key requirements of an MTC-optimized 6G network

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outline

connectivity types and traffic modeling

timing performance

Machine Learning: must have and nice-to-have

spectrum and slicing

how is MTC transformed by trusted interactions

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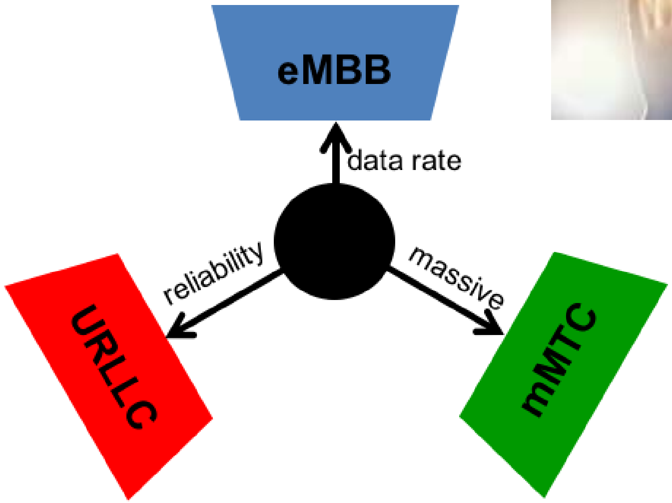
the 5G mantra

