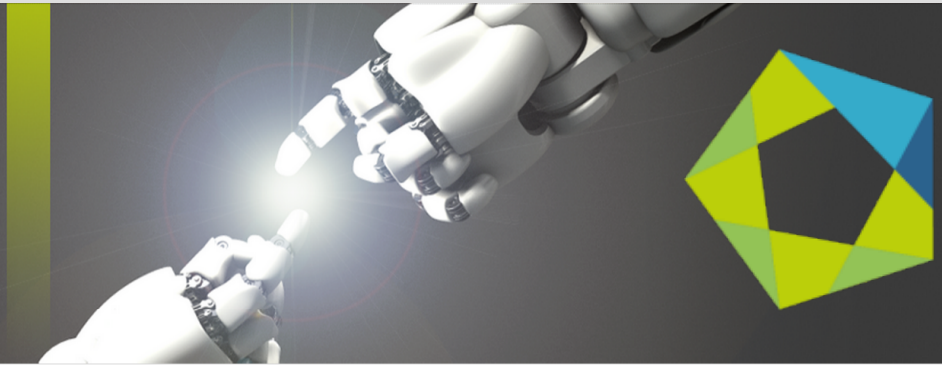
TECHNISCHE UNIVERSITÄT DRESDEN

5G enabling the Tactile Internet



5G LAB GERMANY

Frank Fitzek

Deutsche Telekom Chair Professor

Gerhard P. Fettweis

Vodafone Chair Professor

coordinators

serial entrepreneurs

Alcatel-Lucent BOSCH CLAAS ERICSSON NATIONAL INSTRUMENTS NEC NOKIA ROHDE&SCHWARZ Deutsche Telekom vodafone

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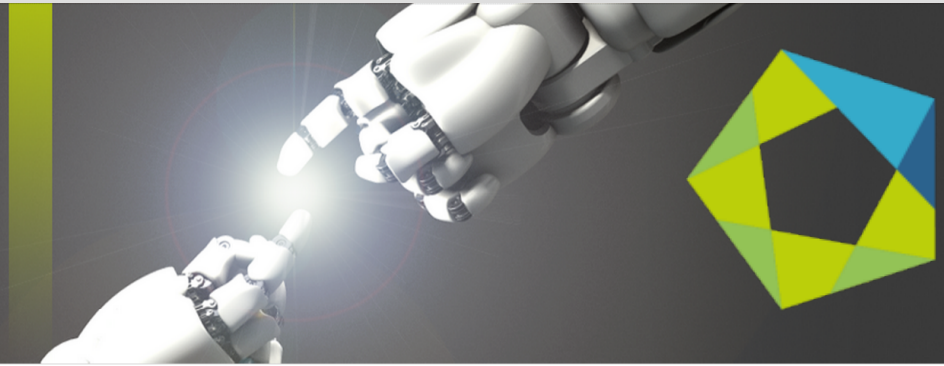
5G enabling the Tactile Internet



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Industry 4.0
Driverless Cars / Transport / Mobility
Smart Grids
Tactile Internet
…

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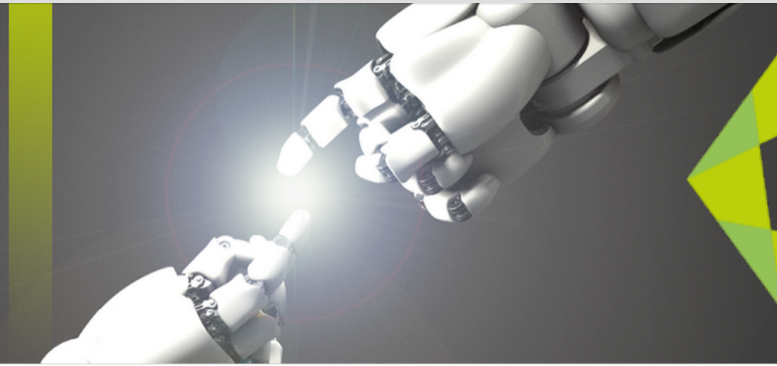
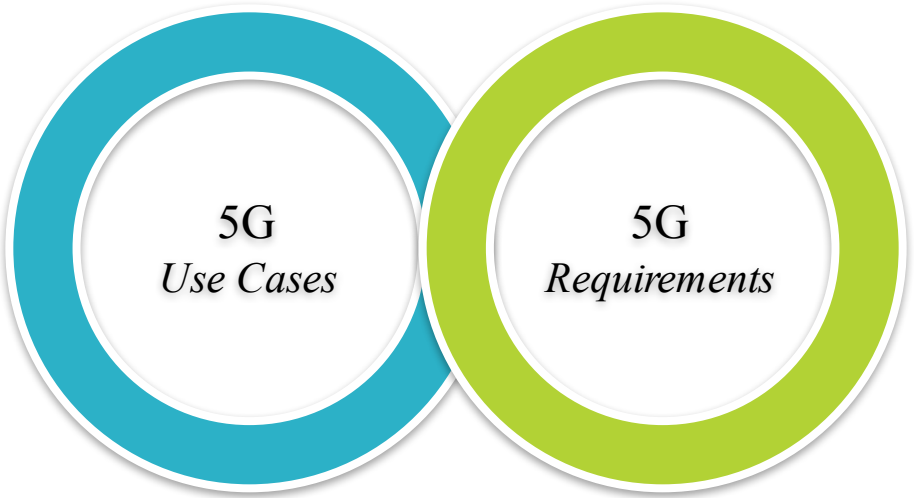
5G enabling the Tactile Internet



5G LAB GERMANY



Data Rate
Security
Reliability
Latency
Heterogeneity
Massive

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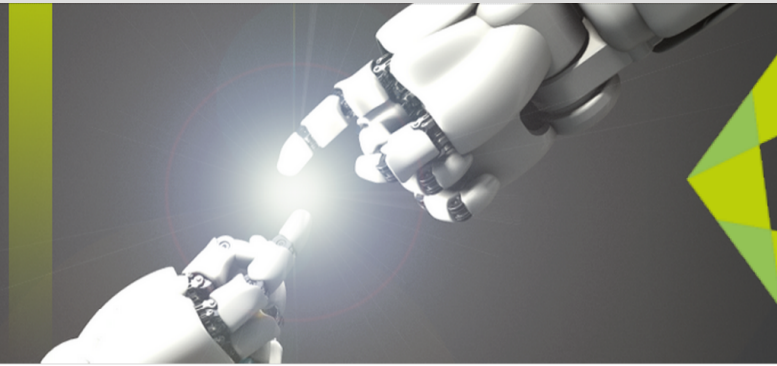
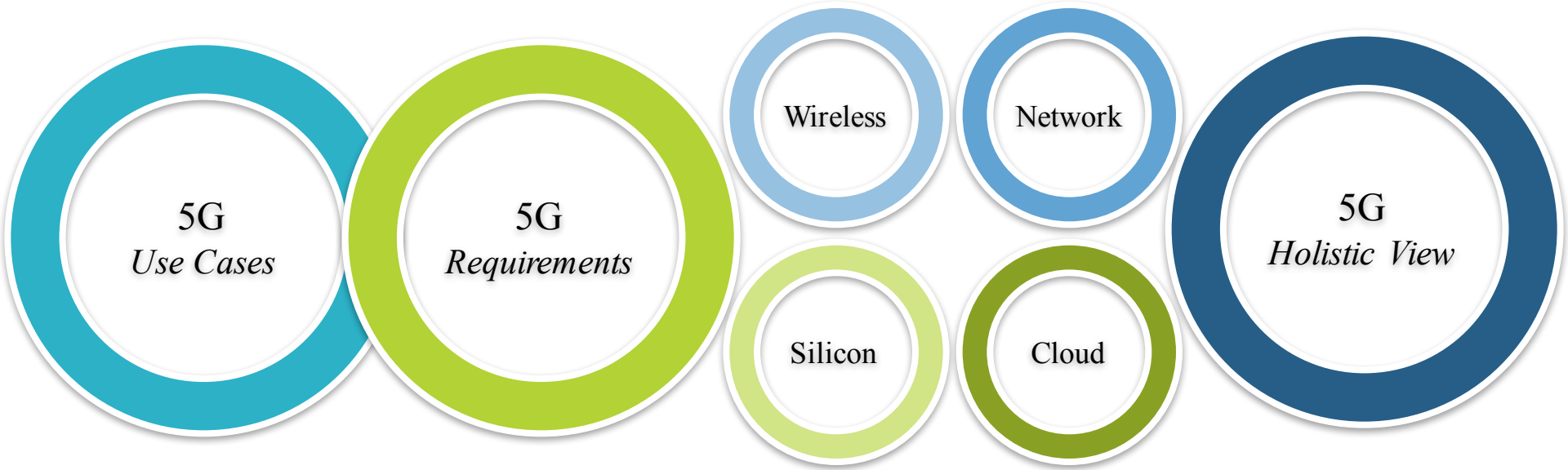
5G enabling the Tactile Internet



5G LAB GERMANY



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GERMANY

THE WAY TOWARDS 5G

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

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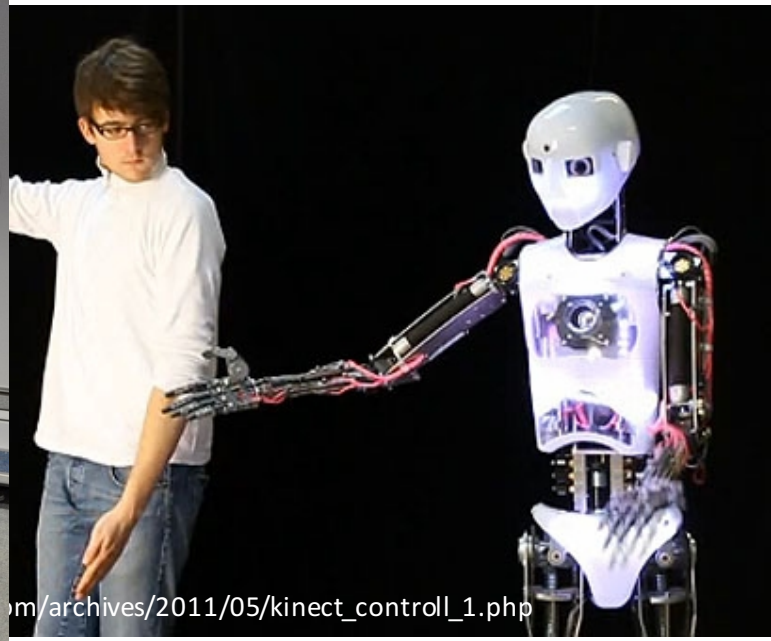
Moving from 50ms round-trip time ➔ 1ms tomorrow

Gaming: They were the first to recognize …

The Tactile Internet: Remote Controlled Humanoid Robots

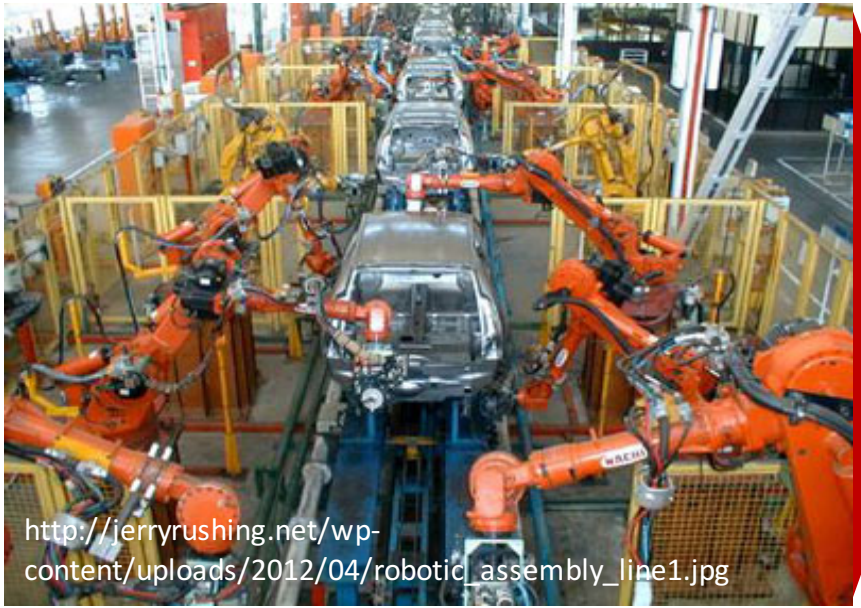
The Tactile Internet: Remote Controlled Humanoid Robots



Human Touch

Precision Farming

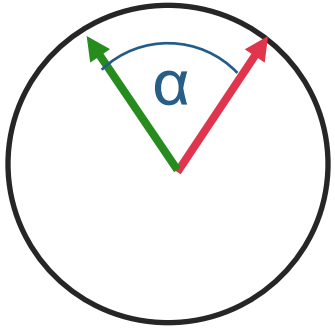
The Tactile Internet
The Manufacturing Revolution Ahead



http://jerryrushing.net/wp-content/uploads/2012/04/robotic_assembly_line1.jpg

http://www.witchdoctor.co.nz/wp-content/uploads/2013/01/robot-fabrication-station.jpg

