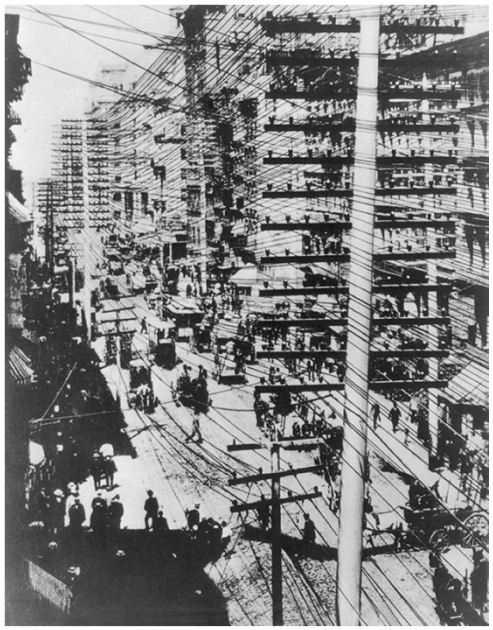
Communication Networks

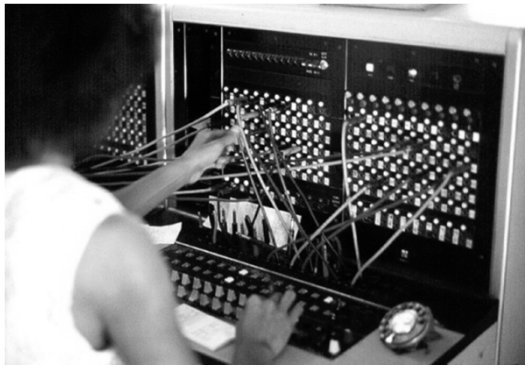
***Circuit* Switched Networks**



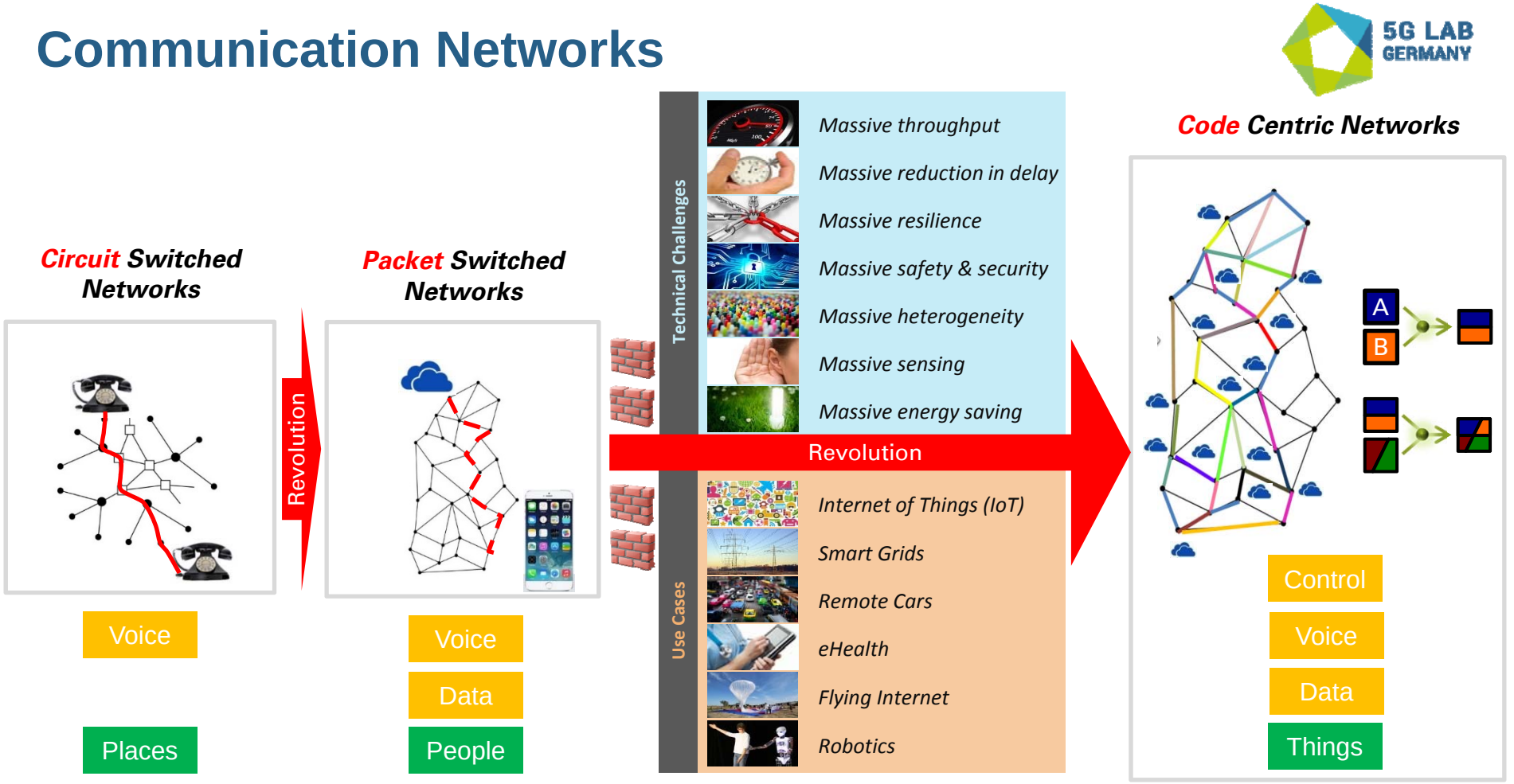
Voice

Places





Communication Networks



5G Communication Networks

- will be dominated by mesh architectures in the fixed as well as in the wireless domain
