FttR as a Feeder for New Wireless Technologies

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Outline

FttR as a Feeder for New Wireless Technologies

Future IoT

- Applications, Requirements

Current In-building Network

- SoA, Problem Statement

Future In-building Network

- FttR for 2.4/5/6 GHz, LiFi and 60 GHz

Summary

Future IoT

Use Cases and Requirements

Future Internet of Things

- Numerous devices use wireless network access
- Imaging sensor data processed in the cloud (cameras, RADAR, LIDAR)
- mobile XR

Use Cases

a) Office, Residential

b) Medical, Industry

Two Requirement Sets

a) Higher data rates with enhanced QoS
   - Full indoor coverage, more reliable
   - 1…20 Gb/s everywhere…maximal

b) Moderate data rates with highest QoS
   - High density of devices in hot spots
   - Ultra-reliable, lowest latency, zero jitter
   - Precise positioning and sensing of the environment

J. P. Linnartz *et al.*, "ELIoT: New Features in LiFi for Next-Generation IoT," *2021 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)*, 2021, pp. 148-153

ELIoT

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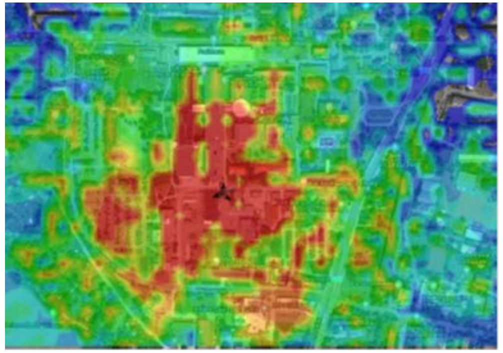
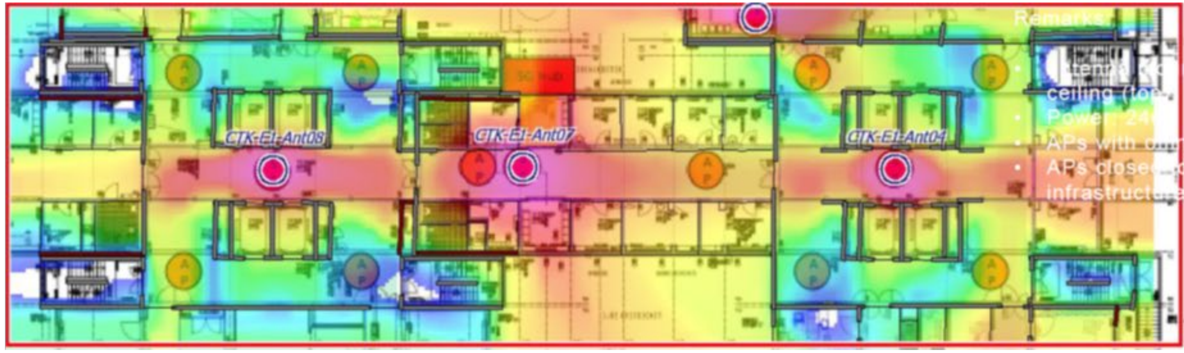
5G Campus Network

Carl-Thiem-Klinikum Cottbus





Projekt ThiemCB5G

- Project funded in 5x5G Initiative of German Federal Ministry of Digital and Transport (BMDV)

Goal is 5G campus network in a hospital

- Patient journey: emergency department → intensive care unit → diagnostics → operating room
- Outdoor area is well served by classical 5G base station
- However, 5G signals penetrate rarely inside the building → needs an additional indoor deployment

Problem: **5G in buildings is expensive**

- Number of base stations is limited due to budget, deployment planning results in fewer access points compared to WLAN
- 5G has similar bandwidth → indoor coverage will be worse than WLAN
- 5G has higher installation and maintenance cost

Could LAN/WLAN infrastructure be used for 5G-like QoS in buildings?