Smart Grids ➔ Minimizing Reactive Power



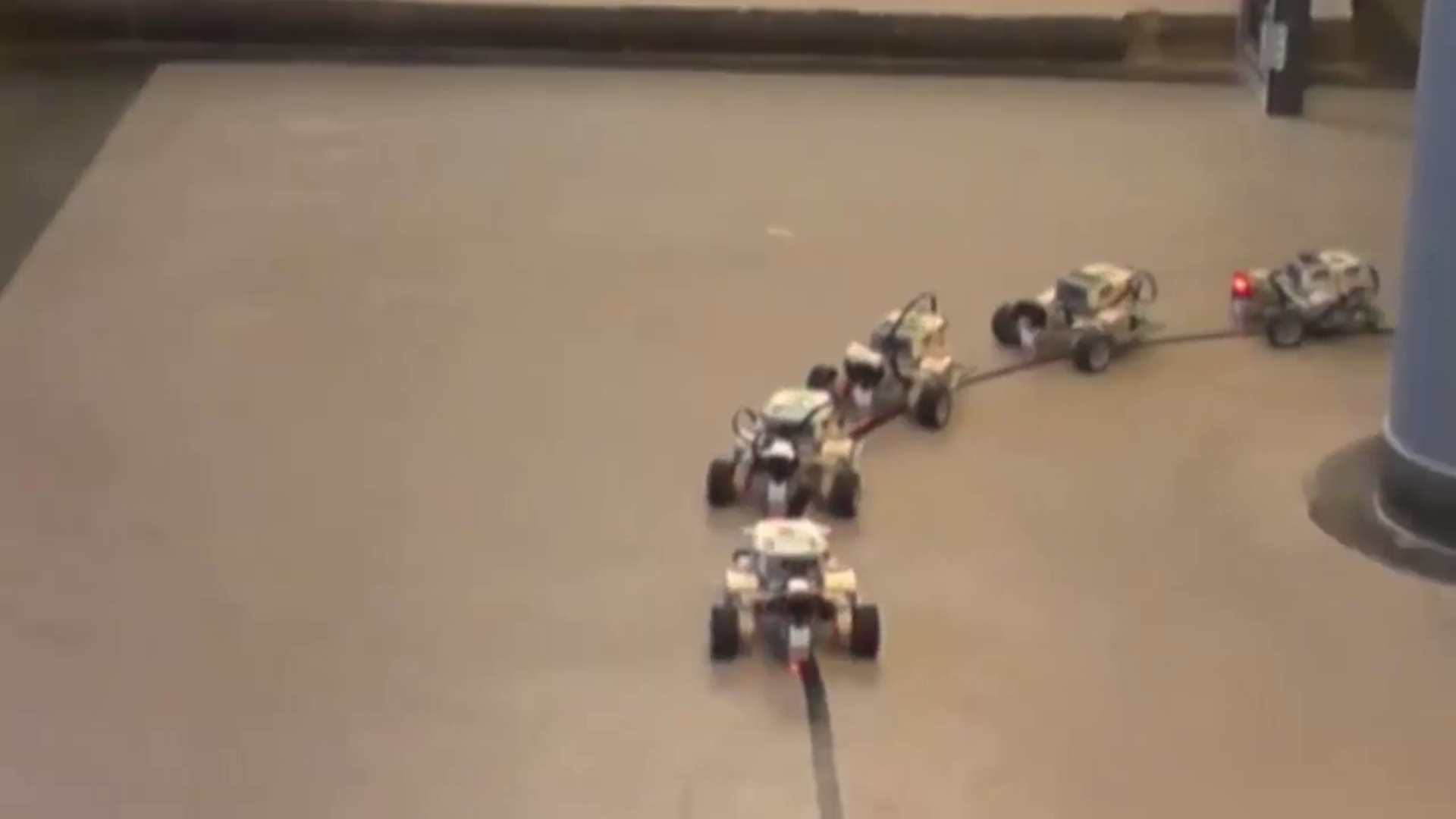
1ms

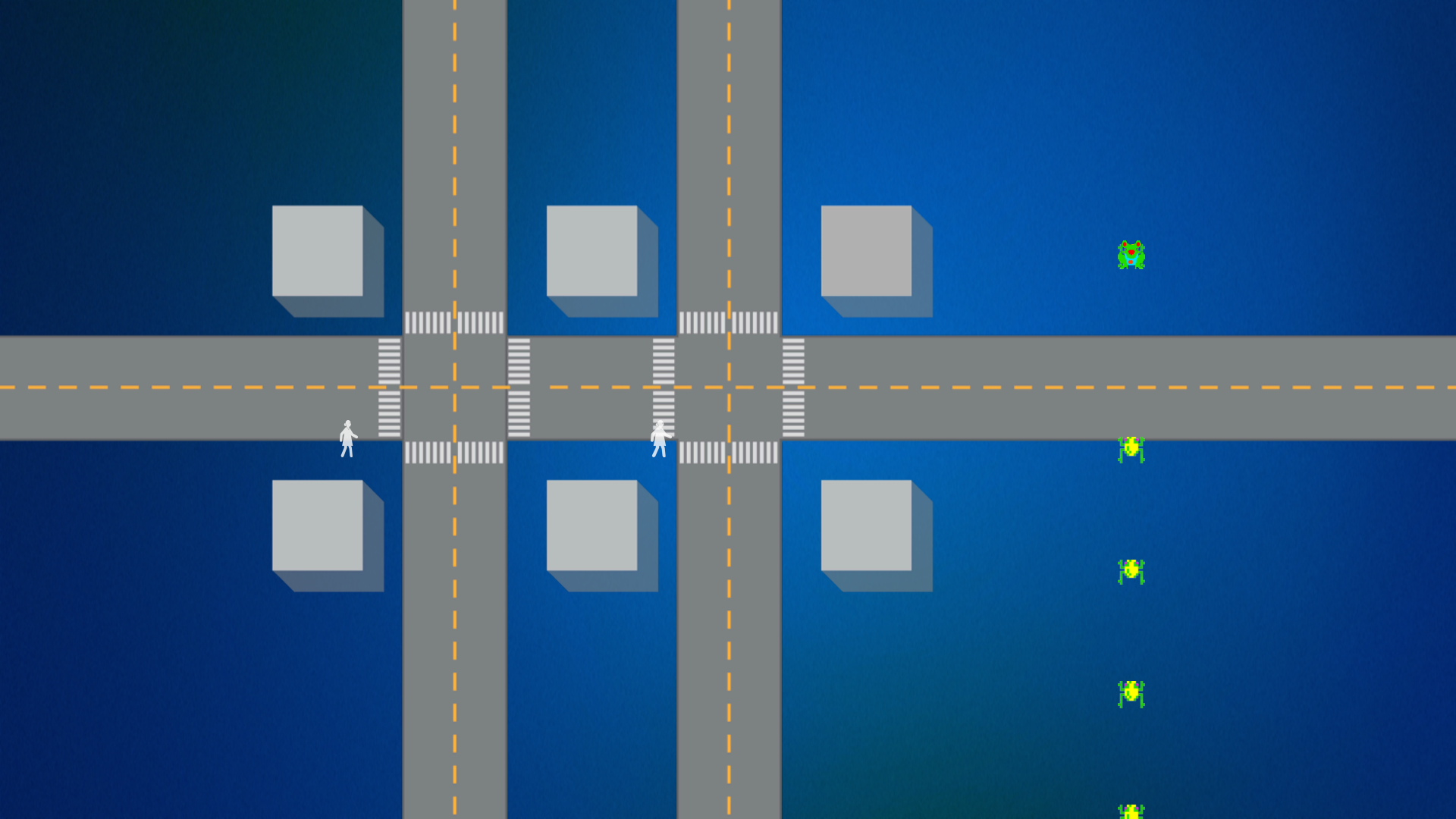
18°

Platooning

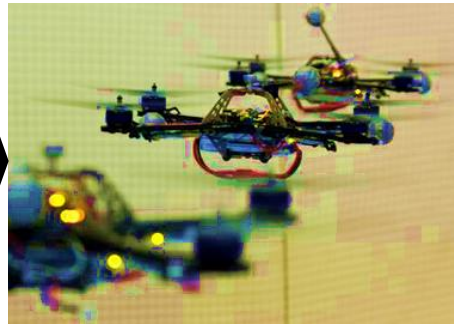
1-2 ms examples of today's cars: ESC, ABS

Tomorrow: platooned ESC & ABS





Revolution Ahead: The Tactile Internet



5G:

Ubiquitous

Steering & Control
Communications

≤ 4G:

Ubiquitous

Content
Communications

Health & Care

Traffic & Mobility

Sports & Gym

Edutainment

Manufacturing

Smart Grid

…

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5G REQUIREMENTS

5G – “Massive” Requirements

State of the art

- Massive throughput
- Massive reduction in latency
- Massive sensing
- Massive resilience
- Massive safety and security
- Massive fractal heterogeneity

5G – “Massive” Requirements

… and they are coupled!

How can we realize 5G?

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	Multi-Path Multi-Link	Mobile Edge Cloud	New Air Interface
Data Rate	✓		✓
Latency		✓	✓
Security	✓		
Reliability	✓		
Heterogeneity	Network Coding		
Massive	Compressed Sensing		

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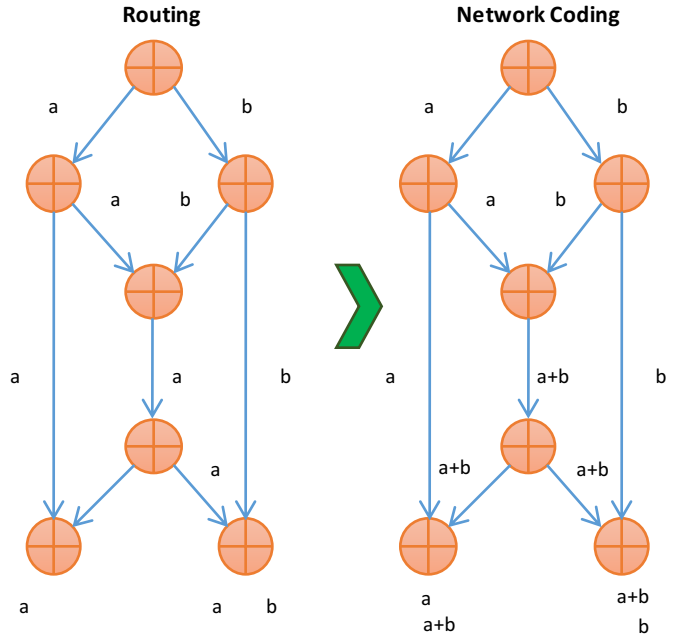
5G NETWORK CODING

Network Coding



a | a b

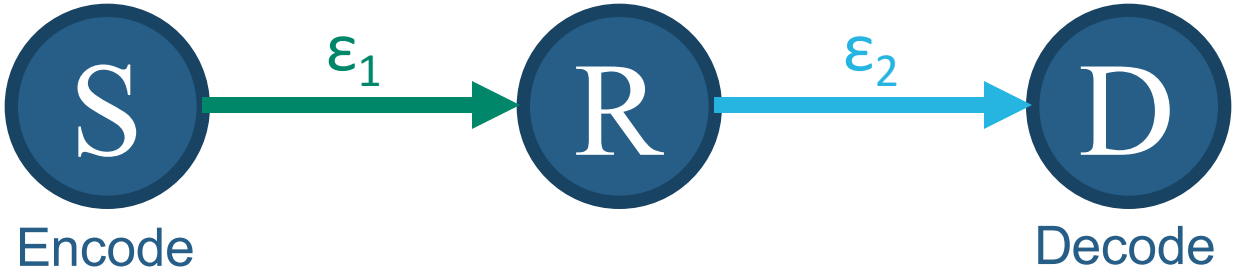
Rate: 1.5 symbols/time
Distributed (but planned)
Sub-optimal
Low processing cost

a b | a b

Rate: 2 symbols/time
Centralized, Planned
Optimal
Low-Medium processing cost
One Finite Field in use
Does not consider device capabilities
- One encoder, one decoder
- One recoder