- require changes mainly in the fixed network (70%)
- will see fusion of storage and transport
- use network coding to break with the end to end paradigm and enabling low delay recoding

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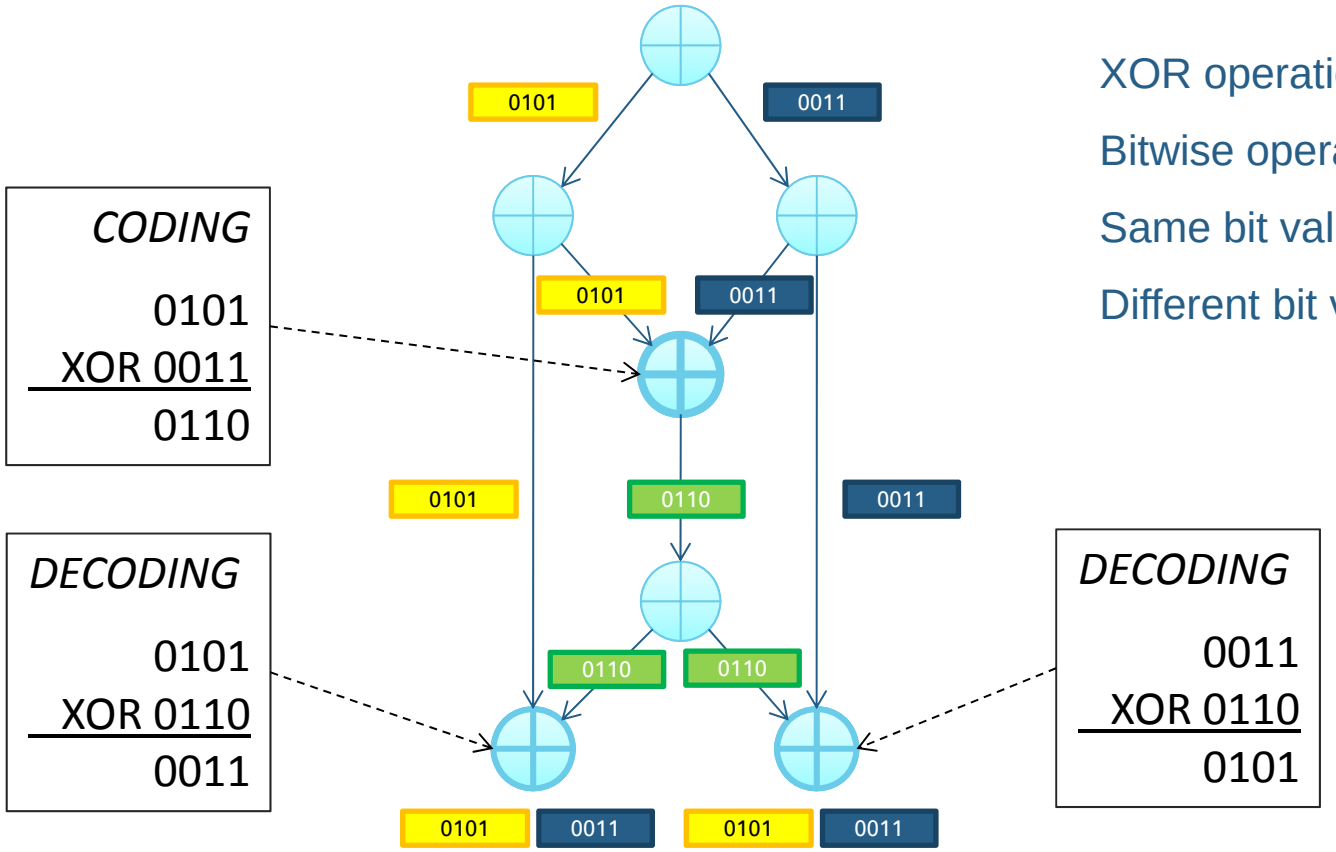
NETWORK CODING