enhanced Mobile Broadband

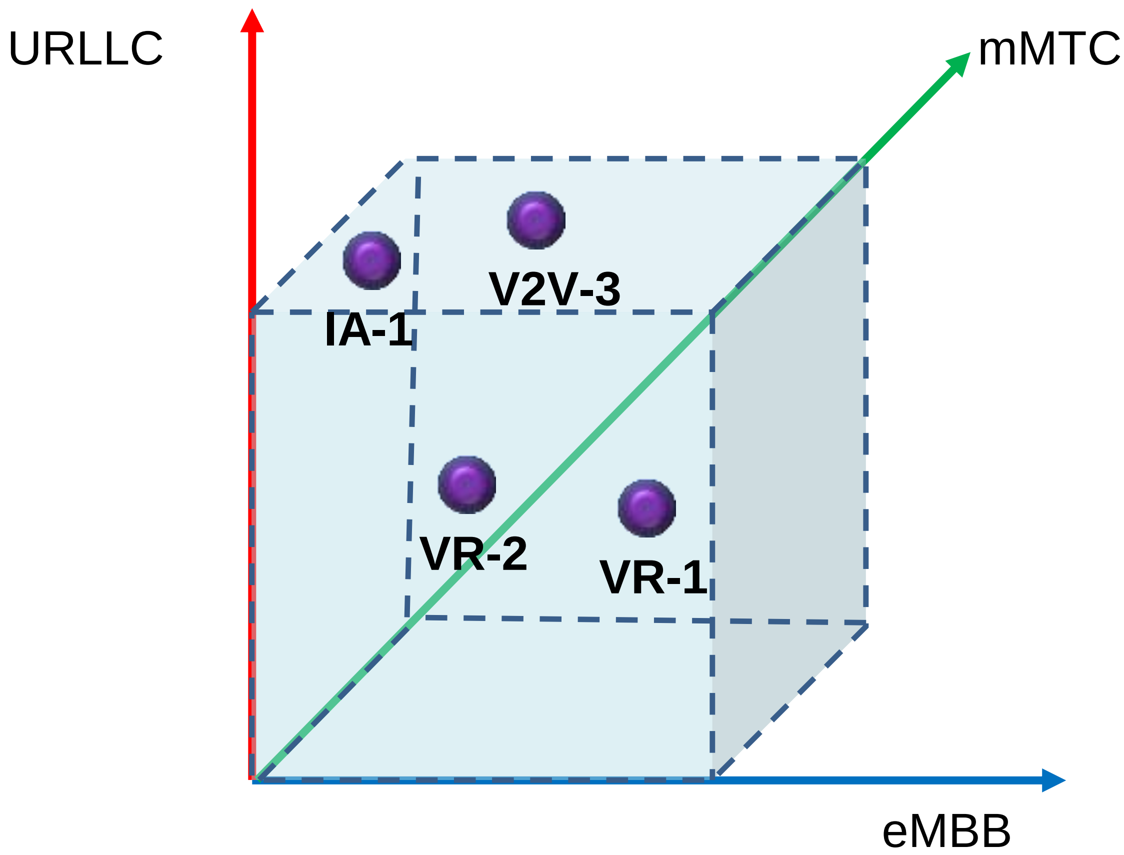


Ultra-Reliable
Low Latency
Communication

massive
Machine Type Communication

perhaps the main innovation in 5G: offer a platform for flexible support of heterogeneous services

