Webinar on SRIA

Strategic Research and Innovation Agenda (SRIA) 2021-27

“Smart Networks in the context of NGI”

Radio Technology and Signal Processing

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NetWorld 2020 SRIA: Smart Networks in the context of NGI

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4. System Architecture
5. Edge Computing and Meta-data
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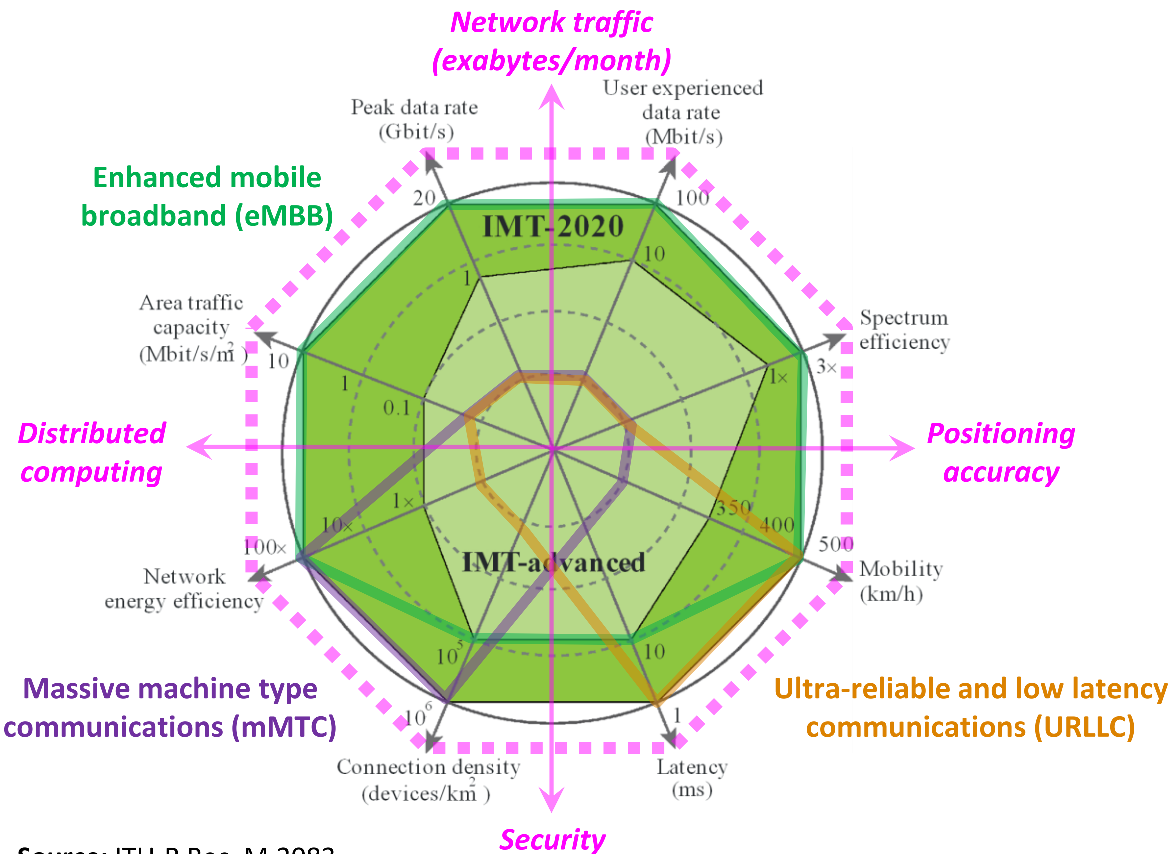
Smart Networks: Vision and Use Cases

Smart Networks



Source: ITU-R Rec. M.2083 (modified)

Target use cases

- Tbps throughput
- sub-ms latency
- Gbps availability
- Extreme reliability
- mMTC everywhere
- Extreme energy efficiency
- Very high security
- Very high mobility
- cm-level localization
- ...