Network Coding: The Butterfly



XOR operation

Bitwise operation

Same bit value results in „0“

Different bit value results in „1“

The Technology: RLNC

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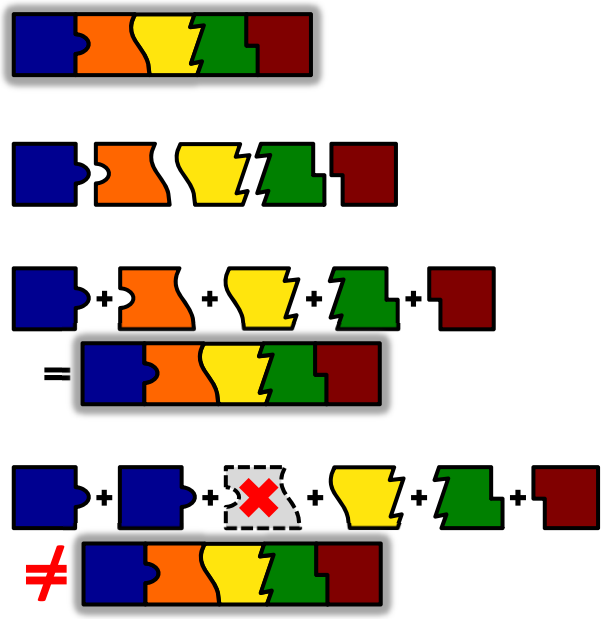
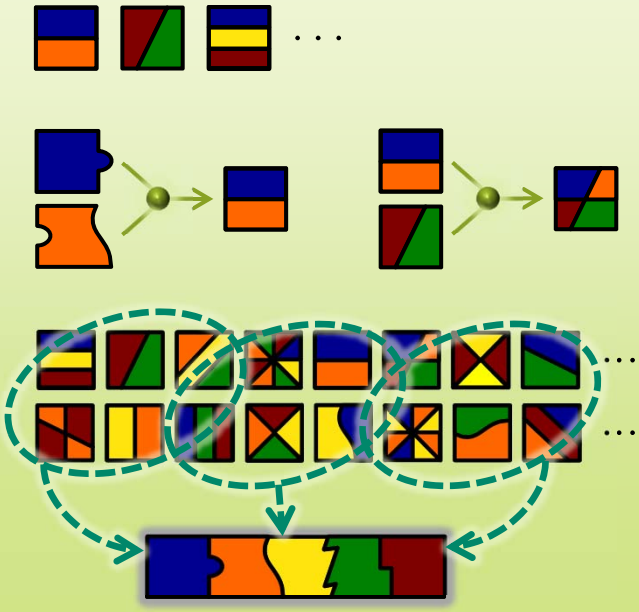
At the heart of many communications problems is a collectors' problem.