Network Coding

Network Coding

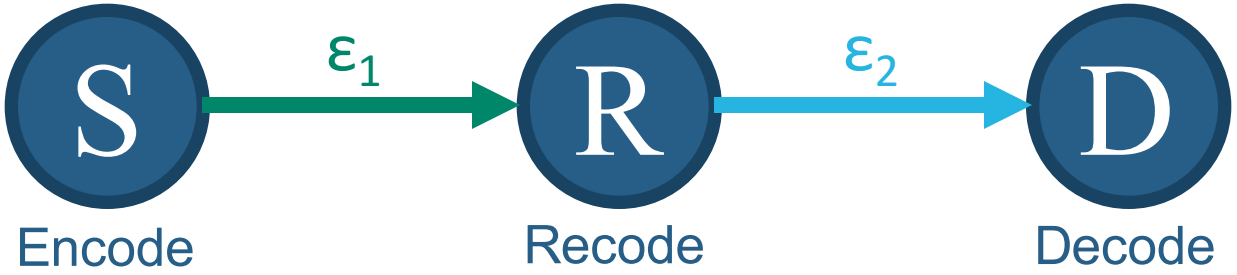


Reed Solomon
LDPC
LT
Raptor

$(1-\varepsilon_1)(1-\varepsilon_2)$

Store and Forward

Network Coding



Reed Solomon
LDPC
LT
Raptor

$(1-\varepsilon_1)(1-\varepsilon_2)$

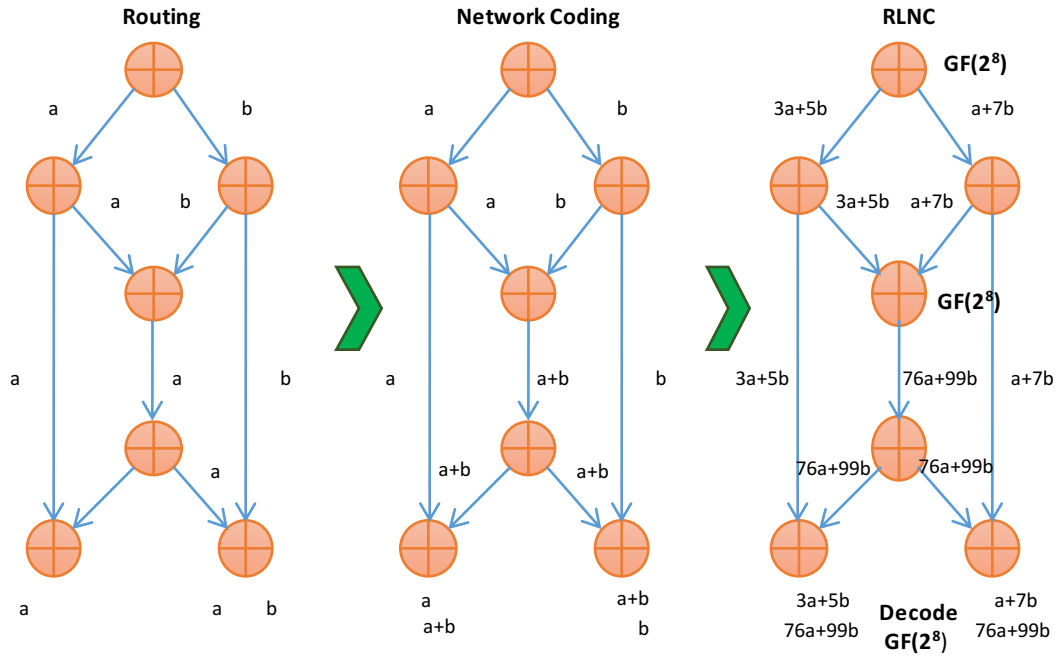
Store and Forward

Network Coding

$\min\{(1-\varepsilon_1);(1-\varepsilon_2)\}$

Compute and Forward

Network Coding



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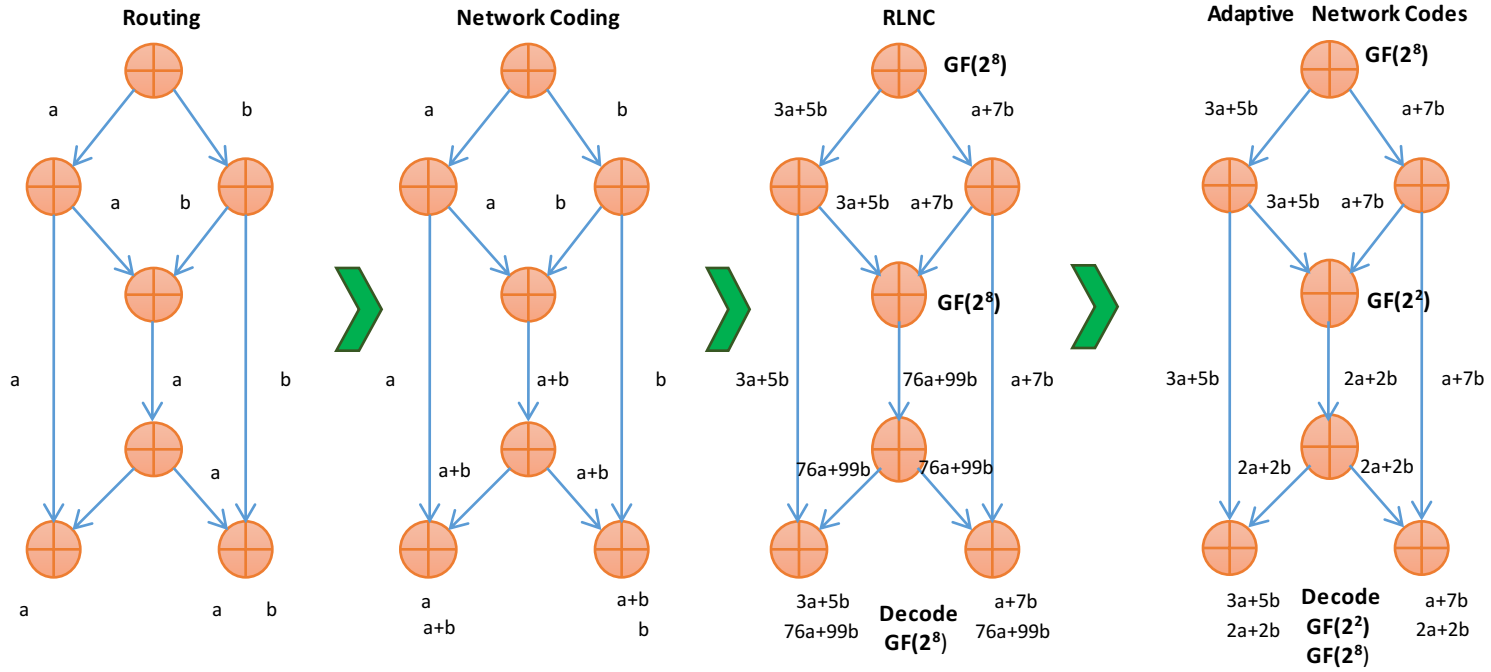
Does not consider device capabilities
- One encoder, one decoder
- One recoder

a b | a b

Rate: 2 symbols/time
Distributed (not planned)
Optimal (high probability)
High processing cost
One Finite Field in use

Does not consider device capabilities
- One encoder, one decoder
- One recoder

Network Coding



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Rate: 2 symbols/time
Centralized, Planned
Optimal
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One Finite Field in use
Does not consider device capabilities
- One encoder, one decoder
- One recoder

Rate: 2 symbols/time
Distributed (not planned)
Optimal (high probability)
High processing cost
One Finite Field in use
Does not consider device capabilities
- One encoder, one decoder
- One recoder

Rate: 2 symbols/time
Distributed (not planned)
Optimal (medium-high probability)
Medium processing cost
Multiple (compatible) finite fields
Adaptive to device/traffic
- **One encoder, multiple decoders**
- **Multiple recoders**

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5G COMPRESSED SENSING

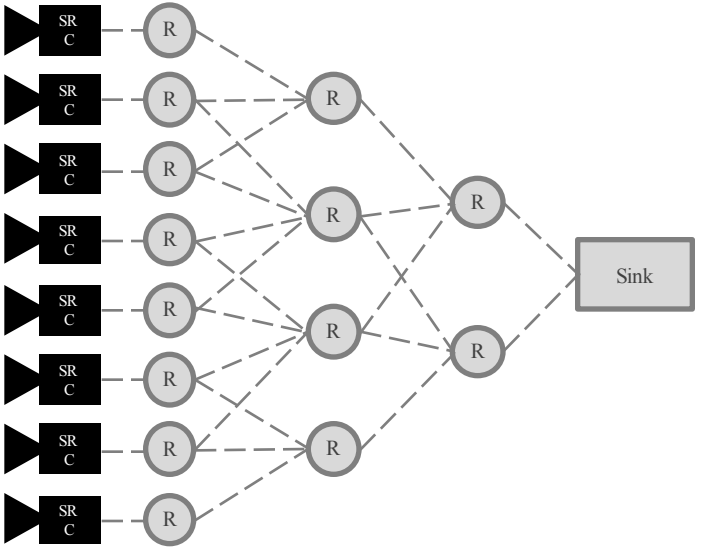
Compressed Sensing

Several 5G applications are possible, we focus on meshed multi-camera scenarios (e.g. augmented reality)

Objective: Combine CS and NC (analog and digital) in theory and implementation to improve delay ↓, resilience ↑ and complexity ↓.

Agnostic combination CS/NC: Only individual gain per camera (spatial correlation not exploited), reconstruction/decoding at the sink resulting in high complexity

Proposed joint CS/NC design (analog and digital): Holistic in-network processing based on compressed compute and forward (CCF) with distributed partial decoding and clever protocol design (active sensing).



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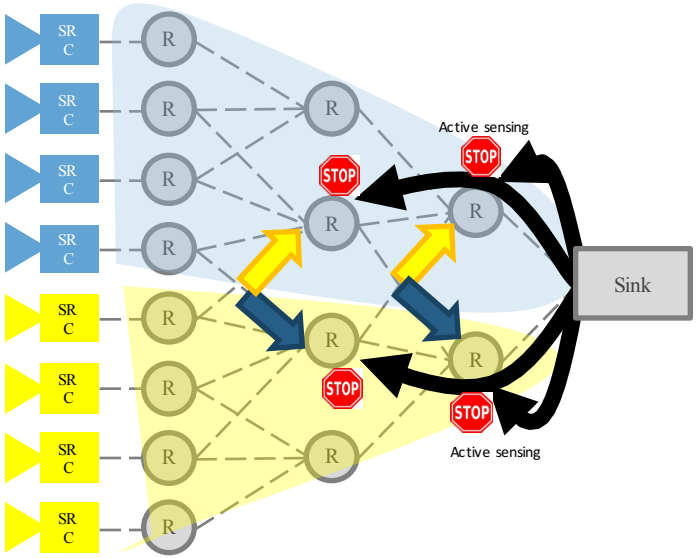

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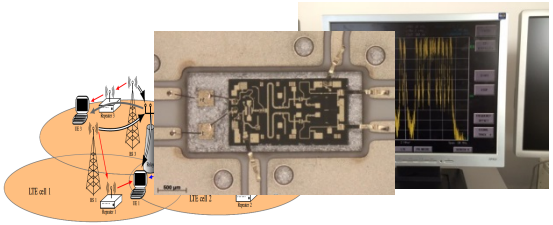
5G Research on four Tracks



Wireless & Network

Tactile Internet applications

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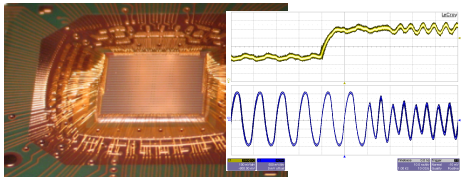