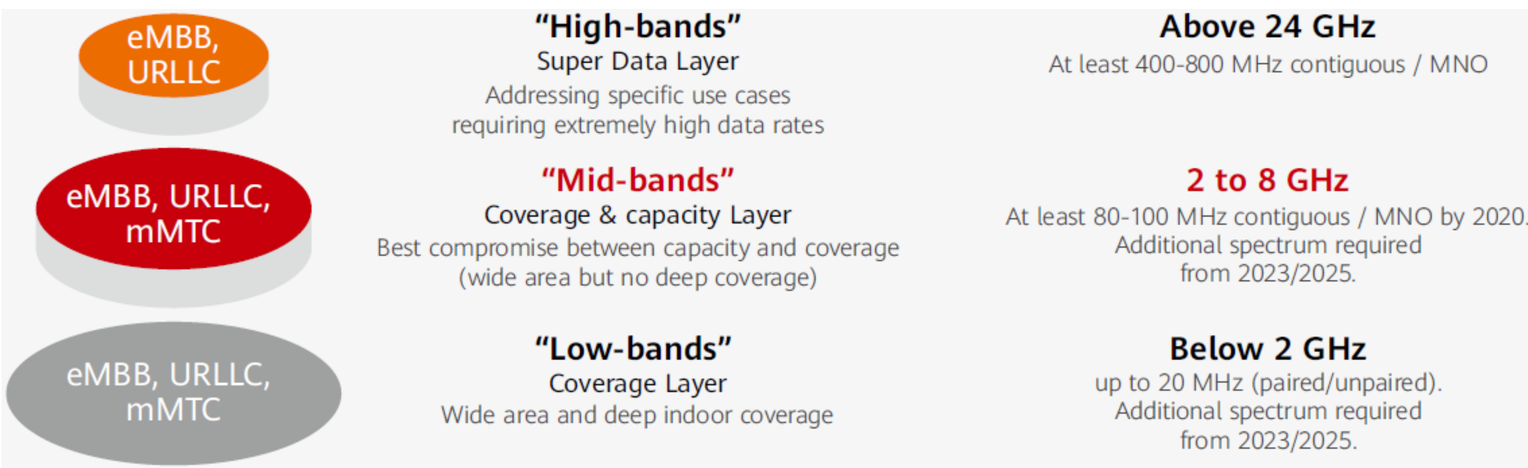
1. Spectrum Re-farming and Reutilisation

Motivation

- Traditionally, dedicated spectrum allocated to each radio access technology (RAT).
- Spectrum reutilization between RATs (spectrum sharing) offers an efficient utilization of resources and great flexibility, e.g. for load-balancing.

Target & Challenge

- Efficiently re-utilize the existing spectrum resources, improve spectral efficiency, reliability, availability, ...
- Jointly utilize licensed and unlicensed spectra.
- Spectrum usage supported by multi-RAT connectivity, e.g. using cognitive radio based solutions. UE can choose the best RAT depending on link qualities.



Source: *5G Spectrum Public Policy Position*, Huawei, 2020, https://www-file.huawei.com/-/media/corporate/pdf/public-policy/public_policy_position_5g_spectrum_2020_v2.pdf?la=en.

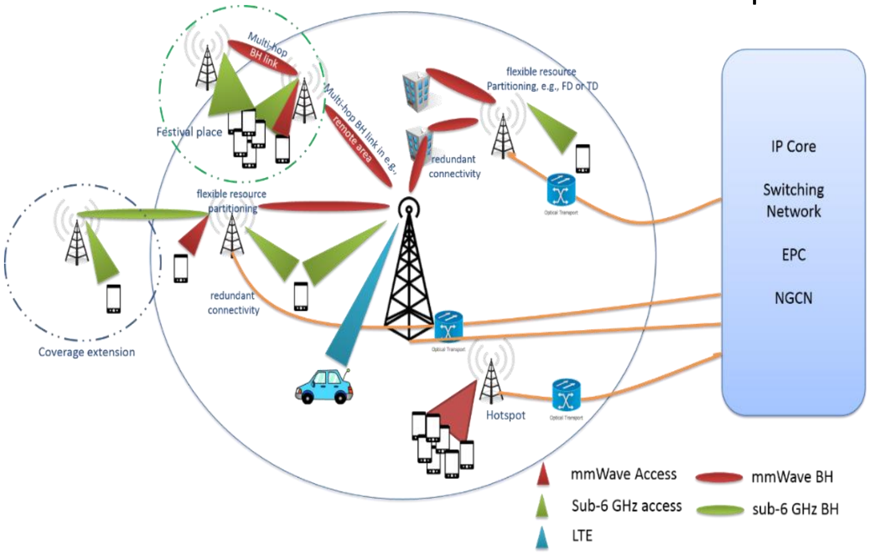
2. Millimetre Wave System

Motivation

- ❑ mmWave roughly below 50 GHz considered for 5G NR.
- ❑ Diverse requirements on throughput, latency and reliability, pose new challenges, e.g. on backhaul links
  - Massive content with data rates up to 1000 Gbps.
  - Massive control with 1 ms response time to enable mobile edge caching (MEC) and extreme reliability.