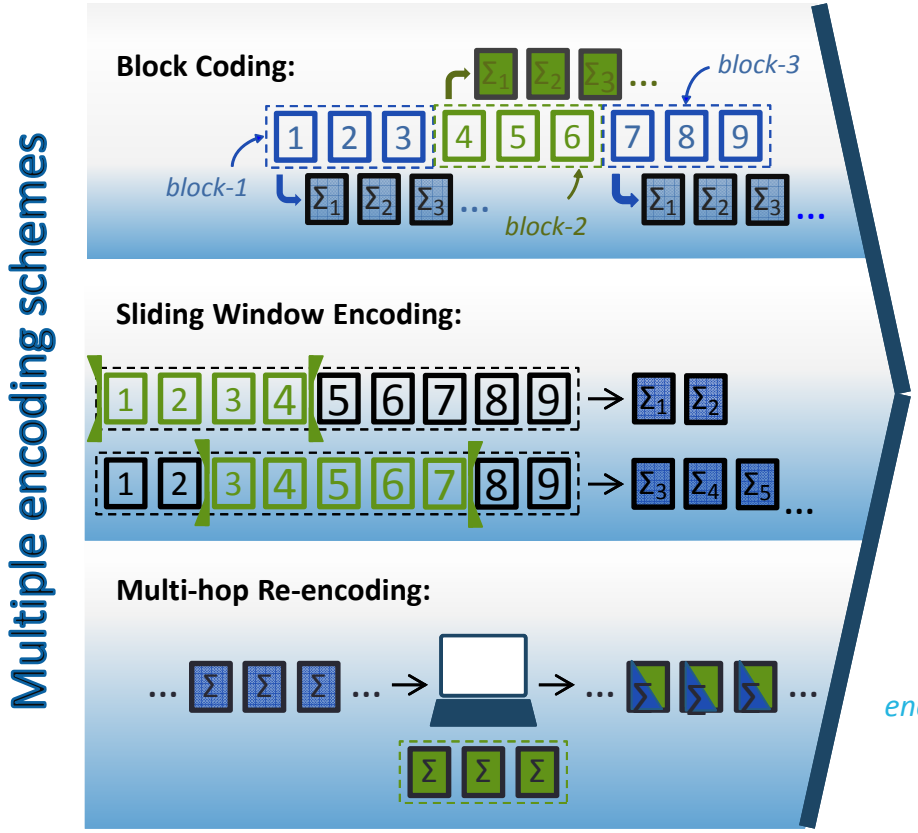
Traditional Approach



RLNC



RLNC Features



One decoding scheme

(simple equation-solving)

$$1 = a'_1 \Sigma_1 + b'_1 \Sigma_2 + g'_1 \Sigma_3$$

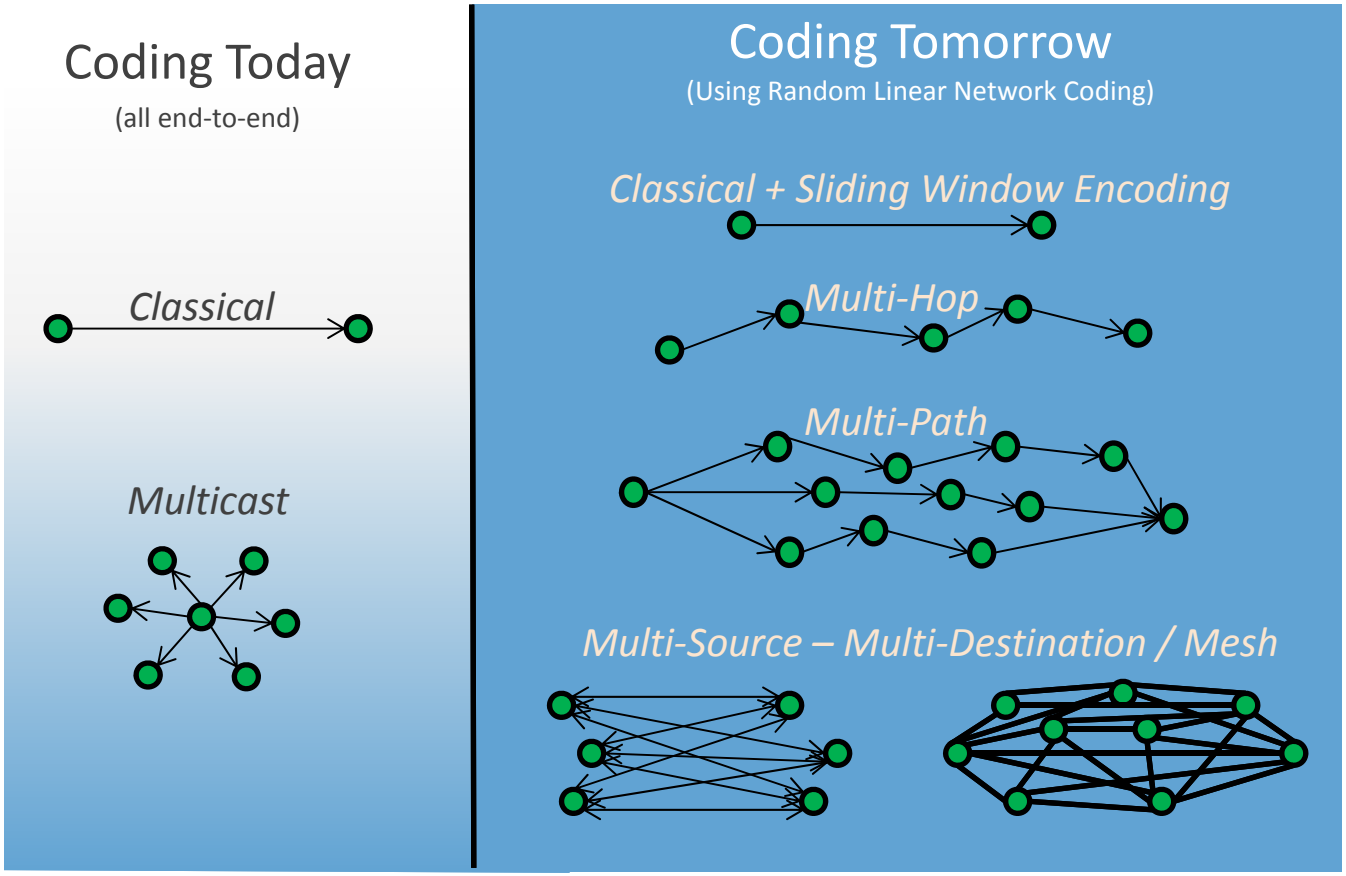
$$2 = a'_2 \Sigma_1 + b'_2 \Sigma_2 + g'_2 \Sigma_3$$