- LAN cables und wave propagation are in principle the same, just protocols (software) differ from each other
- 5G: own specs, own chipsets, high complexity, license costs, maintenance → > 50x as expensive than managed WLAN solutions
- New WLAN releases introduce similar features like cellular networks (MIMO, OFDMA, multilink operation, mm-wave, …)

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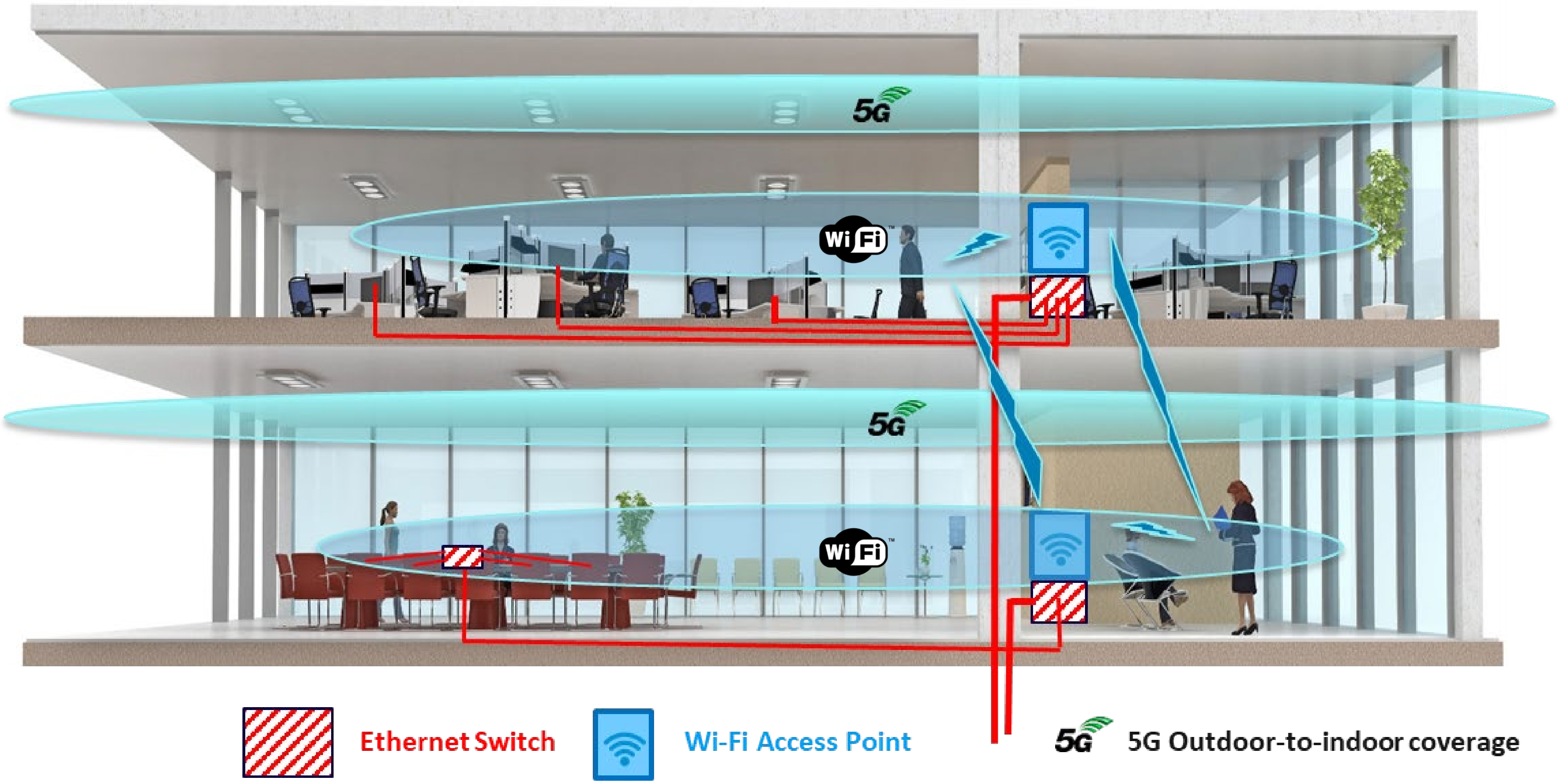
In-building Network, SoA