Target & Challenge

- ❑ Efficient TX and RX beamforming (BF) in terms of high data rate, low power consumption, minimized size.
- ❑ Modulation coding scheme implementation with low power, low cost, high throughput.
- ❑ Overall system development with target < 1pJ/bit.
- ❑ E.g. using multi-stream approach (e.g. OAM), 1-bit ADC, constant envelope modulation, etc.



Source: 5GPPP Project *5G-XHaul*, "D4.3 Use of mm-Wave technology for backhaul, fronthaul and access networks," 2017, https://www.5g-xhaul-project.eu/publication_deliverables.html.

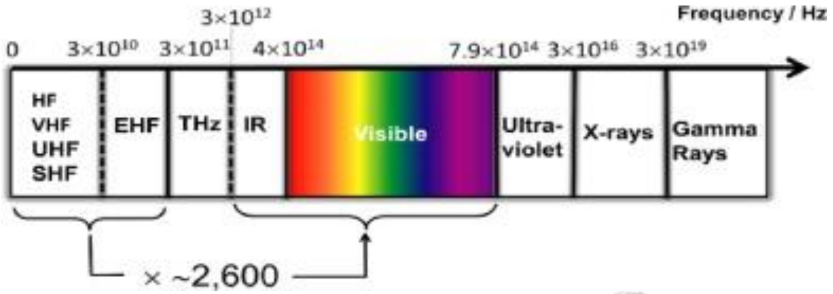
3. Optical Wireless Communication (OWC)

Motivation

- Today's Wi-Fi is used for data-offloading, but limited by the available unlicensed spectrum.
- Optical wireless communications (OWC) consists of infrared and visible light spectrum, which is ~2600 times the size of the entire RF spectrum of 300 GHz.
- It complements RF communications to fulfill the ever-increasing demand in data traffic.
- It can combine illumination and data communication.
- No need of beamforming to direct beams.
- Off-the-shelf optical devices can be used.
- MIMO structures can be implemented at chip-level, due to extremely small wavelength.
- No multipath fading, as detector sizes >> wavelength.
- Using 'solar cell' can achieve simultaneous energy harvesting and high-speed data communication.
- E.g. 8 Gbps from single light emitting devices and 17.6 Gbps using laser diodes reported.
- E.g. IEEE standards 802.11, 802.15.13, etc.

Target & Challenge

- Interference mitigation to ensure that within the region of strong co-channel interference, a UE can achieve high SINR.
- The signals in OWC are positive and real-valued.
- LiFi-bespoke networking methods to be developed, and integrated into 6G.
- LiFi signals are spatially confined, hence new physical layer security concepts are needed.



Source: H. Haas, "LiFi is a paradigm-shifting 5G technology," *Reviews in Physics*, vol. 3, 2018.

4. Terahertz Communication

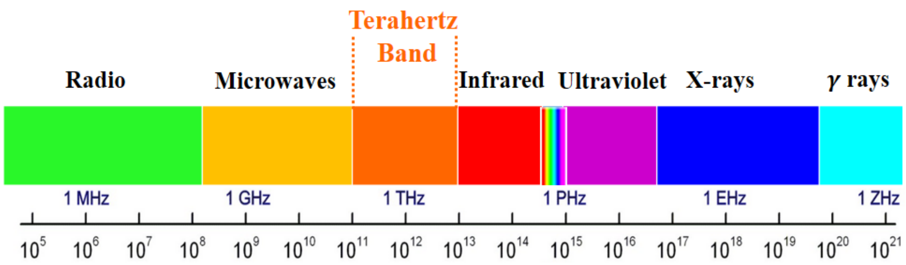
Motivation

- THz communication in the 0.1-10 THz band,*) between microwave and infrared bands.
- <1 m range possible at ~10 THz carrier.
- > tens m range possible at tens or hundreds GHz.
- While the total consecutive bandwidth of mmWave systems is less than 10 GHz, the one in THz communication is in in the order of multiple THz.