$$3 = 1 + b'_3 \Sigma_2 + g'_3 \Sigma_3$$

obtained through Gaussian Elimination

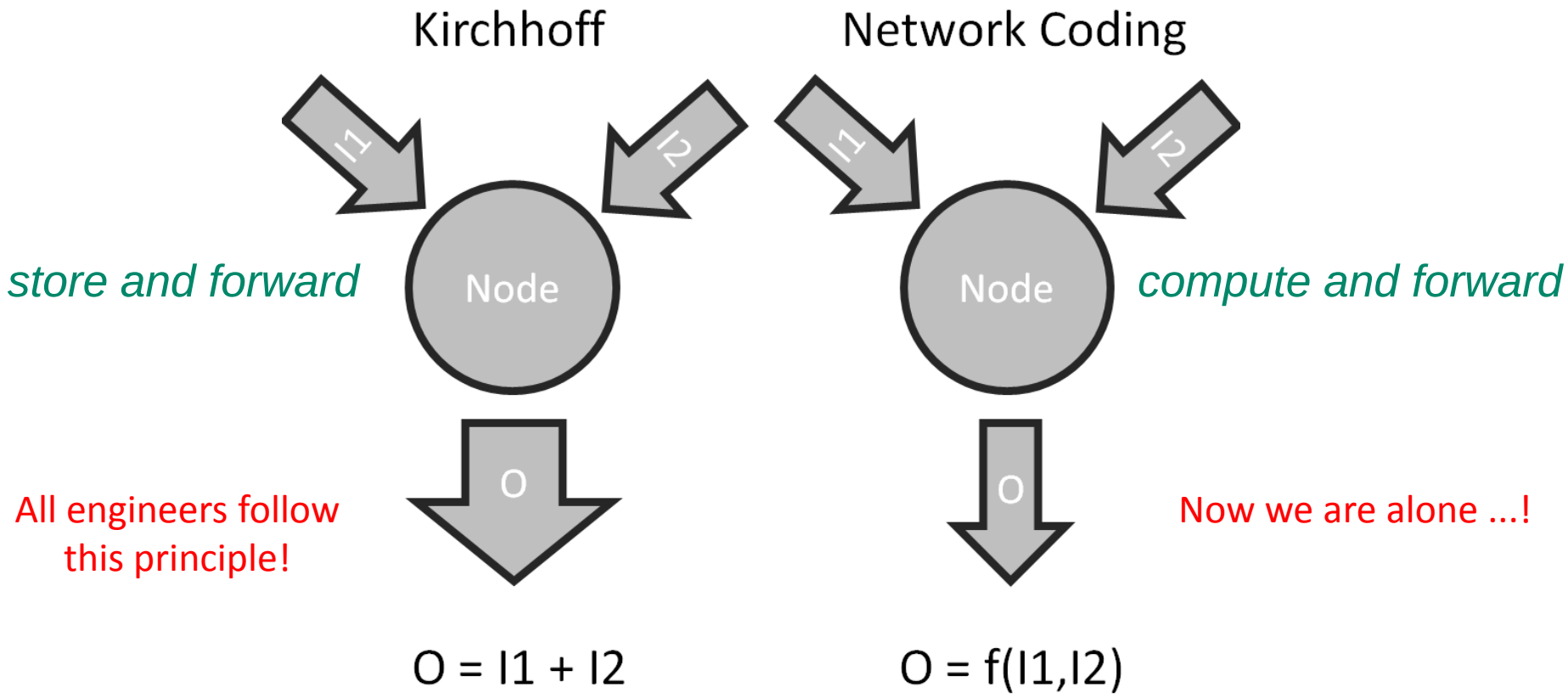
Can decode using both encoded and un-encoded packets