the space of 5G connectivity services

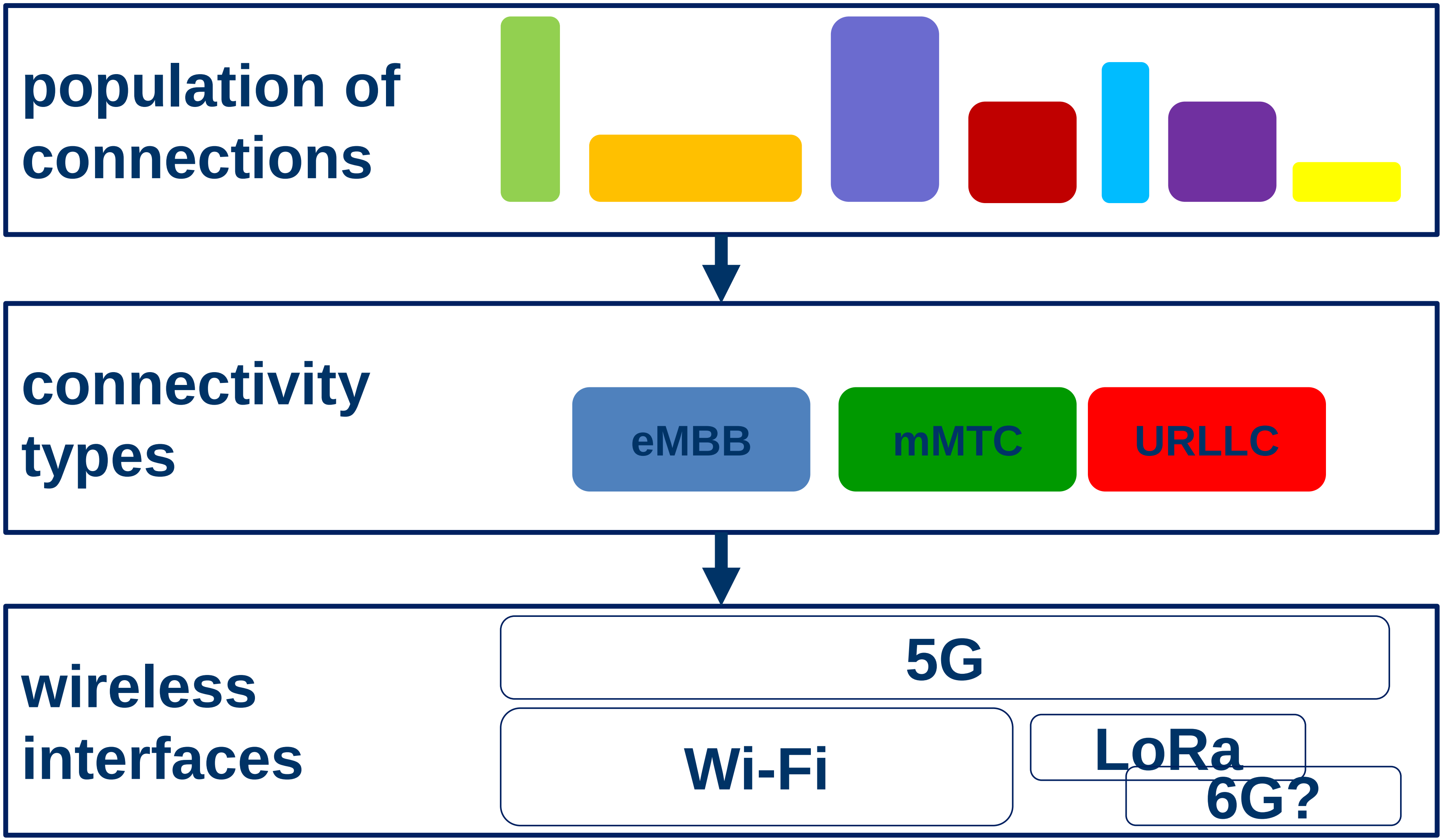


IA: Industrial Automation

VR: Virtual Reality

V2V: Vehicle-to-Vehicle

relation to other wireless interfaces



at least three cases for longer-term URC

resilient connections with large latency budget

mobile health,
remote monitoring

disaster and rescue

smart grid

industrial connectivity

5G-ACIA defines different notions of Real-Time (RT):

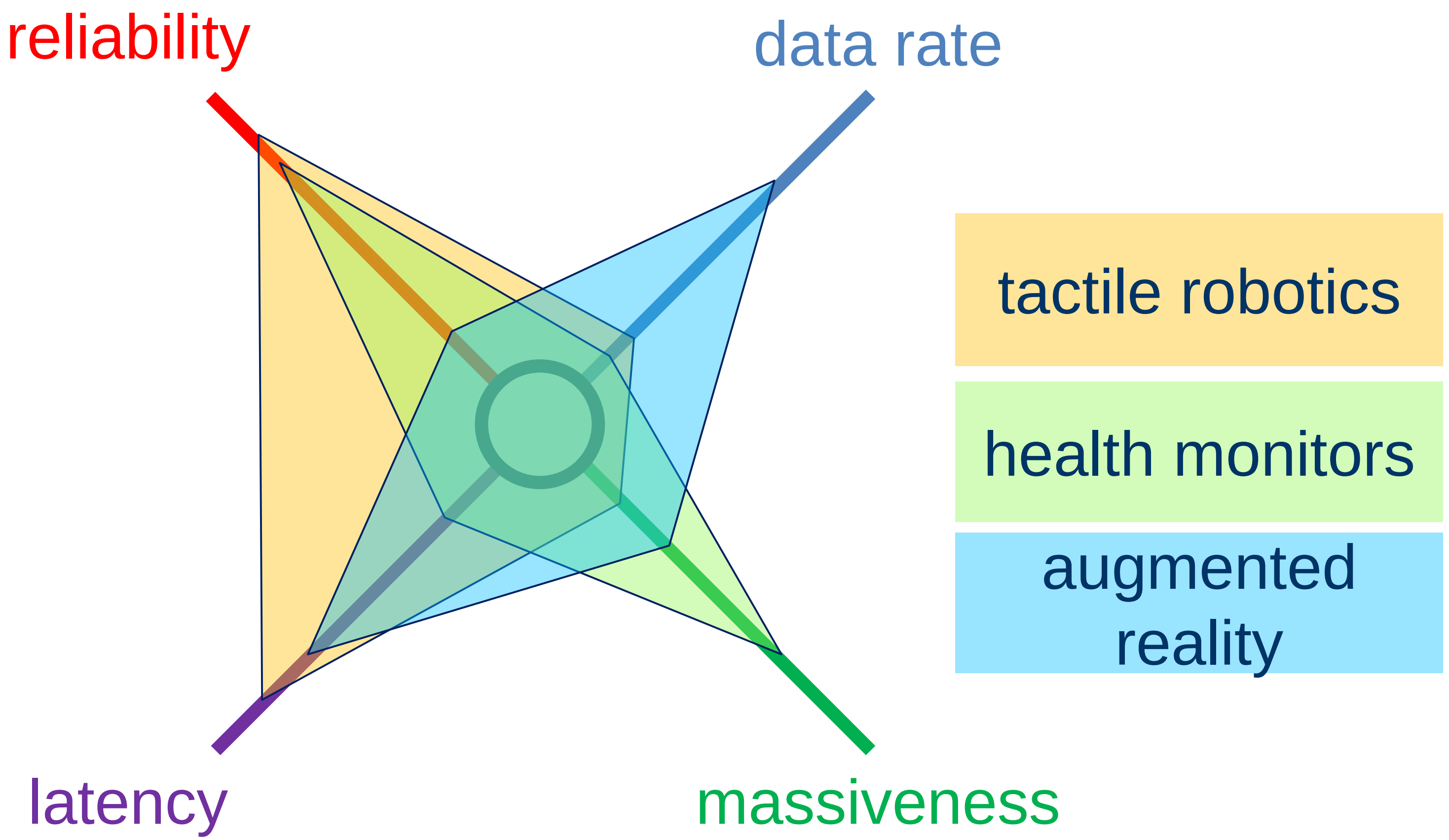
- Non-RT (seconds)
- Soft-RT (~second)
- Hard RT (ms or us)