*) I. F. Akyildiz, J. M. Jornet and C. Han, "Terahertz band: Next frontier for wireless communications," *Physical Communication*, vol. 12, 2014.

Target & Challenge

- New channel models for THz band: spreading loss, molecular absorption loss, scattering loss, etc.
- New experimental platforms and testbeds that can operate at THz frequencies.
- Novel MAC protocols: The huge bandwidth may eliminate the need for contention-based schemes, packet size optimization, adaptive error control, etc.



Source: https://bwn.ece.gatech.edu/projects/teranets/index.html.

- New congestion control at the transport layer to accommodate traffic in the order of Tbps.
- Modeling and mitigating non-linearities, phase noise, …
- New modulation types, e.g. femtosecond-long pulse-based modulation.
- ADCs/DACs for tens of Giga samples/sec.
- Efficient realizations of MIMO antenna arrays, e.g.
  - Graphene, a carbon based nano-material, supports the propagation of Surface Plasmon Polariton (SSP) waves
  - 1024 antenna elements could be packed in an area smaller than 1mm^2 if plasmonic material is used.
- Regulation and standardization of THz bands, …

5. Massive and Ultra-Massive MIMO

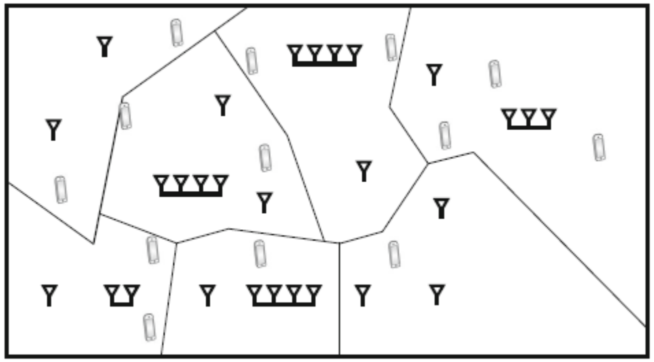
Motivation

- Ultra-massive MIMO (um-MIMO): Antenna arrays in the order of thousands of elements, e.g. to be employed in THz bands.
- Highly directional antenna elements to achieve very high array/BF gains and combat the very large path loss.
- Another new way to improve wireless communications is to change propagation characteristics of wireless channel, e.g. through intelligent reflecting surfaces (IRS) or large intelligent surfaces (LIS).
- To effectively offer almost uniform services across the network, the current network centric CoMP architecture needs to be transformed into the true UCNC, and cell-free massive MIMO (mMIMO).

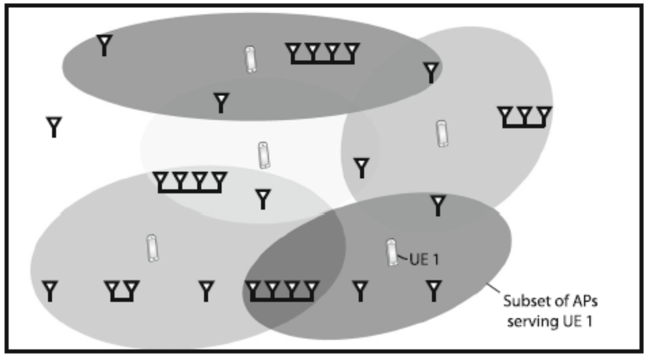
Target & Challenge

- Construction of graphene-based antenna arrays.
- Channel modeling of um-MIMO; modeling the mutual coupling among antenna elements.
- Feeding/control of each antenna element.
- Real-time estimation and feedback of a large number of channel elements, … to enable um-MIMO operation.
- Advanced space-time-frequency coding to exploit all diversities and achieve optimal performance, etc.

Network centric CoMP



True user centric no cell (UCNC)



Source: G. Interdonato et al., "Ubiquitous cell-free massive MIMO communications," *EURASIP JWCN*, 2019.