RLNC Application Field



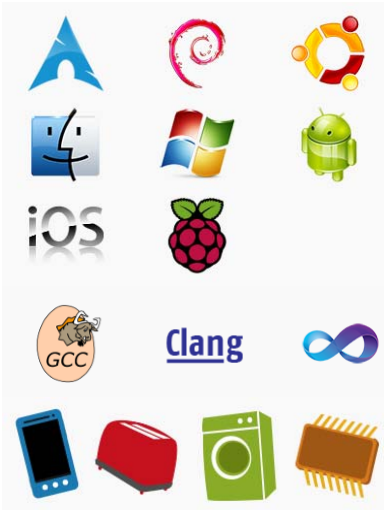
- Point-to-Point with delay constraints (TCP)
- Reliable Multicast (see IETF NORM)
- Channel Bundling (see IETF Multi Path TCP) – Small Cells
- Peer-to-Peer (see IETF WebRTC)
- Device-to-Device Communication (3GPP LTE-A)
- Wireless Mesh (LTE, WiFi, IoT, M2M, etc)
- Satellite Communication (Inter vs Intra)
- Software Defined Networks (see IETF/IRTF)
- Distributed Storage and Edge Caching

Kirchhoff versus Network Coding



KODO

- Fast track to utilize network coding for research and industry by flexible, tested, maintained & high performance solution
- Hardware and multi core support
- Library source code fully available. Licenses free for research/educational, but paid if commercial interest exist
- C++ but bindings for C, Java and Python