Silicon systems

Mobile edge cloud

Members on Tracks

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Silicon systems track


Rene Schüffny


Frank Ellinger


Dirk Plettemeier


Michael Schröter

Wireless & Networking track


Gerhard Fettweis


Eduard Jorswieck


Frank Fitzek


Silvia Santini

Mobile edge cloud track


Wolfgang Nagel


Christof Fetzer


Wolfgang Lehner


Thorsten Strufe


Hermann Härtig


Christel Baier

Tactile Internet application track


Leon Urbas

Uwe Aßmann

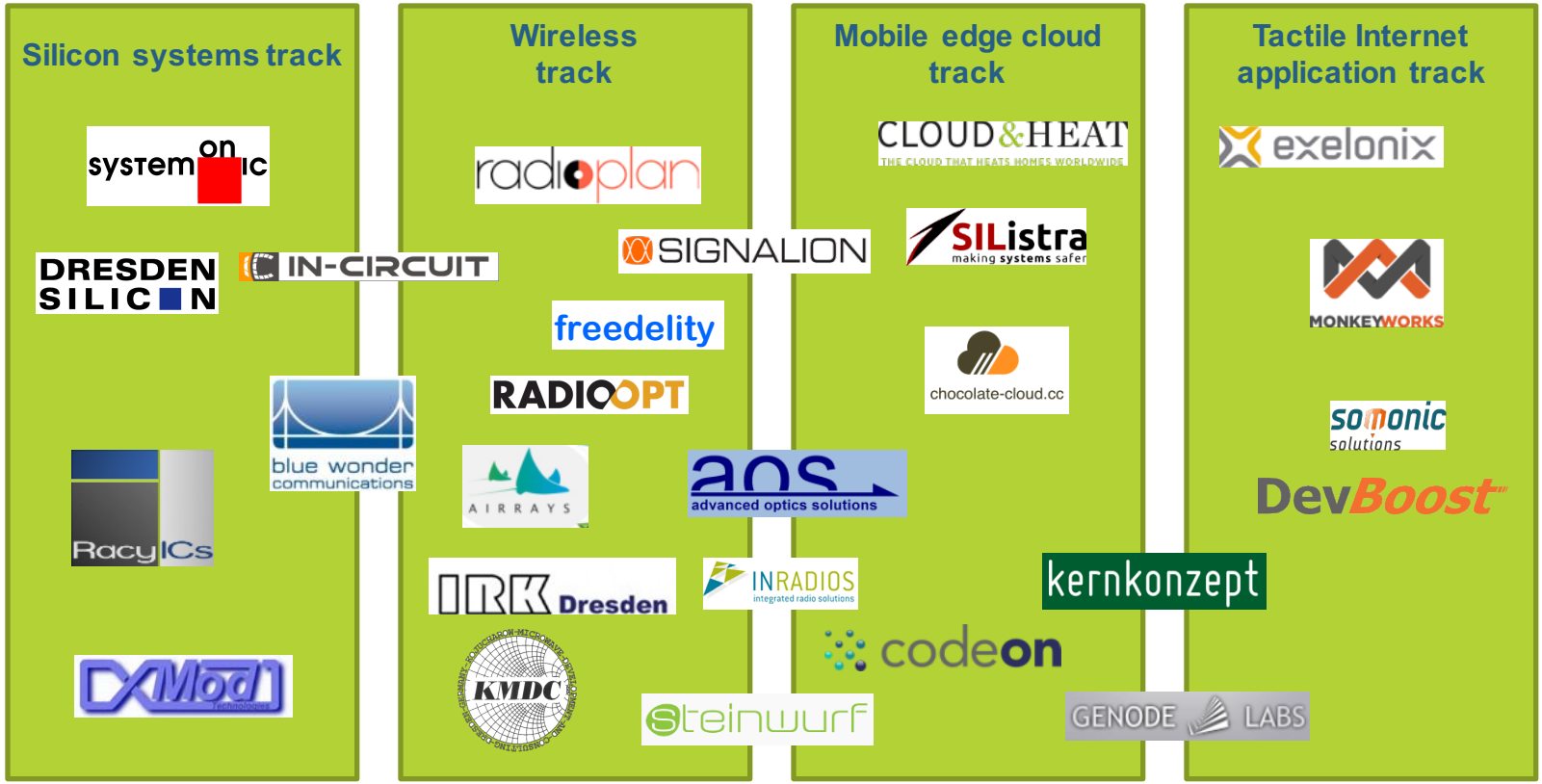

Ercan Altinsoy


Klaus Janschek


Thomas Herlitzius

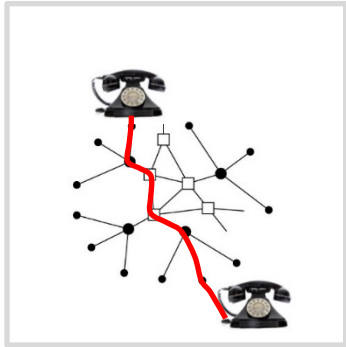
Team of 500+ Researchers !!!

Relevant Startups Generated by Team



Communication Networks

Circuit Switched Networks



Voice

Places

Communication Networks

Network

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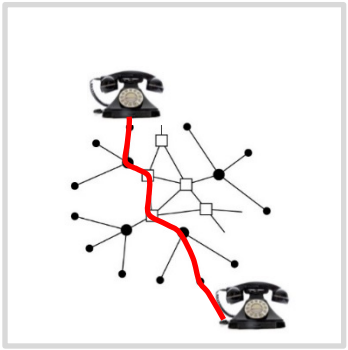
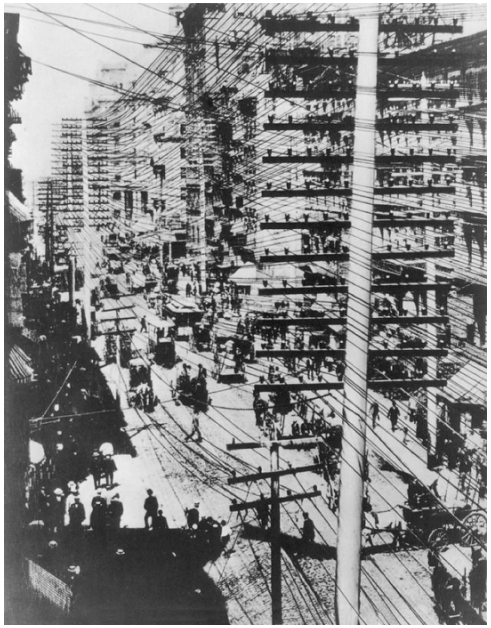
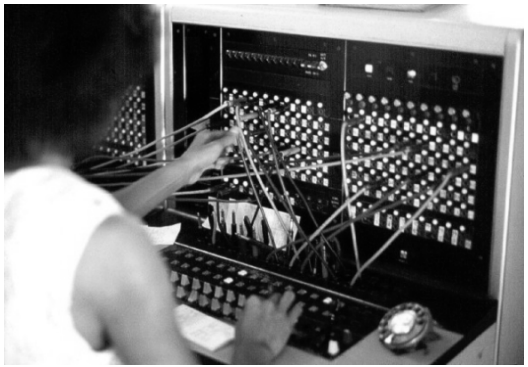
***Circuit** Switched Networks*





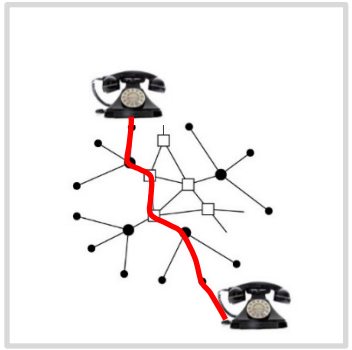


Voice

Places

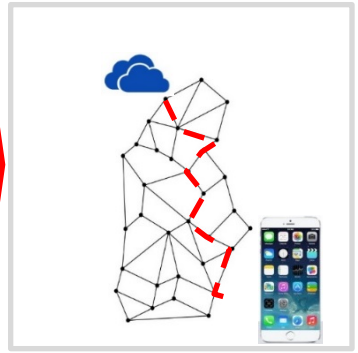
Communication Networks

Circuit Switched Networks



Revolution

Packet Switched Networks



Voice

Places

Data

Voice

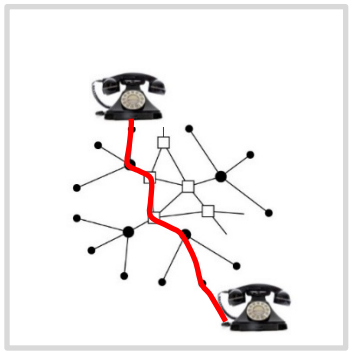
People

Communication Networks

Network

5G LAB GERMANY

***Circuit* Switched Networks**



Revolution

***Packet* Switched Networks**

Voice

Places

Data

Voice

People

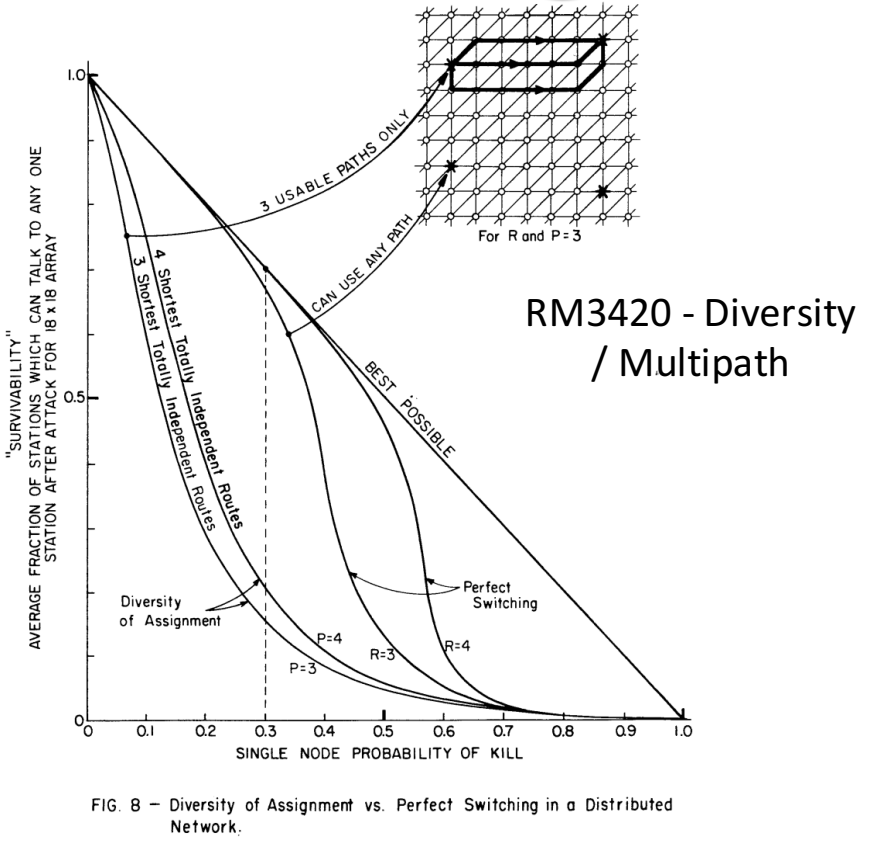


FIG. 8 — Diversity of Assignment vs. Perfect Switching in a Distributed Network.

RM3420 - Diversity / Multipath

Communication Networks

Network

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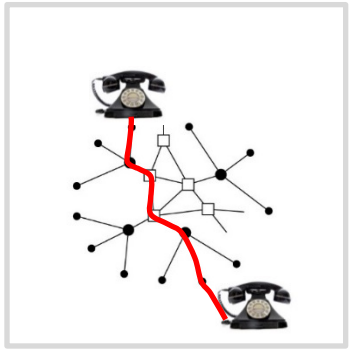
Circuit Switched Networks



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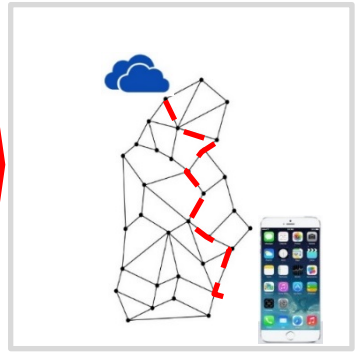


Voice

Places

Data

Voice

People

Technical Challenges

Massive throughput

Massive reduction in delay

Massive resilience

Massive safety & security

Massive heterogeneity

Massive sensing

Massive energy saving

Use Cases

Internet of Things (IoT)

Smart Grids

Remote Cars

eHealth

Flying Internet

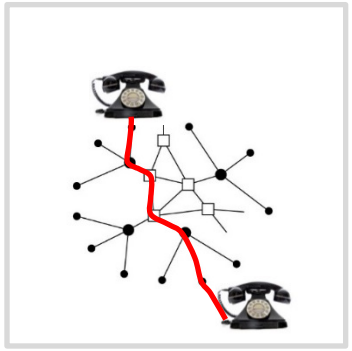
Robotics

Communication Networks

Network

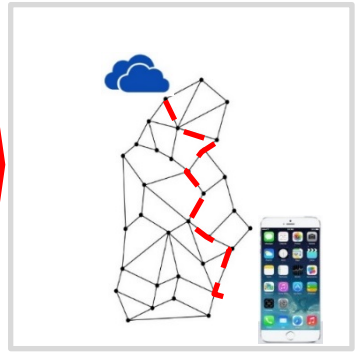
5G LAB GERMANY

Circuit Switched Networks



Revolution

Packet Switched Networks



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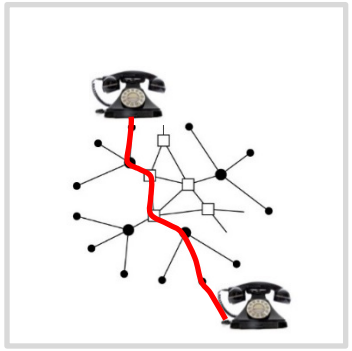

Voice

Places

Revolution

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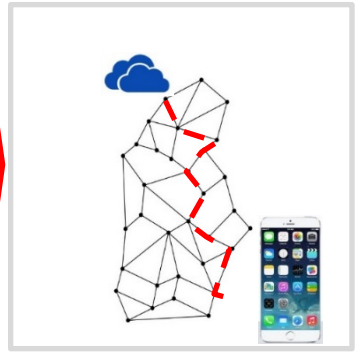

Data

Voice

People

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Revolution

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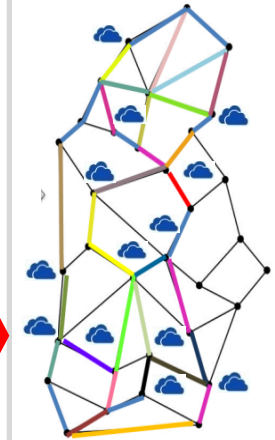
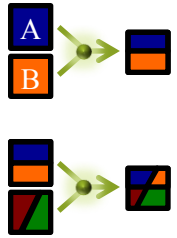
Robotics