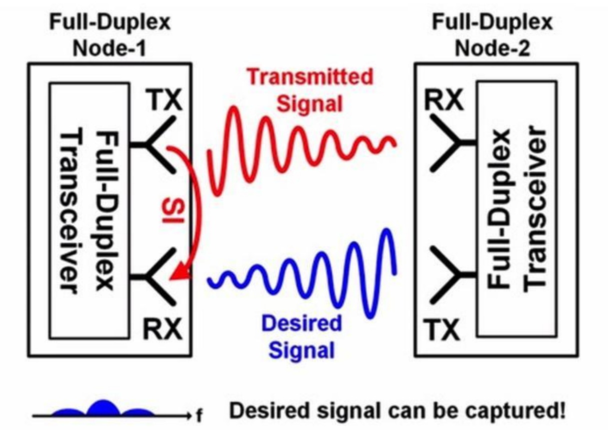
6. Waveform, Multiple Access and Full-Duplex

Motivation

- ❑ CP-OFDM waveform has been adopted in several wireline and wireless standards such as xDSL, Wi-Fi, 4G and 5G. Strict synchronization is required for CP-OFDM to maintain orthogonality.
- ❑ Relaxing the orthogonality constraint leads to a more efficient and flexible use of the wireless channel. Non-orthogonal multiple access (NOMA) can result in larger achievable rates and provide means for grant-free access.
- ❑ Advanced self-interference cancellation (SIC) techniques needed to enable full-duplex transceivers. *)
- ❑ TDMA, CDMA, OFDMA are used for 2G, 3G, 4G and 5G. What are the best suitable waveform, multiple access schemes for 6G?

Target & Challenge

- ❑ Develop advanced waveform, NOMA schemes, etc, which can cope with new requirements and use cases, e.g. THz channel, Tbps throughput, extreme URLLC, asynchronous mMTC, extremely low power consumption, …
- ❑ Develop SIC and full-duplex schemes, incl. antenna and circuit design, esp. for MIMO and mMIMO.



Source: https://www.techrepublic.com/article/researchers-accomplish-full-duplex-radio-communications-using-an-ic/

*) D. Kim, H. Lee and D. Hong, "A survey of in-band full-duplex transmission: From the perspective of PHY and MAC layers," *IEEE Communications Surveys & Tutorials*, vol. 17, 4Q 2015.

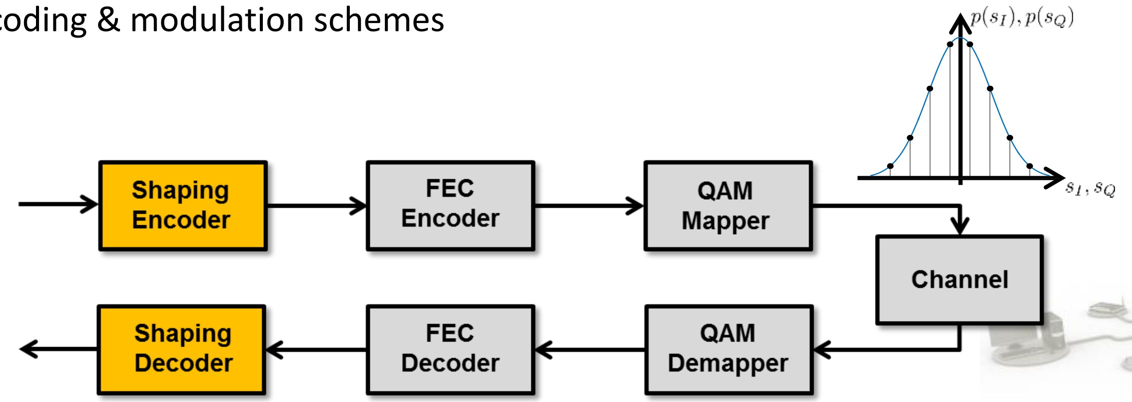
7. Coding and Modulation

Motivation

- Channel decoder is often considered as the most complex part of the TRX chain.
- Future new use cases like Tbps throughput, extreme URLLC and low-energy consumption pose new requirements on designing coding & modulation schemes.
- Current mobile systems use BICM and generate uniformly distributed channel input symbols, resulting in a signal shaping loss of up to 1.53 dB for higher order modulations.
- What are the suitable coding & modulation schemes for 6G?

Target & Challenge

- Design advanced channel coding and modulation schemes for Tbps throughput and extreme reliability, e.g. Tbps channel decoder.
- Design extreme low-power consumption coding and modulation schemes, esp. for extreme mMTC.
- Develop advanced coded modulation schemes which remove signal shaping loss and close the gap between Shannon limit and practical implementations.



Source: *3GPP R1-1701713*, “Signal shaping for QAM constellations,” 2017.