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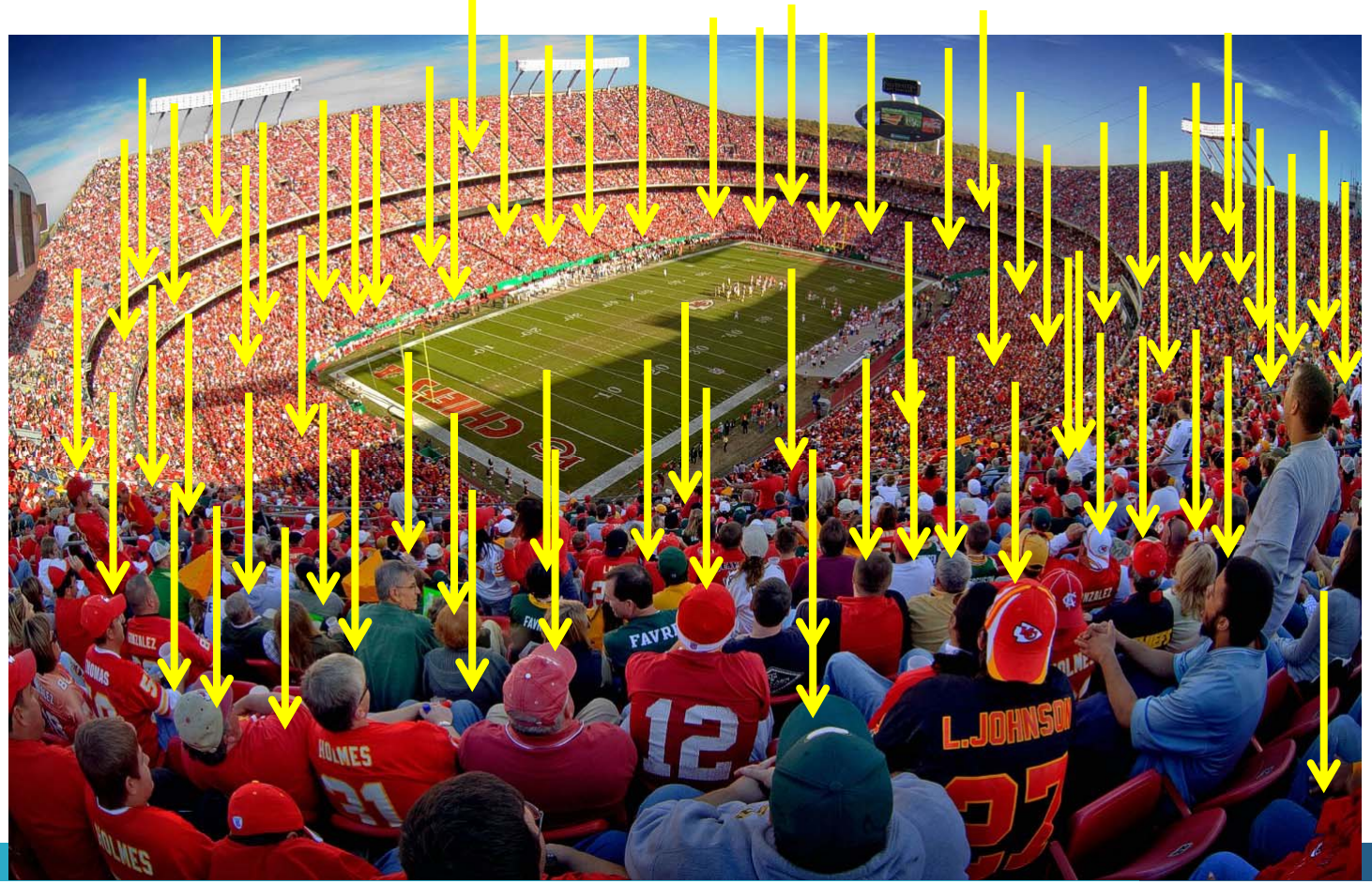
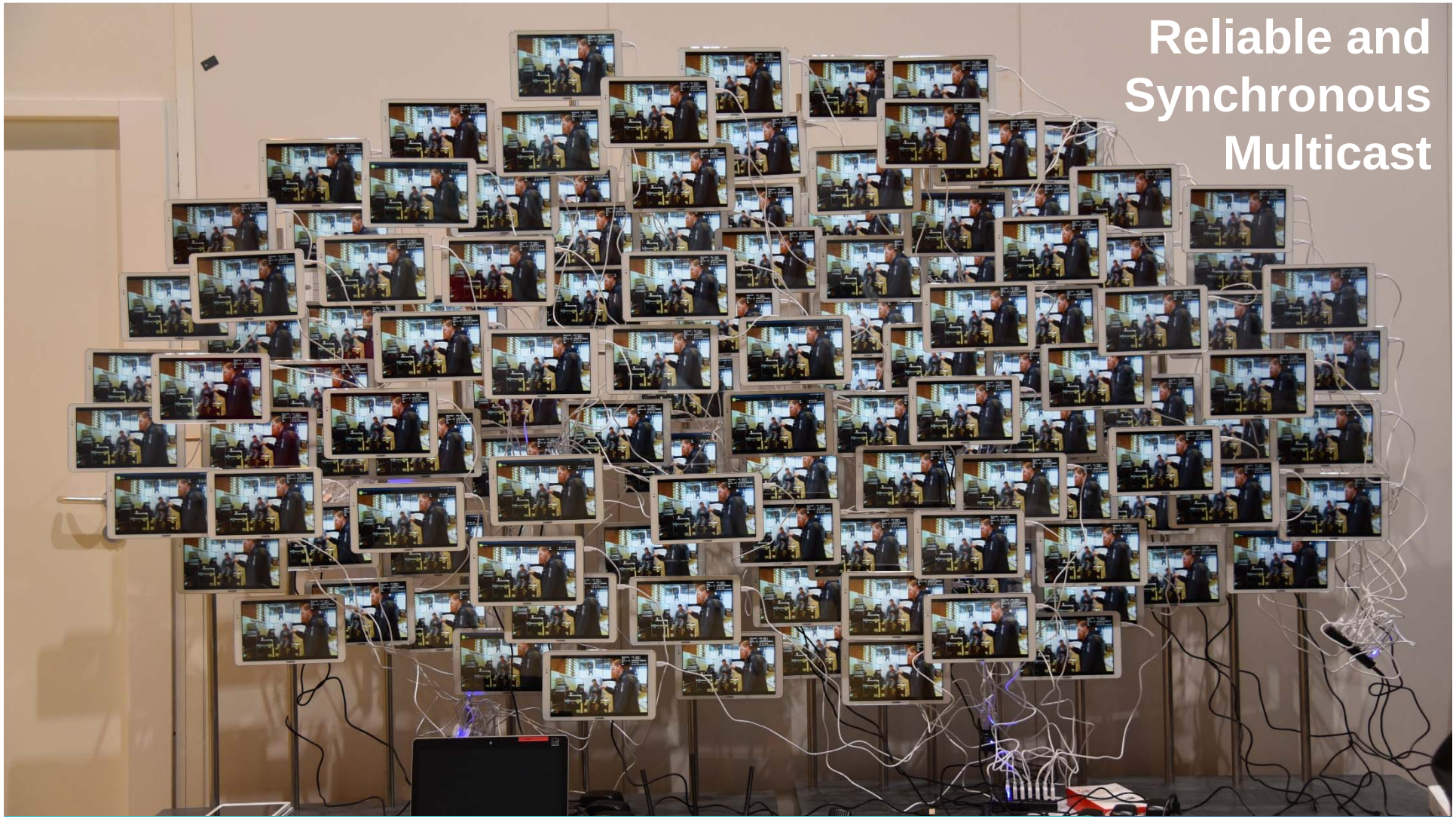
5G RELIABLE MULTICAST

Reliable Multicast (1)




Reliable and
Synchronous
Multicast

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Reliable Multicast (2)