Code Centric Networks





Control

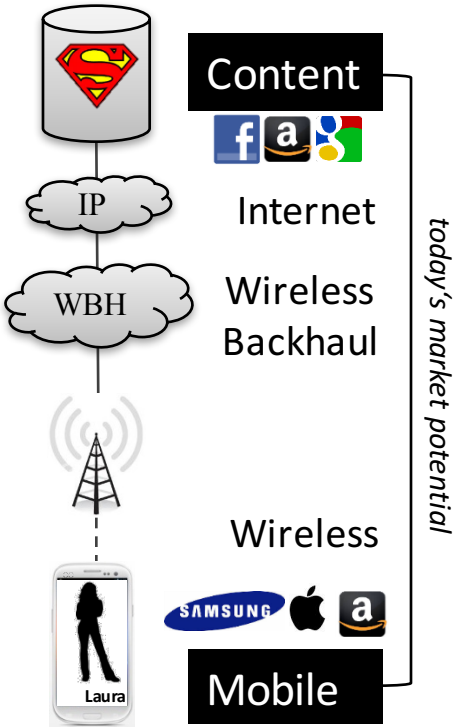
Data

Voice

Things

5G the game changer

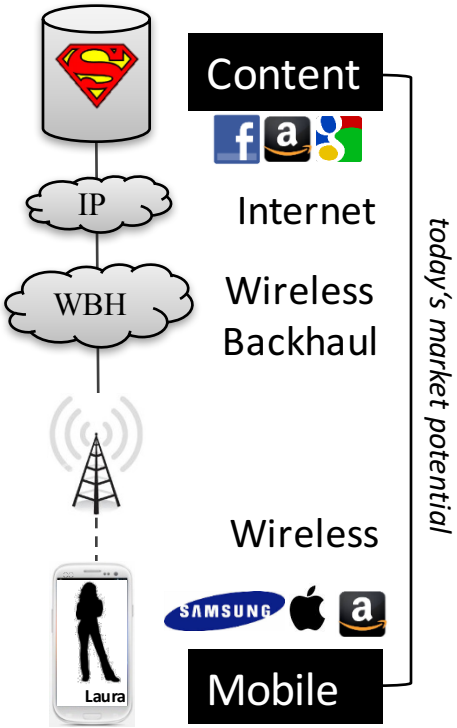
4G and before



5G the game changer

Network Cloud 5G LAB GERMANY

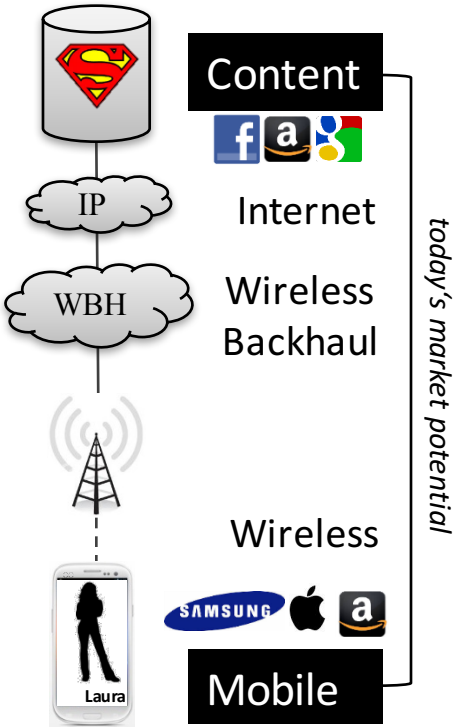
4G and before



5G the game changer

Network Cloud 5G LAB GERMANY

4G and before



API available

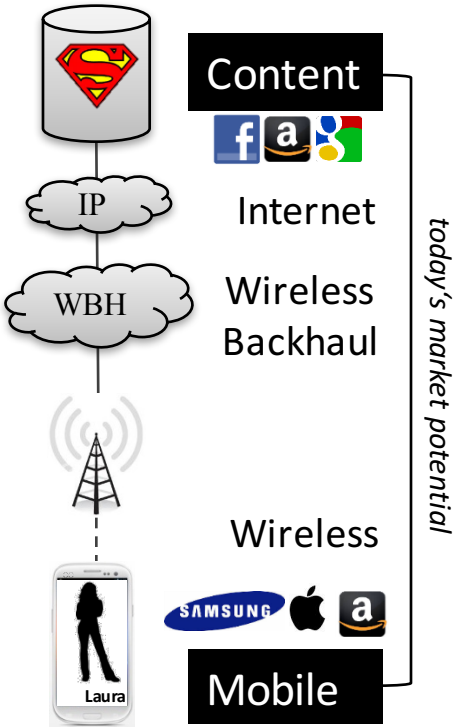
No API available

API available

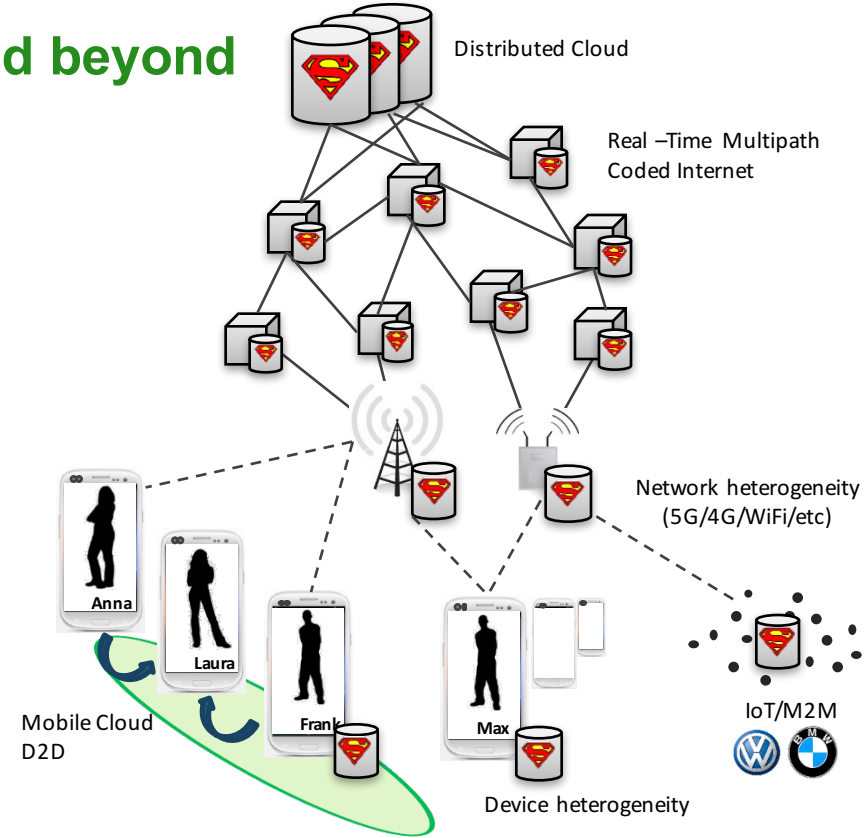
5G the game changer

Network Cloud 5G LAB GERMANY

4G and before



5G and beyond



5G the game changer

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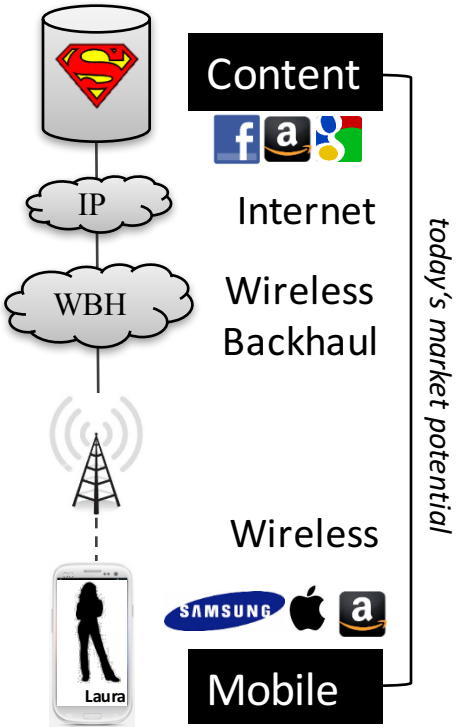
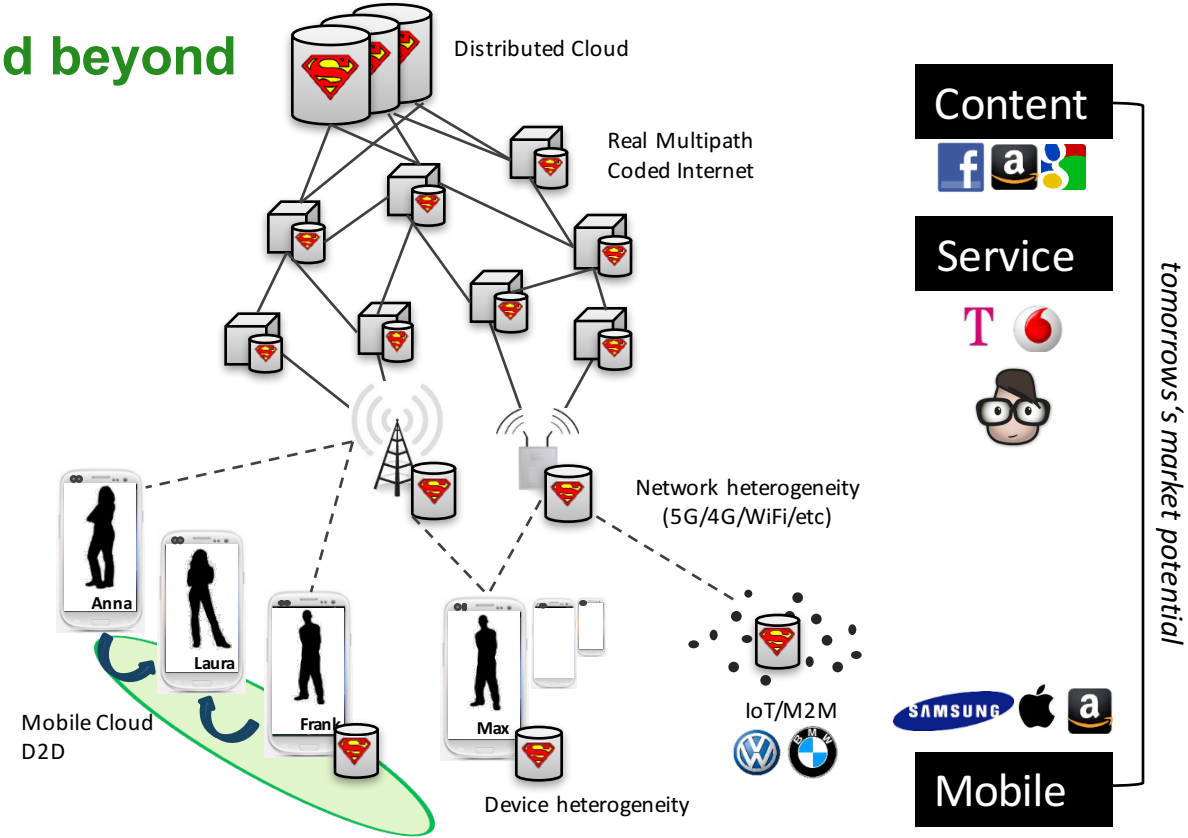
4G and before



5G and beyond



RLNC: The Technology

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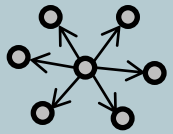
Coding Today

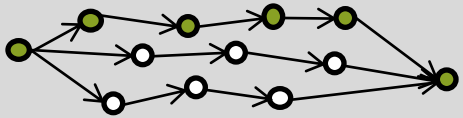
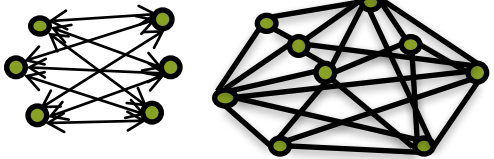
(all End-to-End)

Classical

Multicast



Coding Tomorrow with RLNC

Classical + Sliding Window Encoding 	Real time video streaming, TCP, SDN…
Multihop 	Edge caches, wireless mesh, reliable multicast, satellites, small relay topologies, SDN…
Multipath 	Multi-source streaming Multipath TCP, channel bundling, heterogeneous network combining, SDN…
Multisource – Multi-destination / Mesh 	Distributed cloud, SDN, advanced mesh (IoT, car2car, M2M, smart grid) …

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5G MULTICAST

Norm – Reliable Multicast

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Steinwurf

Reliable Multicast

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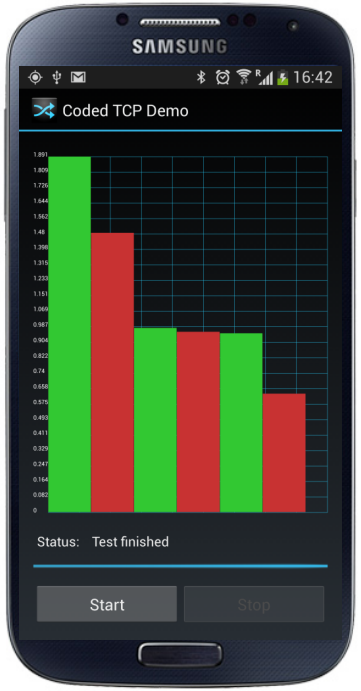
5G CODED POINT TO POINT