8. Positioning and Sensing

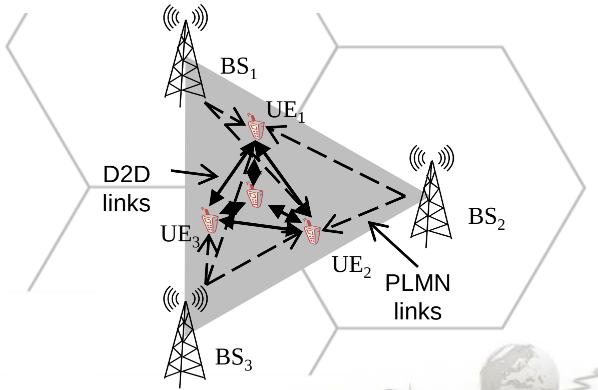
Motivation

- Accurate positioning has been identified as a key enabler for many applications, e.g. autonomous driving for connected cars, local collaboration of unmanned aerial vehicles, etc.
- FCC set a requirement of ~50 m accuracy for localization in case of an emergency call (so-called E-911), which can be met by 3G and 4G. *)
- For 5G, the toughest requirement (as set in 3GPP TS 22.261 – Service requirements for the 5G System, R16) is ~0.5 m for locating moving objects, by using 3GPP and non-3GPP technologies.
- For smart factory, V2X vulnerable road user discovery, etc, a cm-level positioning accuracy may be required.
- With integrated positioning/sensing and communication, improved spectral/energy efficiency and reduced latency will become possible.

*) W. Xu, M. Huang, C. Zhu and A. Dammann, "Maximum likelihood TOA and OTDOA estimation with first arriving path detection for 3GPP LTE system," *Transactions on Emerging Telecommunications Technologies (ETT)*, vol. 27, 2016.

Target & Challenge

- Cooperation can greatly improve positioning accuracy. Future wireless systems will have higher bandwidth, more antennas, densed network and D2D links, which may enable a radio positioning with cm-level accuracy. But how to design a system to efficently achieve this?
- Radar can sense the environment and hence increase communication efficiency. How should radar and communication converge, esp. for 6G?



Source: W. Xu, A. Dammann and T. Laas, "Where are the things of the internet? Precise time of arrival estimation for IoT positioning," in *The Fifth Generation (5G) of Wireless Communication* (Ed. by A. Kishk), 2018.

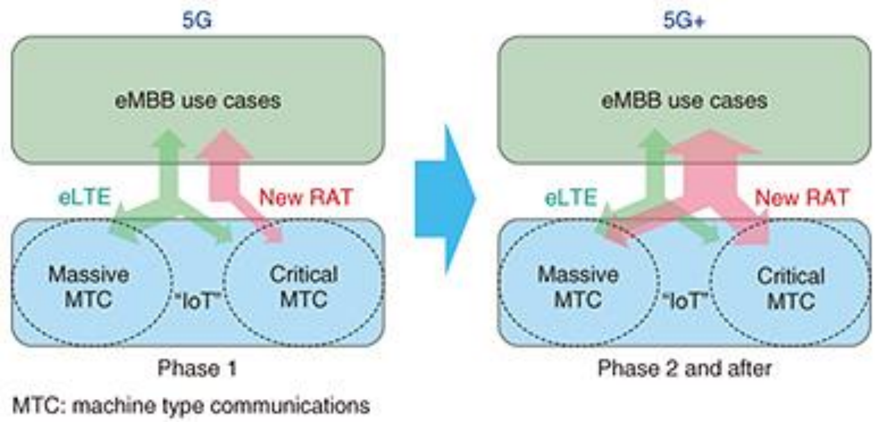
9. Massive Random Access

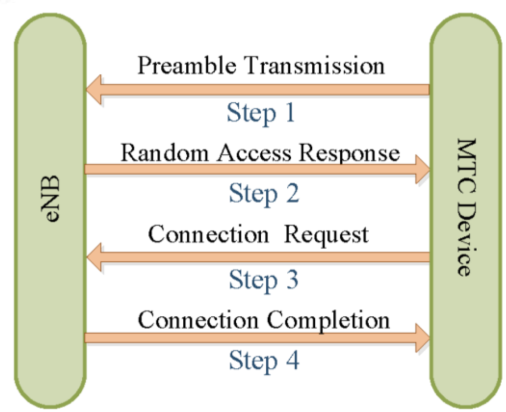
Motivation

- The future vision of IoT envisages a very large number of connected devices, generating and transmitting very sporadic data (mMTC).
- How to coordinate such a network without spending the whole network resource and node energy in protocol overhead?