	Use case	Category
1.	Connectivity for the factory floor	Hard RT
2.	Seamless integration of wired and wireless components for motion control	Hard RT
3.	Local control-to-control communication	Hard RT
4.	Remote control-to-control communication	Soft RT
5.	Mobile robots and AGVs	Soft RT
6.	Closed-loop control for process automation	Soft RT
7.	Remote monitoring for process automation	Non-RT

Source: 5G-ACIA

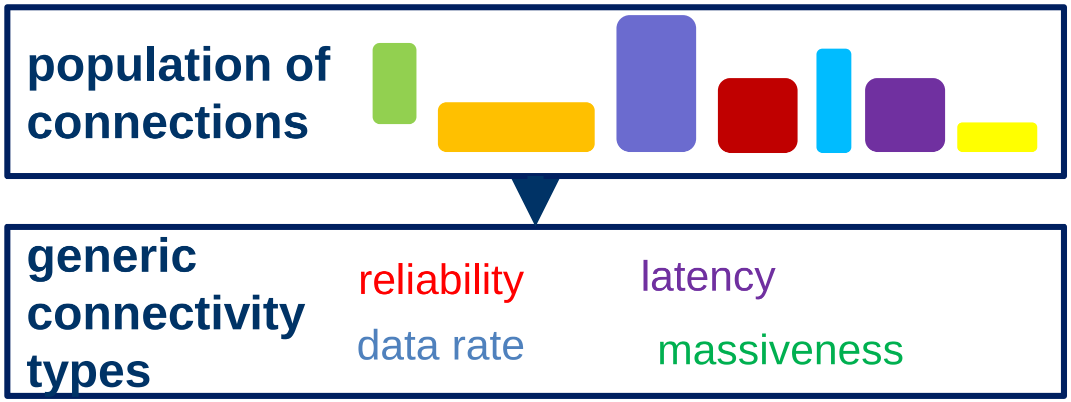
[2] 5G-ACIA, “Key 5G Use Cases and Requirements,” white paper, May 2020.