Coded TCP



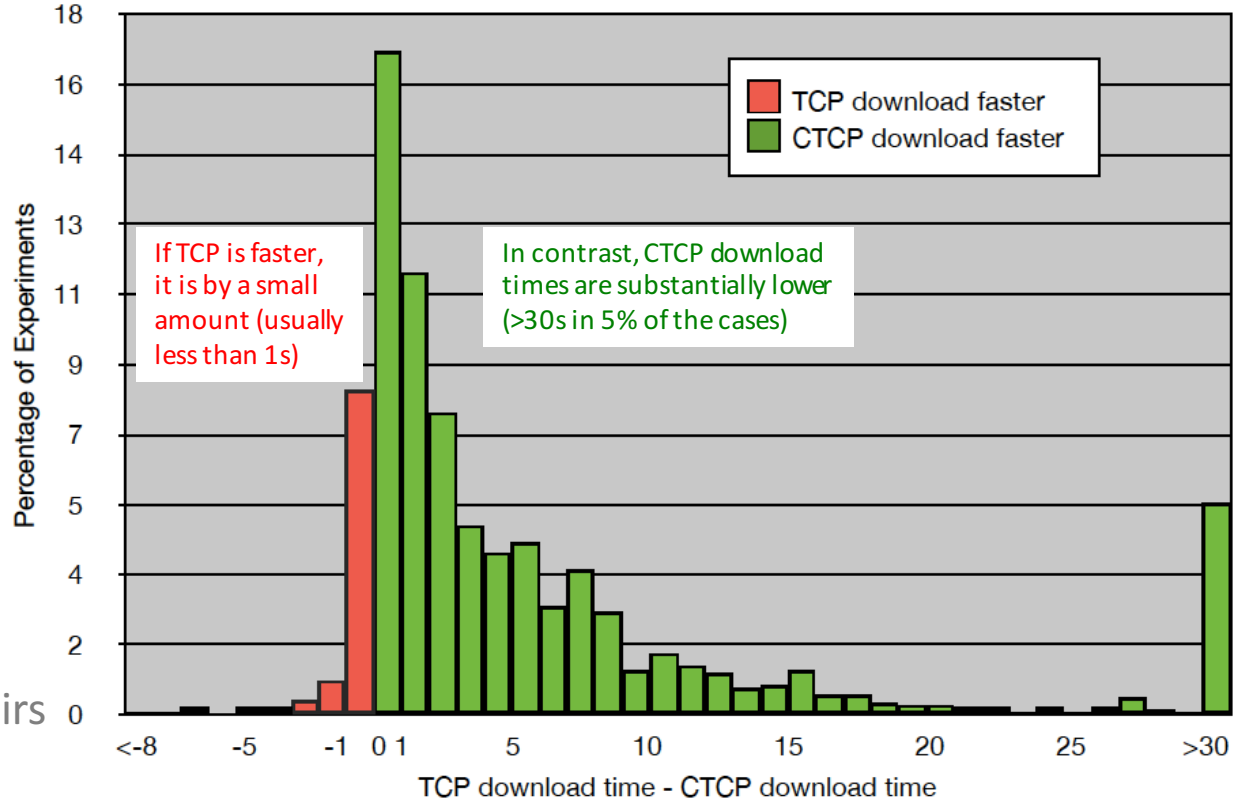
Germany

Irland

US East Coast

US West Coast

Histogram of CTCP-TCP Data Pairs



1354 data pairs

Pacific Island Testbed

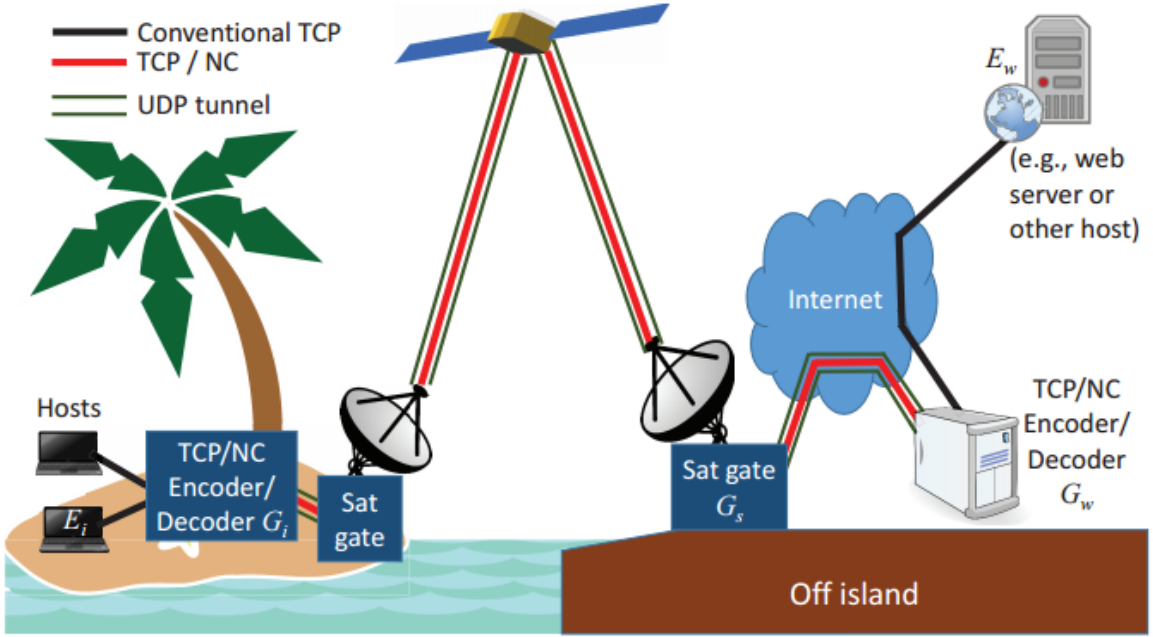


Fig. 1. TCP/NC network topology

http://arxiv.org/pdf/1506.01048v1.pdf

Pacific Island Testbed

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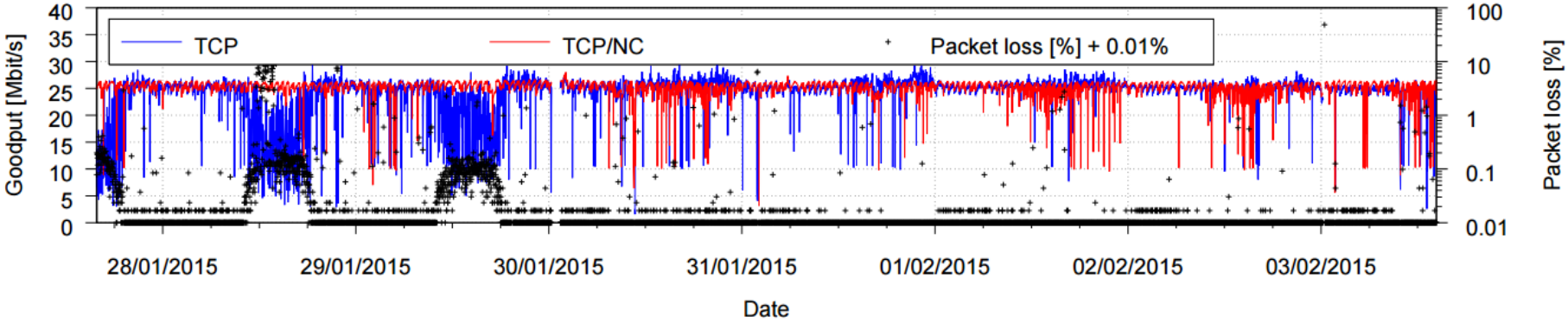

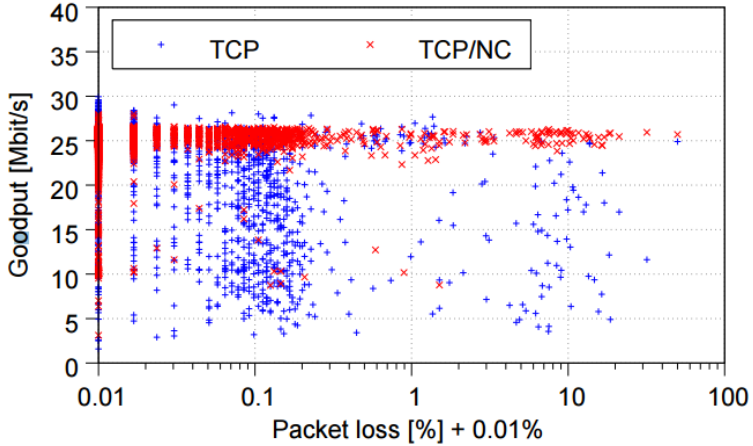

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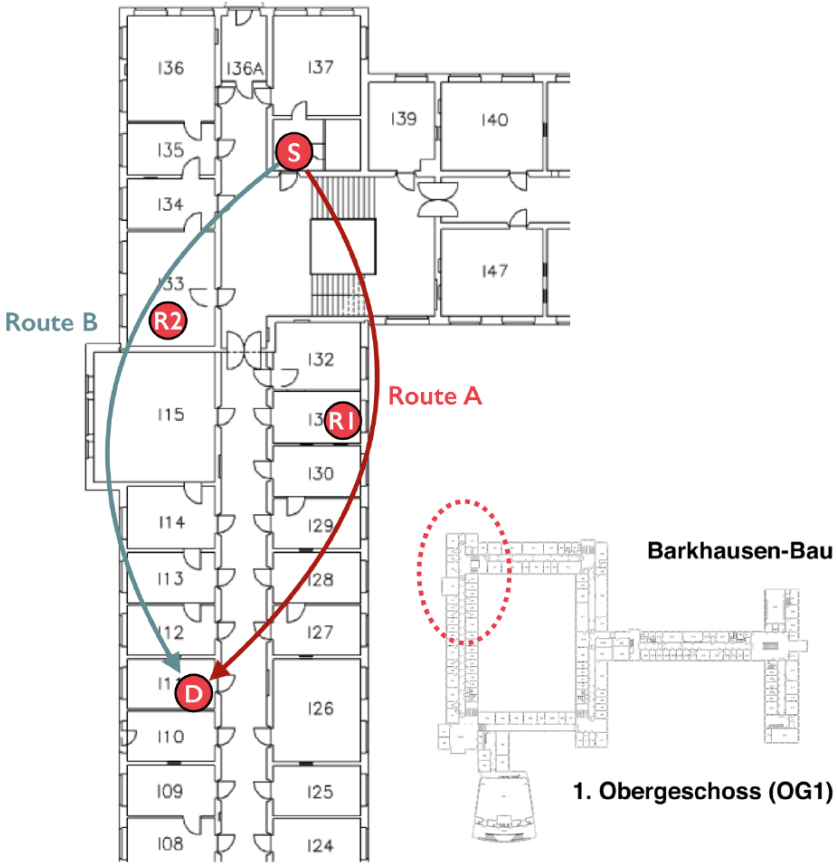
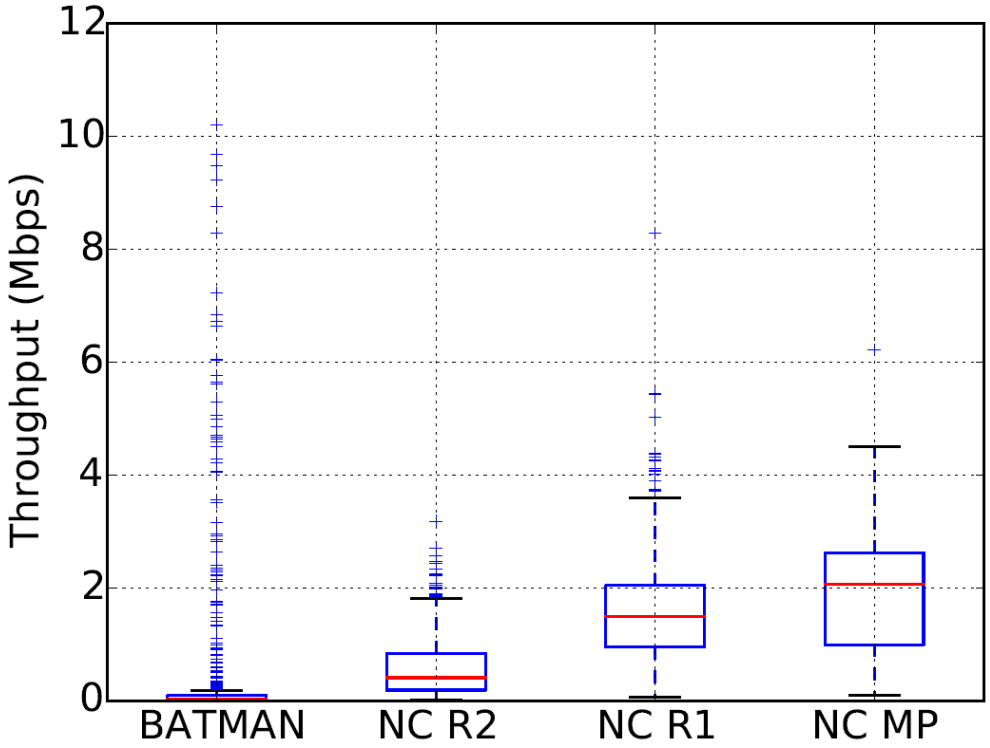
5G WIRELESS MESH