Target & Challenge

- Design new random access codes for which the superposition of a large number of distinct codewords can still be uniquely decoded. Note the design of such channel access protocols departs from conventional approaches used for predictable, persistent, and synchronized data sources.
- Challenges include
  - Low complexity/energy protocols, low-cost devices.
  - Massive number of devices with low overhead, and potentially with energy and latency constraints.





Source: Y. Kishiyama, S. Nagata and T. Nakamura, "Standardization status towards the introduction of 5G in 2020," *NTT Technical Review*, vol. 15, 2017.

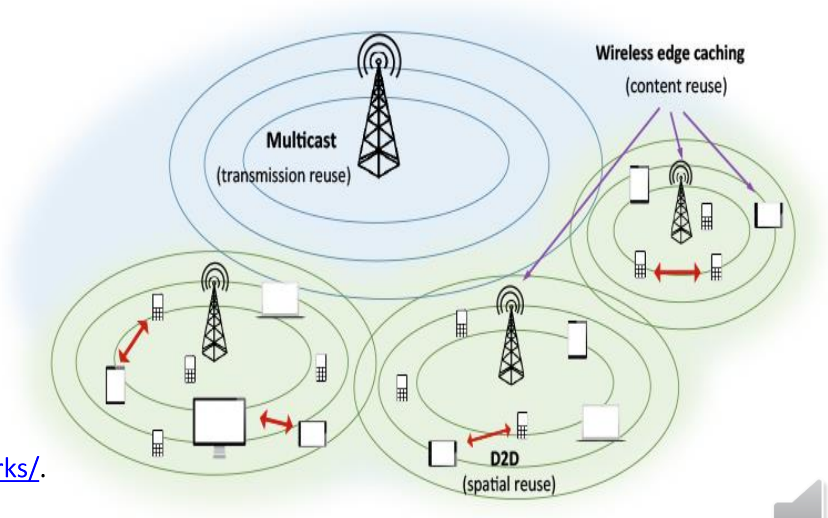
10. Wireless Edge Caching

Motivation

- On-demand video streaming and Internet browsing
  - Asynchronous content reuse
  - Highly predictable demand distribution
  - Delay tolerant, variable quality
- Some issues
  - The wireless capacity of macro-cells is not sufficient.
  - Wired backhaul to small cells is weak or expensive.
- Caching can reduce network load and interferences, and consequently increase spectral and energy efficiency (due to efficient reuse of resources), and decrease latency (due to smaller distance between content and user).

Target & Challenge

- Caching is usually implemented in the core network, how to efficiently implement it for wireless?
- Challenges include
  - Coding, e.g., combining edge caching with modern multiuser MIMO physical layer schemes.
  - Protocol architectures, e.g., combining edge caching with schemes for video quality adaptation.
  - Machine learning based content popularity prediction can be used to efficiently update the cached content.



Source: https://wireless.engineering.nyu.edu/cache-aided-wireless-networks/.

Conclusion

- **Future 6G wireless networks need to address challenging use cases/schenarios, e.g.**
  - ✓ Tbps throughput
  - ✓ sub-ms latency
  - ✓ Gbps availability
  - ✓ Extreme reliability (e.g. with packet error rate < 10^{-8})
  - ✓ Extreme energy efficiency
  - ✓ cm-level radio positioning accuracy
  - ✓ etc
- **NetWorld2020 identified the research areas to be addressed in Radio Technology and Signal Processing, also aided by AI/ML, for potential 6G use cases/schenarios, incl.**
  1. Spectrum re-farming and reutilisation, as well as co-existence
  2. Millimetre wave system
  3. Optical wireless communication, esp. VLC
  4. THz communication, incl. new materials (graphene)
  5. Massive and ultra-massive MIMO, incl. IRS, cell-free mMIMO, etc
  6. Improved waveform, multiple access and full-duplex
  7. Enhanced coding and modulation
  8. Integrated positioning, sensing and communication, incl. radar
  9. Random access for massive connections
  10. Wireless edge caching for further increased spectrum and energy efficiency

Thank you!

www.networld2020.eu