5G from outdoor base stations, LAN and WLAN from indoor deployment



Problem Statement

LAN and WLAN vs. 5G

LAN: High data rates and high QoS

- Ethernet: 1 Gb/s point-to-point (P2P) per user/device
- Coax-/Powerline Communications: 1-2 Gb/s, shared among 1…16 users/devices (G.hn)

WLAN: High data rate but limited QoS

- **Shared Spectrum**: up to 10 Gb/s is shared among users/devices
- “Listen-before-Talk” random channel access to avoid interference
- a) through other technologies, b) through same technology in adjacent rooms
- User/device bandwidth is constricted, if traffic load is increased
- High data rates only as “best effort”, high QoS only with low data rates

5G: High QoS but only limited data rate

- **Licensed Spectrum**: deterministic channel access enables highest QoS
- Energy efficiency: long distance to the base station, attenuation through walls and metal-coated heat insulation windows

Goal for future IoT is cable-like QoS for wireless network access in buildings

- **Extend WLAN to provide higher QoS:** Low-cost alternative to 5G deployment in buildings

Comparison of in-building network technologies

	Data rate	QoS	Cost
LAN	High	High	Low
WLAN	High	Low	Low
5G	Low	High	High

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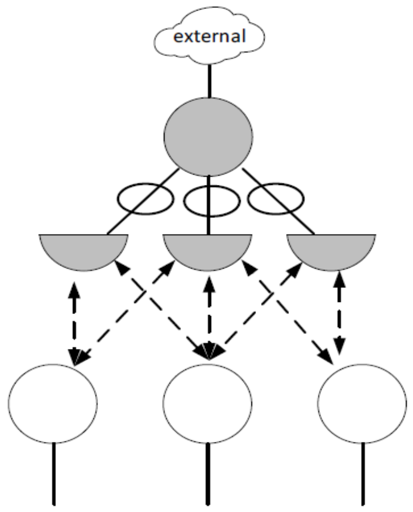
New Approach
Coordinated LAN + WLAN



Source: IEEE Std 802.15.13-2023

In-building networks with high QoS

- WLANs operate in shared spectrum. How can they be as reliable as 5G operating in licensed spectrum?

Cable

- Cables reach their limits at around 1 Gb/s, more needs multiple twisted pairs or ribbon cables
- Cables should be complemented by optical fiber also inside buildings (fibre-to-the-room, FttR)