Wireless Mesh

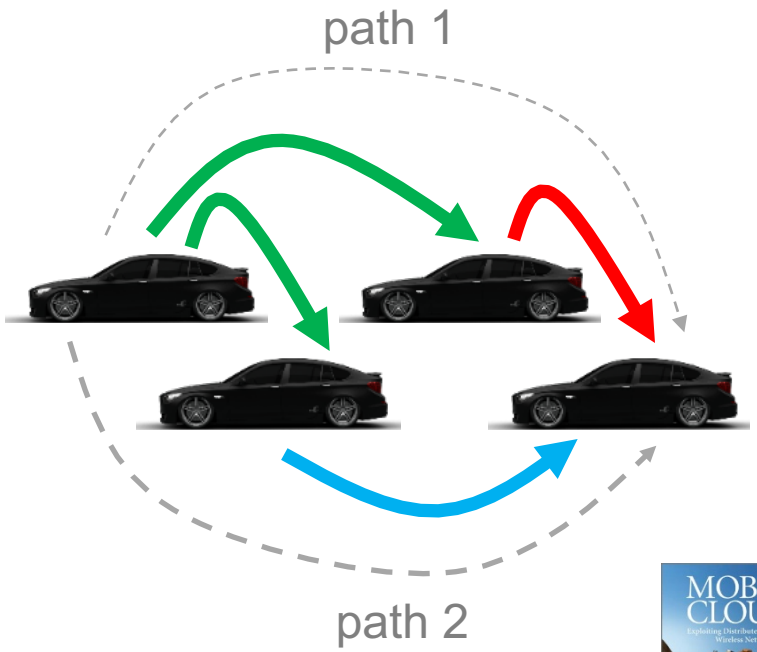
Foto: Torsten Proß, Jeibmann Photographik

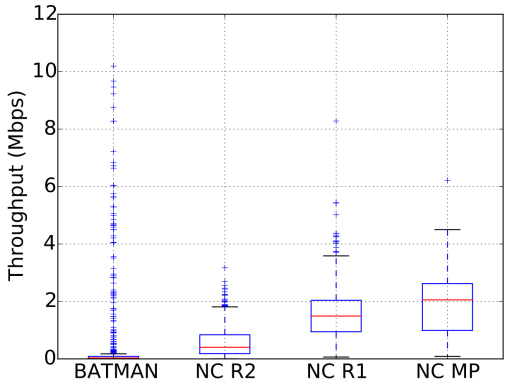
Some Real Stuff





Connected Cars, but how?





0.52 0.58 1.53 1.89

Practical implementation of network coding in 802.11 wireless mesh.

TU Dresden Oct. 2015

- Routing
- NC worst path
- NC best path
- NC multi-path

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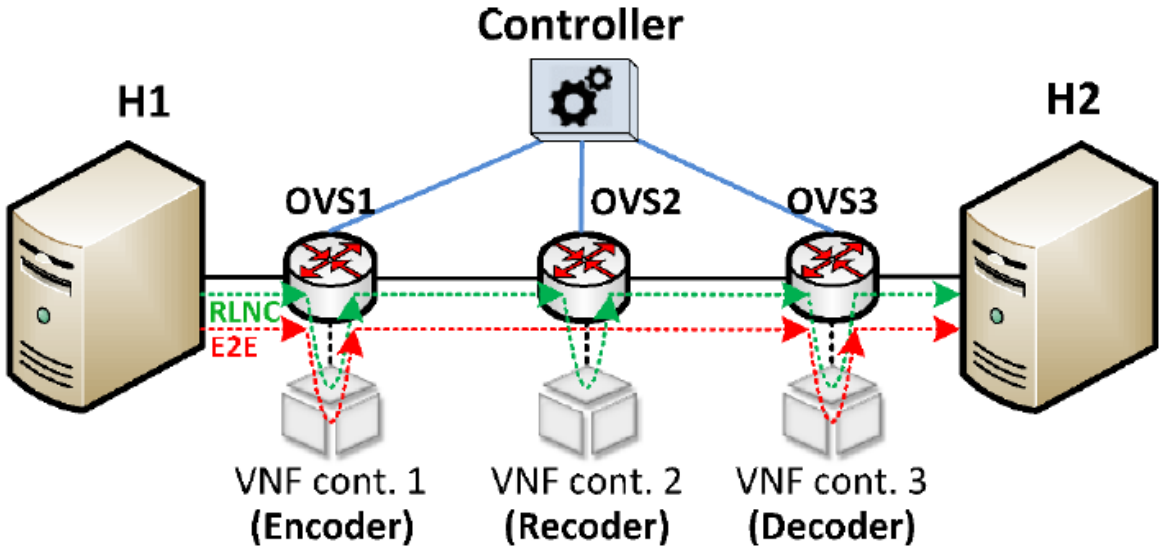
5G SOFTWARE DEFINED NETWORK

Virtual SDN testbed



Software Defined Networks

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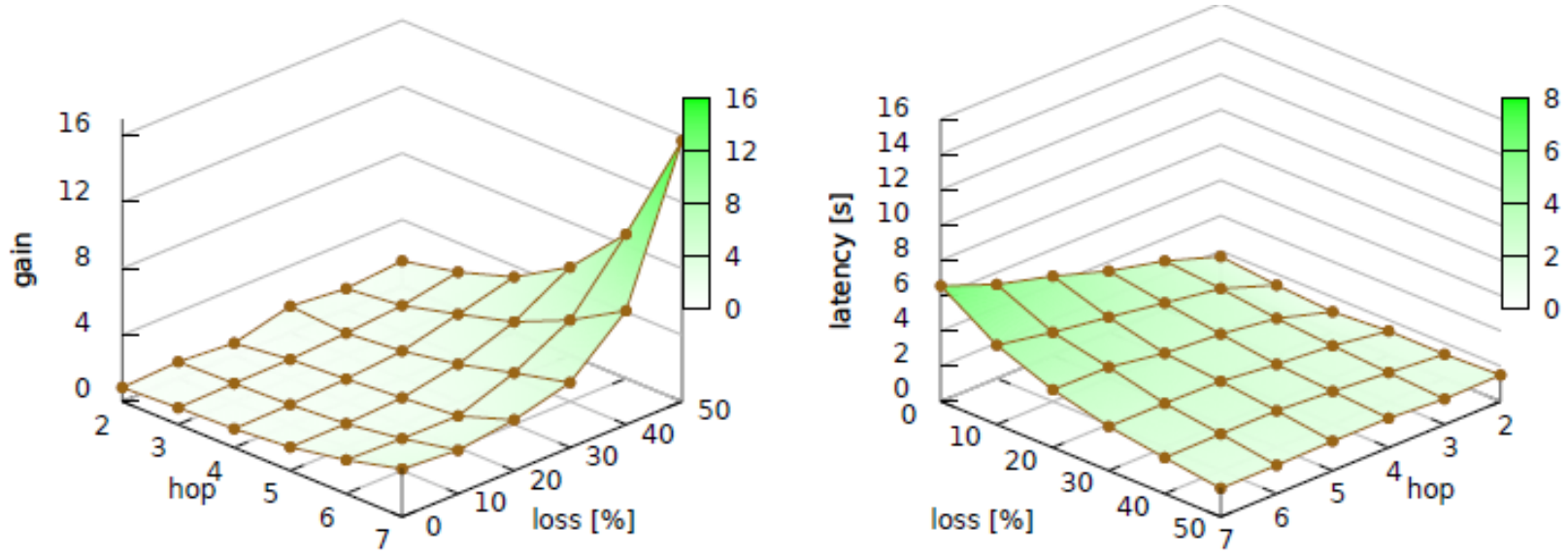
Latency gain of e2e vs RLNC (left) and hbh vs RLNC(right)



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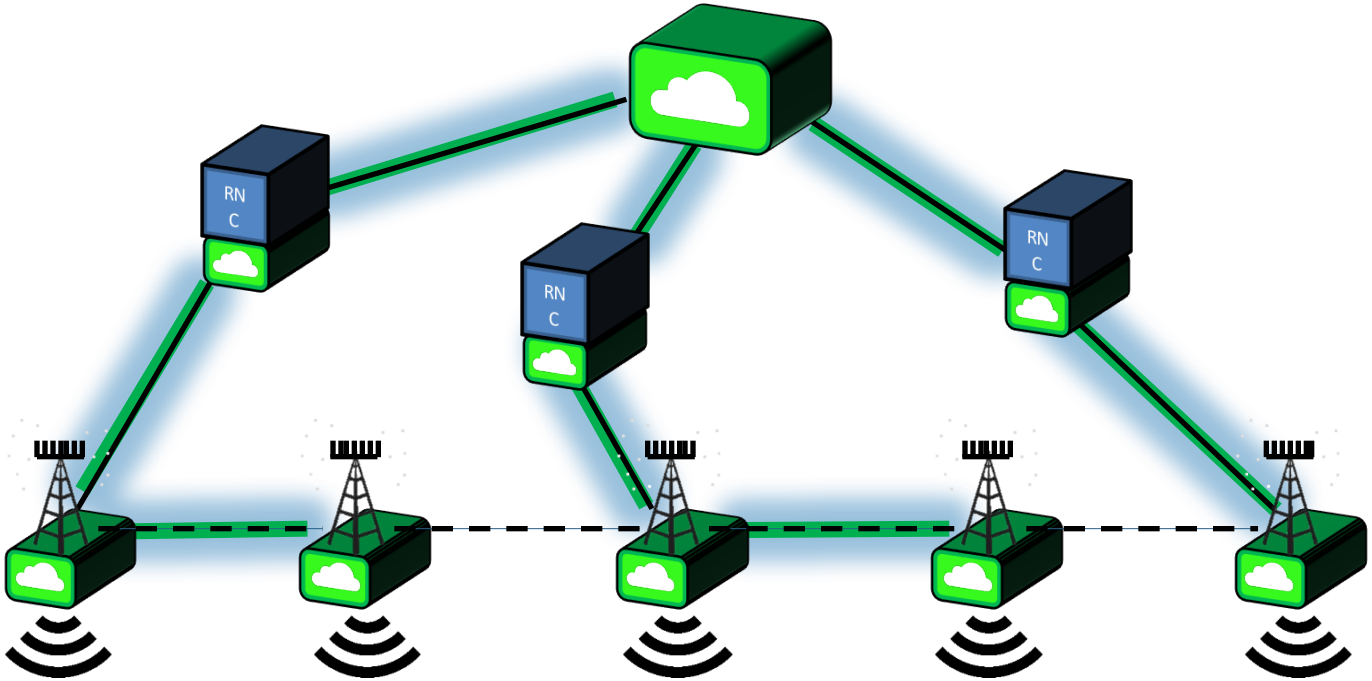
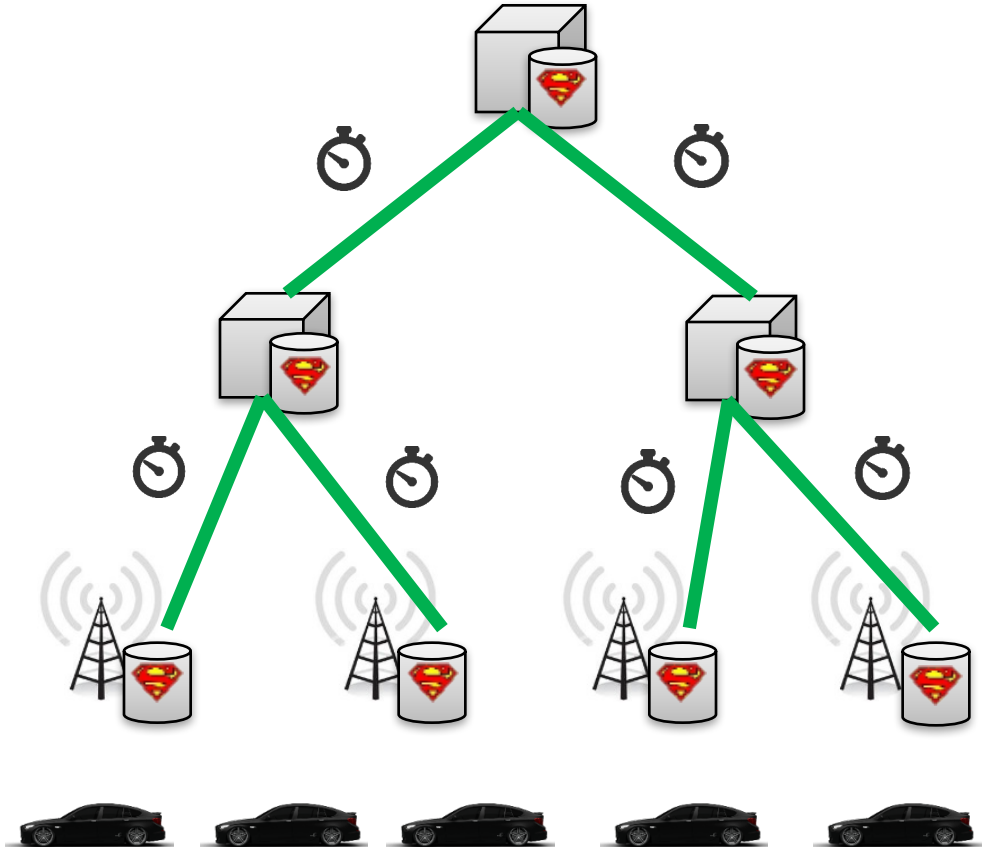
5G AGILE CLOUD