connectivity space revisited



the traffic model challenge

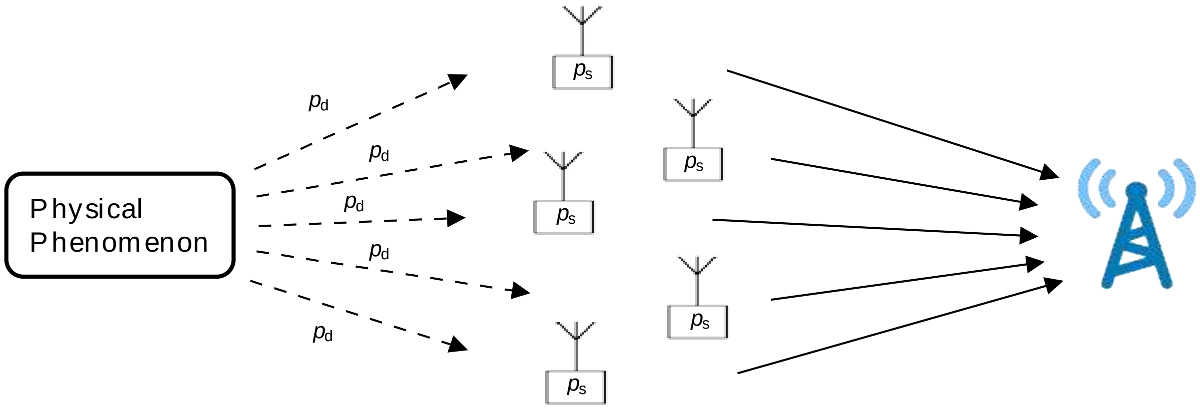
need for improved understanding of the connection ecosystem



characterization of the composite connections

- example: low latency traffic arrivals from the same device correlated with broadband requests

another example: massive + ultra-reliable traffic



a device generates two message types

- individual update, independent of others
- alarm-type message, correlated for all sensors

K. Stern, A. E. Kalør, B. Soret, and P. Popovski, "Massive Random Access with Common Alarm Messages", in Proc. IEEE ISIT, Paris, France, July 2019.

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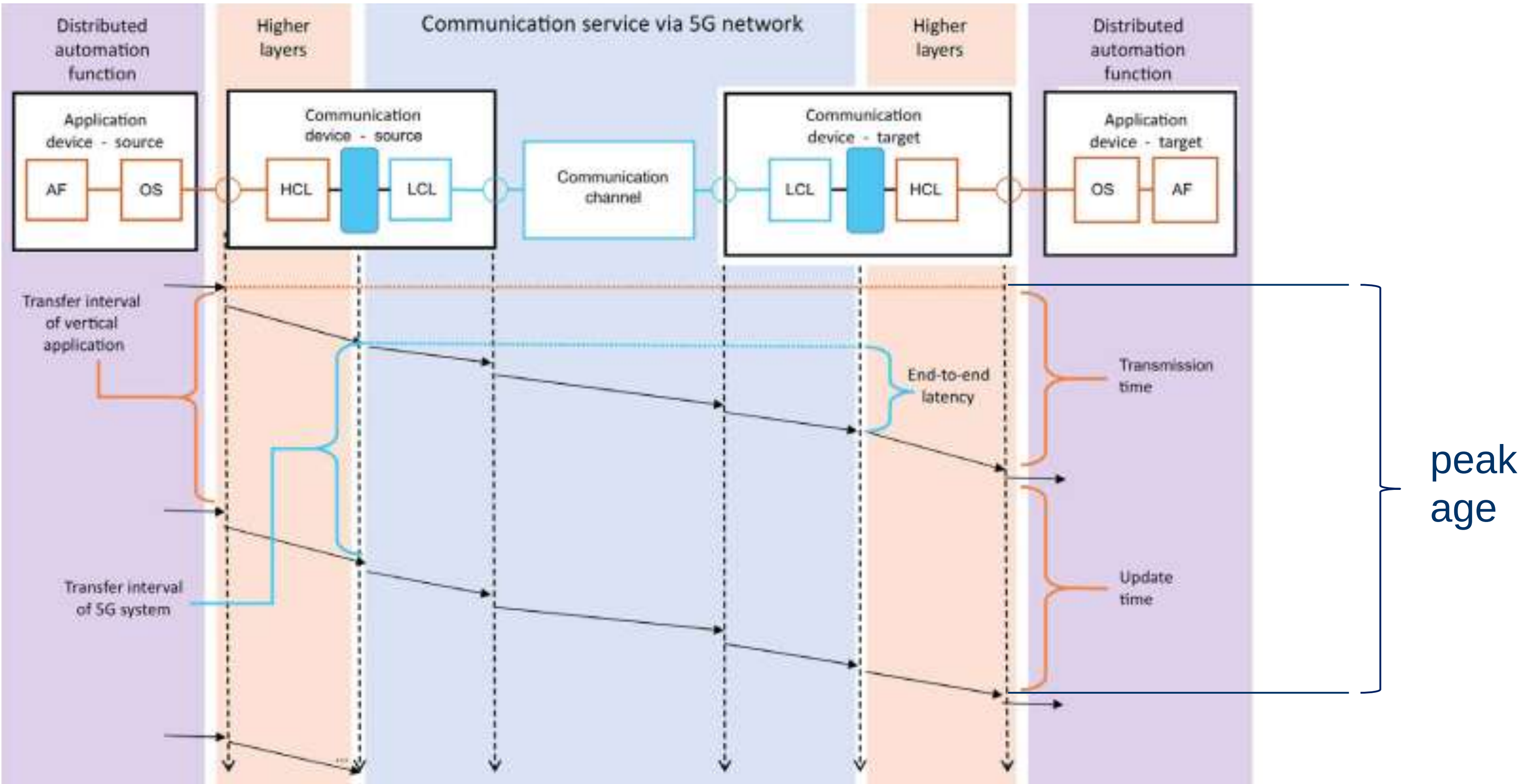
timing requirements beyond latency