Reliable WLAN

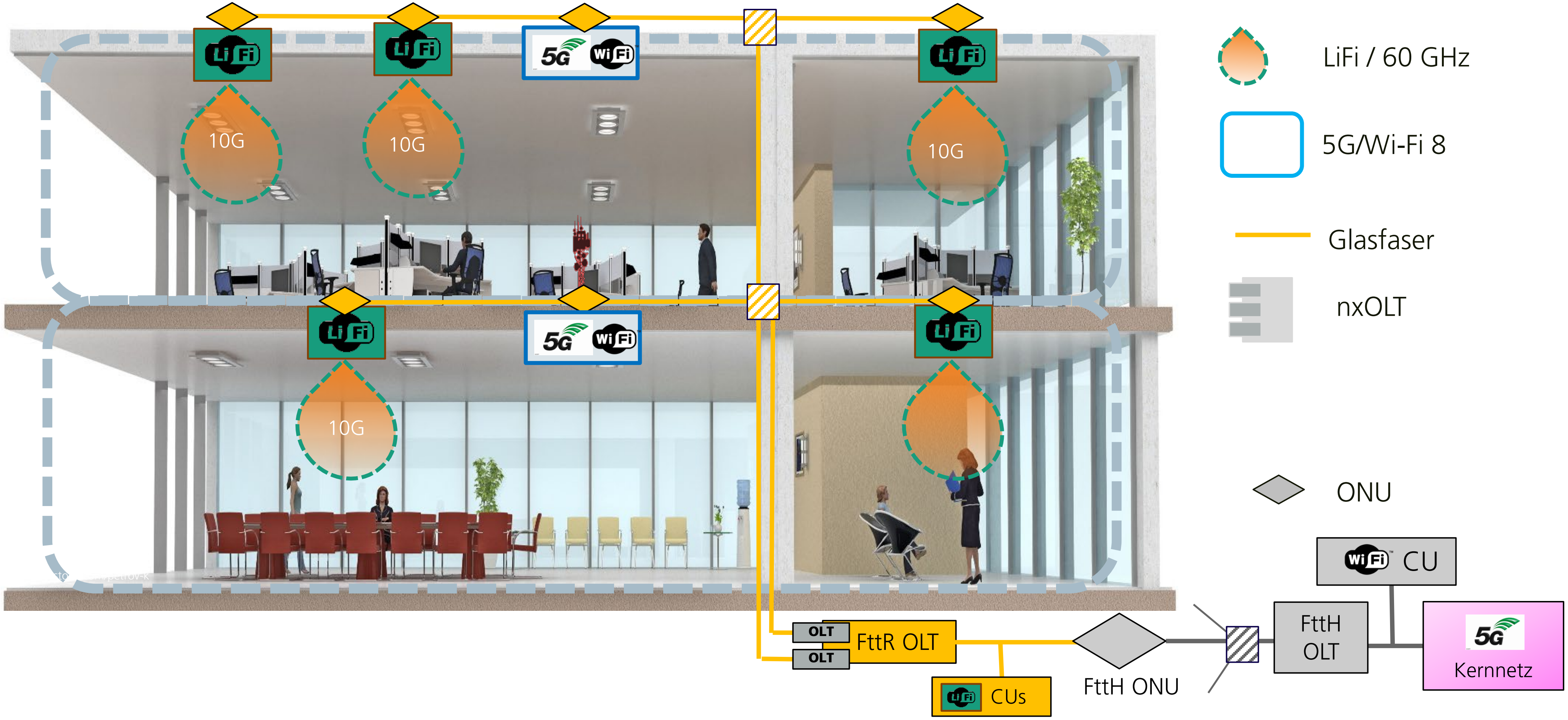
- Normal RF waves go through walls → use distributed MIMO (cell-less WLAN), to reduce interference
  - Central coordination of access points in adjacent rooms: Central unit in cloud (e.g., in the basement or in the operators central office)
- mm-wave and light do not penetrate through walls → use of mm-wave/optical WLAN (LiFi): One room is one cell
- Artificial Intelligence (AI) to support coexistence with other RF system in the same spectrum, e.g., Bluetooth Speaker
  - Wi-Fi chips usually support Bluetooth, UWB is t.b.d. (e.g. in 802.11 Coex SC) → coordinate coexistence of mainstream technologies

5G and In-building network integration via upper layers

- Goal is seamless handover from outdoor to indoor, and LiFi/60 GHz to Wi-Fi
- non-3GPP interworking function, MP-TCP using ATSSS, embed LiFi and 60 GHz into the Wi-Fi 7 MLO framework

Future In-building Network

System concept



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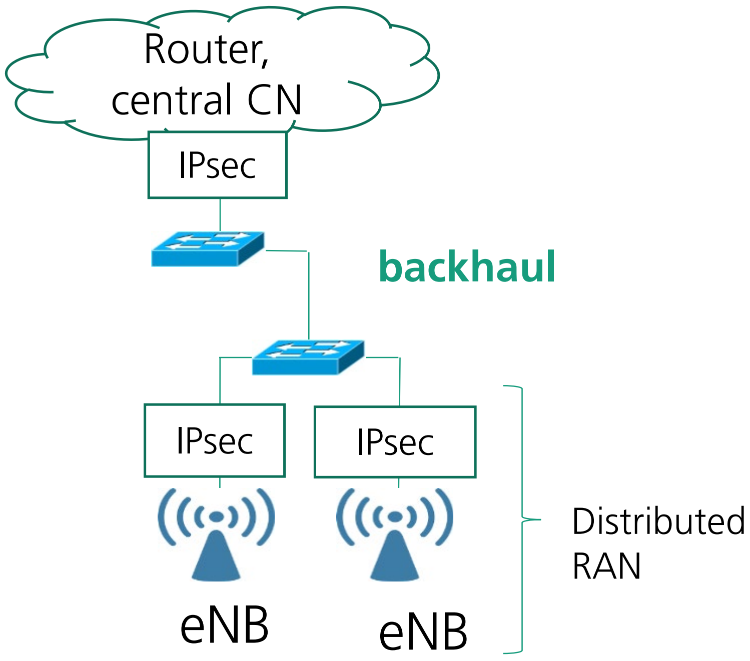
Centralized vs. Distributed RAN