Mobile Edge Cloud / Micro Cloud / Cloud



Mobile Edge Cloud / Micro Cloud / Cloud



Communication and Control Units

openstack™

compute

storage

networking

Actuators and Sensors

Implementation Mobile Edge Cloud

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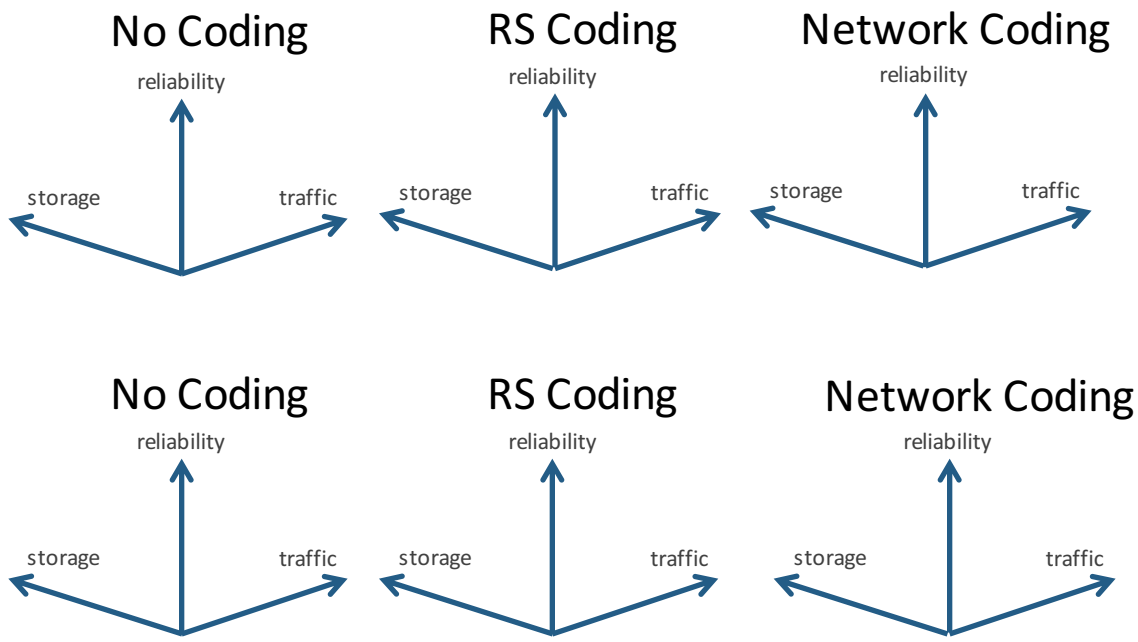
4 elements with 16 odroids each equals 512 cores controlled by openstack

OpenFlow

openstack™

Data Survival over Time



Distributed Policy

Limited knowledge of network state

Local decisions

Practical, scales well

„Genie“ Policy

Perfect knowledge of network state (high cost to update)

Optimal decisions

Not practical in large scale, dynamic systems

Current systems are somewhere in between these two policies

Data Survival over Time

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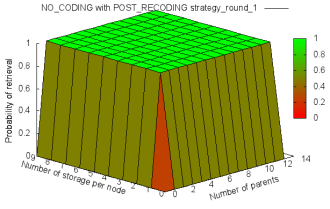
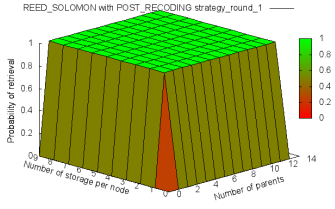
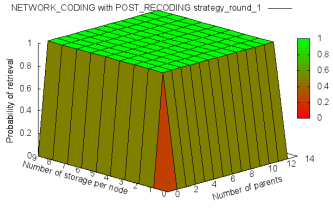
No Coding



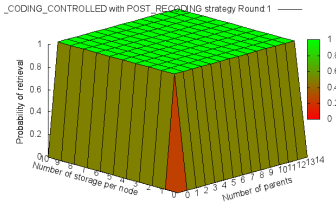
RS Coding

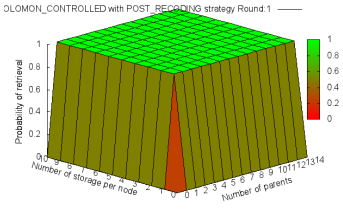


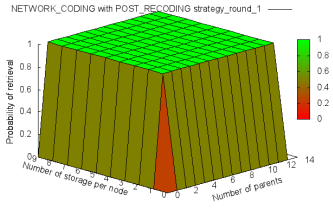
Network Coding



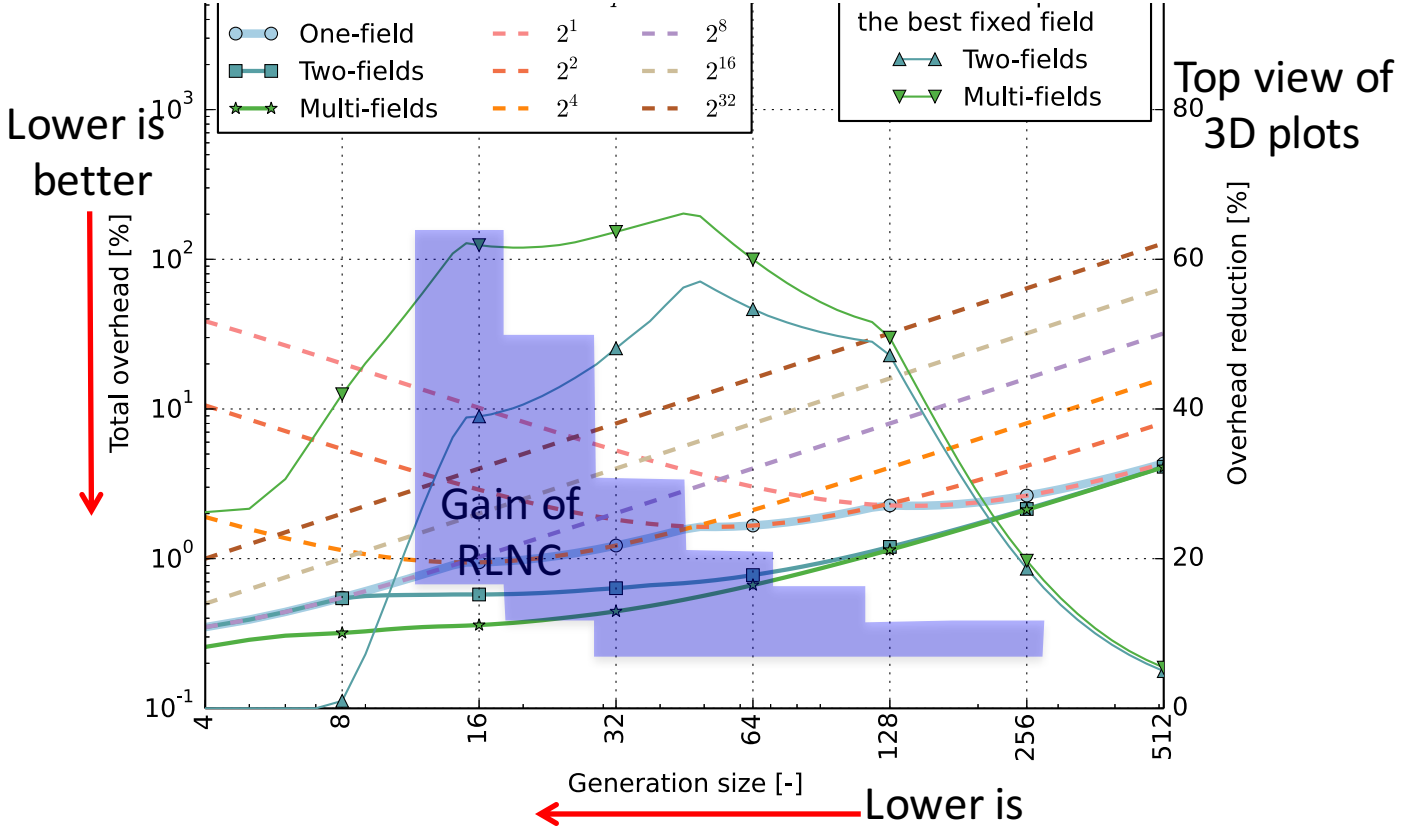
state-less







Data Survival (large # of runs)



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5G COMPUTING

How fast are we now?

http://tinyurl.com/z7vsp4c

5G LAB GERMANY

Kodomark

Steinwurf ApS Libraries & Demo ★★★★★ 6

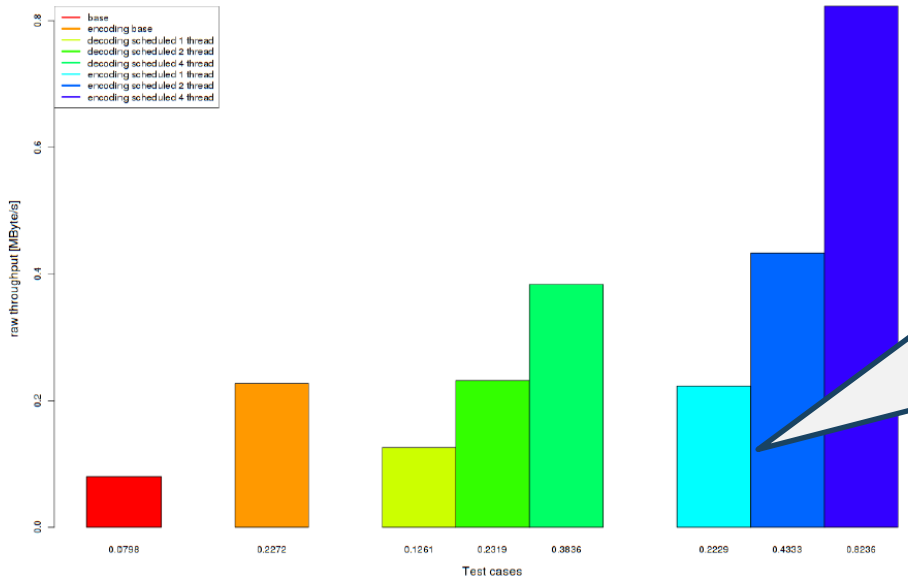
USK: All ages

This app is compatible with all of your devices.

Installed

Please try it out and support our research! If you have an Android device simply install and press START! Change the parameters to learn about network coding.

Many-Core Implementation of Network Coding

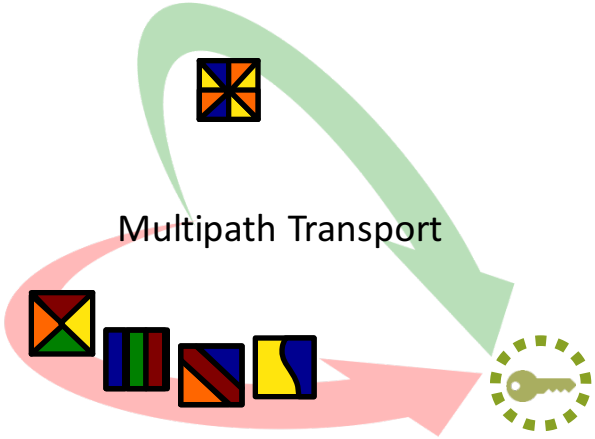


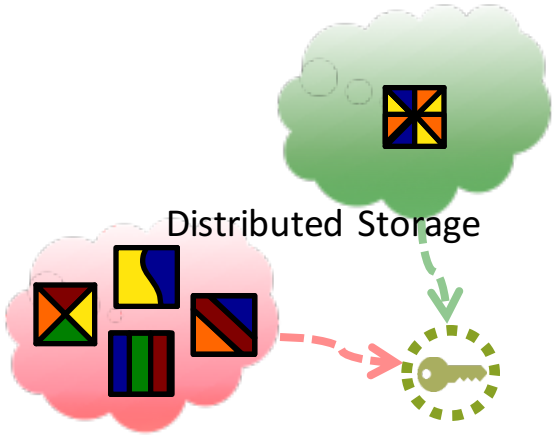
Herb Sutter: „Free lunch is over!“

Lots of research in computer science and engineering focus on achieving low computational complexity (the big O). But perhaps in the future we need to consider algorithms with worse computational complexity but which are easy to parallelize.

On Raspberry Pi 2: 10x speed up over standard SIMD encoding by using 4 cores and cache optimization (generation size 1024)

Coding as an Additional Security Measure





Data on a given path/cloud acts as a cypher


ONE CODE
TO RULE THEM ALL!

5G makes everybody happy!