Foto: Torsten Proß, Jeibmann Photographik

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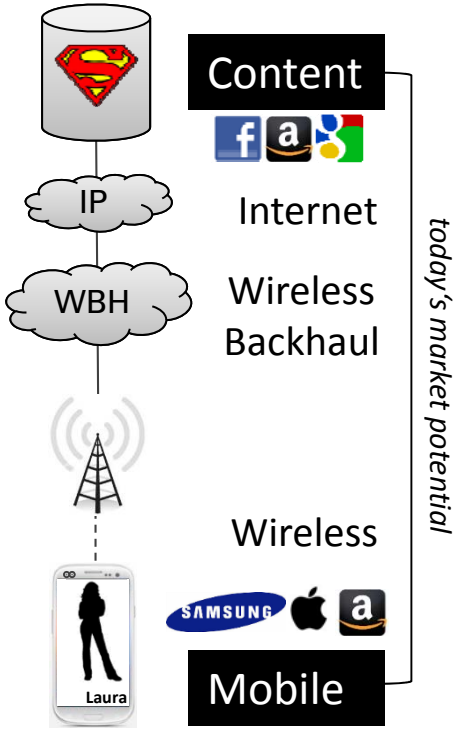
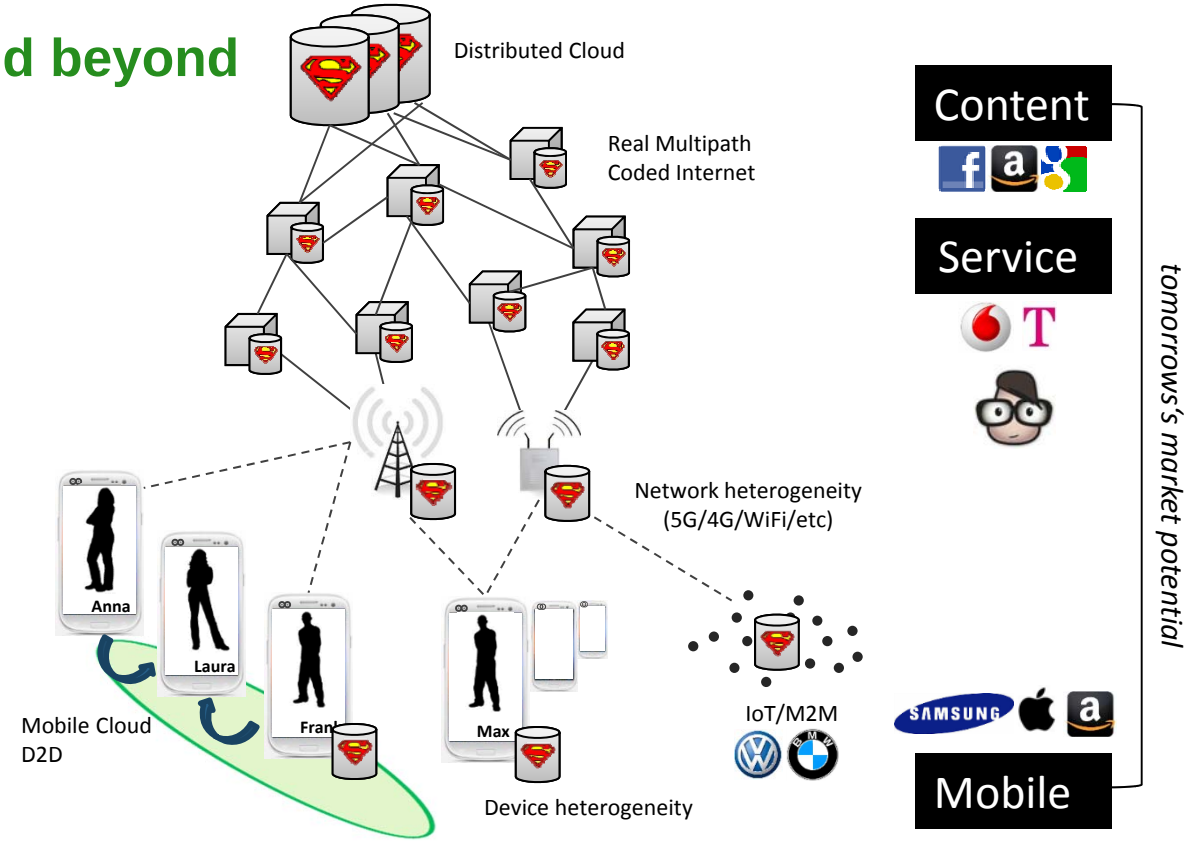
5G THE GAME CHANGER

5G the game changer

4G and before



5G and beyond



CONCLUSIONS

Conclusion

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5G is conceptually different to predecessors 2G, 3G and 4G

Focus on steering and control

Massive requirements on 5G

Multipath is the answer for some of them (resilience, security, throughput)

New network architecture (70% changes in fixed network)

Network coding is key technology

Huge market potential for network providers attacking the digital layer

Thank you

vodafone

Alcatel·Lucent

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