From 4G to 5G architecture

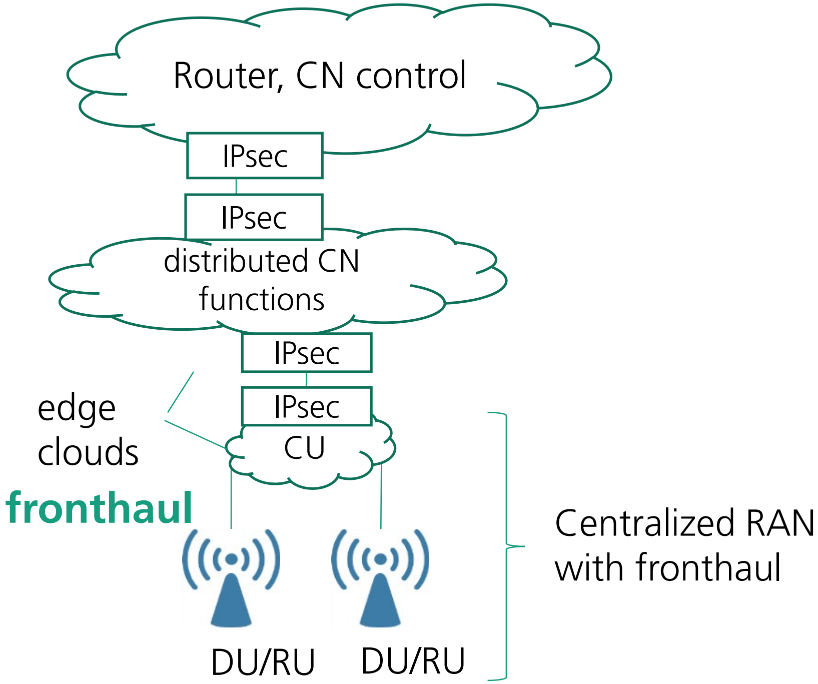
5G introduced centralized radio access network (C-RAN) to overcome interference

4G: - centralized core network
- distributed RAN



Current WLANs have fully distributed RAN

5G: - distributed core network
- centralized RAN



CU = central unit
DU = distributed unit
RU = remote unit

More reliable WLANs may need more centralized RAN

Functional Split

Between CU and DU

5G introduced Centralized RAN with functional split points between CU and DU/RU

- RAN = PHY+MAC layer: Protocol functions in can be divided at several split points

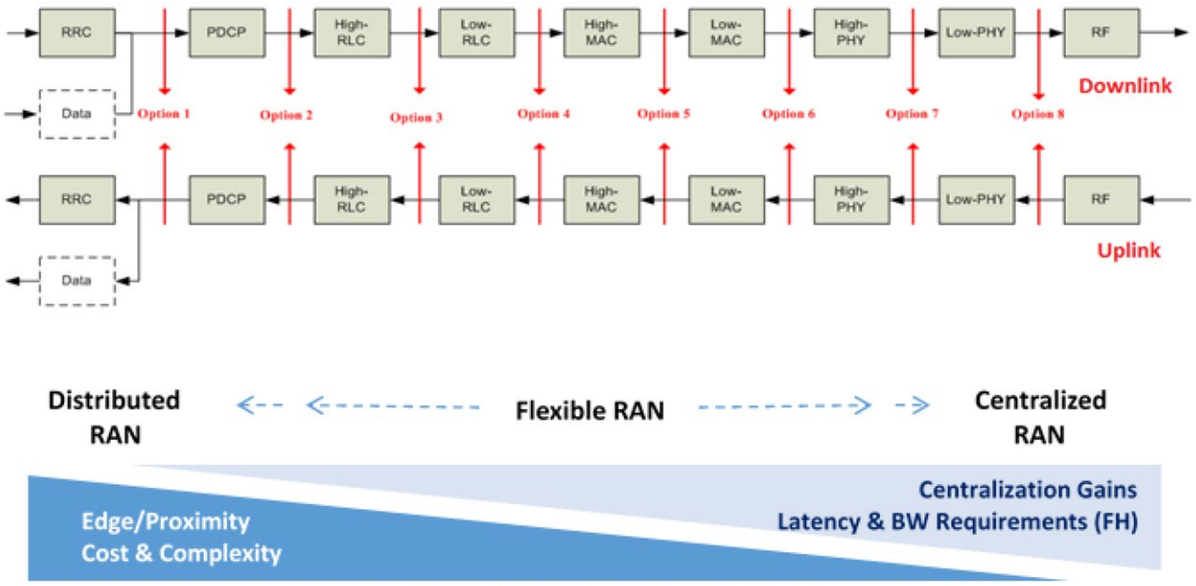
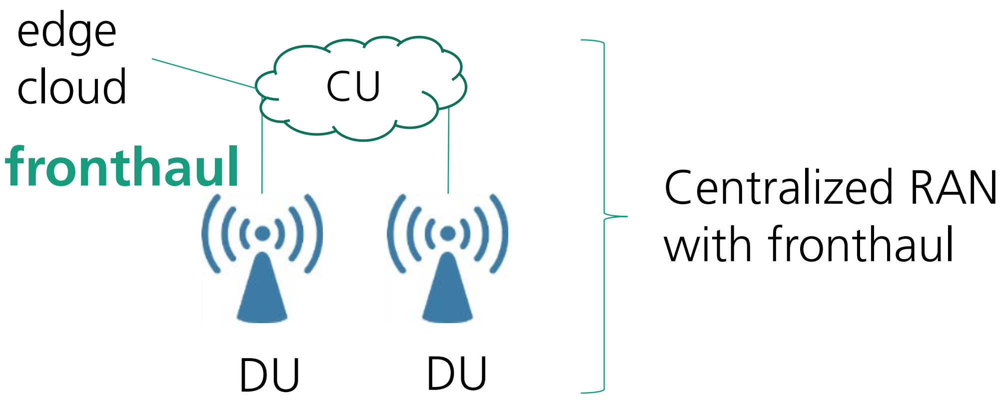


Figure 1: Functional split options



Source: NGMN Overview on 5G RAN Functional Decomposition

5G fronthaul signals are transported over Ethernet (eCPRI protocol)

- Different split options enable different coordination methods for the wireless signals → different fronthaul synchronization requirements
- The nearer to the radio link the split point is, the higher data rates but also the more effective interference can be coordinated

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Fronthaul Requirements

Towards centralized WLAN

Reduced data rates

- Data rates are significantly reduced at split points 1-7 (eCPRI), compared to split 8 (CPRI)

Low latency

- Non-real-time split points 1-3 require 1-10 ms
- Real-time split points 4-8 require 100 to few 100 µs (due to HARQ in 3GPP)

Tight synchronization

- MAC synchronization requirement is 200 ns, coordination/positioning requires 20 ns
- Precision time protocol (PtP) and synchroneous Ethernet (SynchE)

Use centralized RAN with fronthaul

- Wi-Fi philosophy: Keep it simple, stupid (KISS principle)
- In-building networks requires low-cost solutions: easymesh for WLAN → topology
- Consider potential split points in WLAN protocol stack
- Identify the best remote / centralized PHY and MAC configuration
- specify signaling and synchronization schemes for fronthaul over in-building network media

Table 7-2 – Transport bit rates and latency ranges at different functional split interfaces, adapted from Annex A in [3GPP TR 38.801] (Note caveat in the text above)

Protocol split option	Required downlink bandwidth	Required uplink bandwidth	One way latency (order of magnitude)
Option 1	4 Gbit/s	3 Gbit/s	1-10 ms
Option 2	**4016 Mbit/s**	**3024 Mbit/s**	
Option 3	[lower than Option 2 for UL/DL]		
Option 4	4000 Mbit/s	3000 Mbit/s	100 to few 100 µsec
Option 5	4000 Mbit/s	3000 Mbit/s	
Option 6	**4133 Mbit/s**	**5640 Mbit/s**	
Option 7a	**10.1-22.2 Gbit/s**	**16.6-21.6 Gbit/s**	
Option 7b	**37.8-86.1 Gbit/s**	**53.8-86.1 Gbit/s**	
Option 7c	**10.1-22.2 Gbit/s**	**53.8-86.1 Gbit/s**	
Option 8	157.3 Gbit/s	157.3 Gbit/s	

Source: ITU-T G-Series Supplement 66 ((09/2020)

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Coordinated WLAN

Main techniques discussed in 802.11 UHR study group so far

Coordinated Spatial Reuse

- applicable if interference is rather weak
- interference-aware Rx and Tx (IF covariance is known)
- interference measurements in the PHY, moderate synchronization

Coordinated OFDMA/TDMA

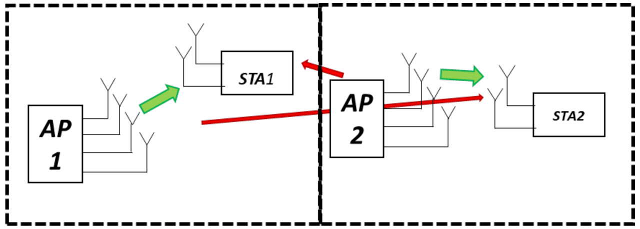
- interference-aware Rx and Tx
- coordinated scheduling, time / frequency synchronization, like MU-MIMO but for APs

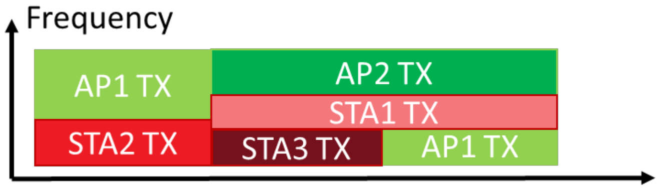
Coordinated Beamforming

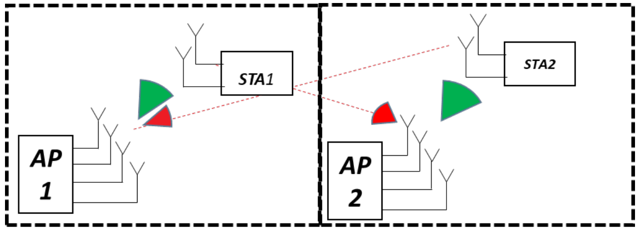
- own-cell transmission is coordinated
- other-cell interference is minimized
- coordinated MAC, time / frequency synchronization

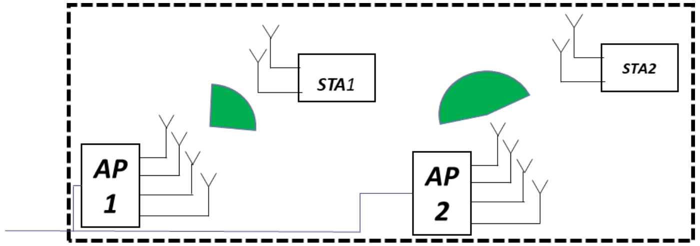
Joint Transmission and Detection

- APs act as one AP with distributed antennas serving all users jointly
- all signals are jointly maximized, cross-talk is jointly reduced
- fully coordinated MAC and PHY, tight time- and frequency synchronization









All figures: Maxlinear

Exploit Wireless Propagation

Notable differences between lower and higher frequencies

Below 7 GHz

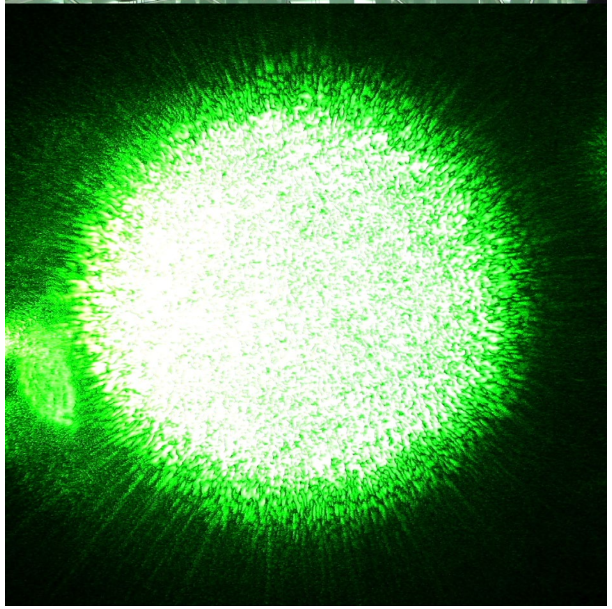
- walls are like semitransparent mirrors (mirror cabinet)
- specular reflections → multipath fading at the centimeter scale
- omnidirectional antennas → *NLOS is the dominant propagation mechanism*
- signal from adjacent rooms is moderately attenuated → **one cell covers multiple rooms**

mm-wave (45-60 GHz)

- very small antenna elements → high path loss → needs beamforming to receive useful signal
- specular reflections → multipath fading at the mm scale
- spatially filtered through beams → *LOS is the dominant propagation mechanism*
- walls are essentially opaque → **one cell covers one room**

LiFi (optical waves)

- large-area transmitters and receivers → wide beams are o.k., narrow beams could save energy
- diffuse reflections → multipath fading (Speckle) at the nanometer scale, averaged by larger Tx/Rx
- objects reflect diffusely → *LOS is the dominant propagation mechanism*
- walls are opaque → **one cell covers one room**



FttR for future WLAN

Requirements for coordination

FttR defines two variants, same as access networks

- **G.fin** has shared medium access, derivative of TDM-PON
- **G.fp2p** has exclusive medium access, derivative of P2P network

Deployment

- **G.fin** is based on PON, has lower cost of deployment, but needs specific infrastructure
- **G.fp2p** is based on P2P Ethernet, more deployed in European buildings

WLAN+FttR: Consider single AP per room

- **mm-wave/LiFi do not go through walls**, interference is only inside one room
  - Single AP per room: APs are well isolated from each other and can work independently, **frequency reuse = 1 becomes possible**
  - **Distributed RAN** architecture with maybe sufficient → **G.fin for backhaul**
- **below 7 GHz goes through walls**, makes interference very difficult
  - Single AP per room will cause interference: required level of coordination is not fully clear, **frequency reuse <<1**
  - **Centralized RAN** architecture with **fronthaul** maybe needed → **G.fp2p for fronthaul**

FttR will need high data rates, low latency and time / frequency synchronization, when used for coordinated WLAN.

- Corresponding protocols to be integrated / further developed, depending on the WLAN coordination technology.

Summary

FttR as a feeder for new wireless technologies

Applications in future IoT require 5G networks with cable-like quality of service

- Bottleneck is high cost for 5G deployment inside buildings

Idea is to further develop LAN+WLAN so that it can reach a quality of service similar to 5G

- Introduce WLAN coordination and new wireless technologies (mm-wave/LiFi) for small cells
- Combine this with FttR so that interference comes under control
- Exploit propagation of higher frequencies: One cell is (only) one room

Use mm-wave/LiFi together G.fin

- One AP per room, no interference coordination is needed

Use coordinated WLAN together with G.fp2p

- One AP per room requires interference management
- Identify functional splits in the WLAN protocoll stack → define the corresponding fronthaul interface
- Ensure that data rate / latency / synchronization are sufficient for WLAN coordination technique

Acknowledgement

This work has been partly funded by the innovation project 5G-COMPASS funded by the German Federal Ministry of Digital and Transport (BMDV) under FKZ. 1OI22017A. Thanks to all the partners for fruitful collaboration.

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