Relationship between application device and communication device [3]

[3] 3GPP Technical Specification 22.104. "Service requirements for cyber-physical control applications in vertical domains" https://www.3gpp.org/ftp/Specs/archive/22_series/22.104/

remarks

- latency, age, peak age are only instances of a class of time-related criteria for mission-fulfillment of the system
- another popular criteria: consecutive errors
- tradeoff between good architecture (layering) and flexible timing requirements
  - the proverbial 1 ms is a “layering victim”

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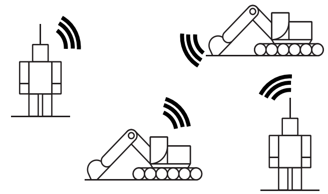
data-driven performance guarantees

Alice sells ultra-reliability to Bob

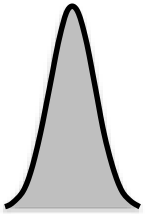




many questions

- how does Alice measure the reliability performance?
- under what conditions is ultra-reliability guaranteed?
- …

uncertainty in ultra-reliable wireless

inherent randomness of wireless



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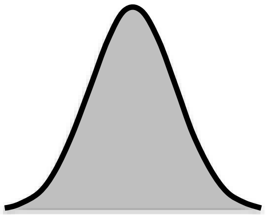
ignorance about channel statistics



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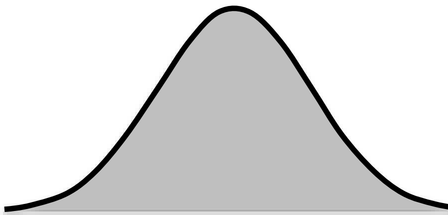
changes of the channel statistics



ML is must-have for ultra-reliability

three key elements

- model selection
  - parametric models for F
  - non-parametric estimation of F
- learning
  - generate an estimate $\hat{F}$ using a training sample X^n
  - bad training data leads to a bad estimate $\hat{F}$
- performance evaluation

☞ specification of the packet error rate only is insufficient

[4] M. Angjelichinoski, K. F. Trillingsgaard and P. Popovski, "A Statistical Learning Approach to Ultra-Reliable Low Latency Communication," in IEEE Transactions on Communications, 2019

ML nice-to-have

solving the complex algorithmic challenges using deep learning

- resource allocation
- cross-layer optimization
- distributed learning across nodes
- multi-antenna optimization
- anticipatory networking

[7] C. She et al., “A Tutorial of Ultra-Reliable and Low-Latency Communications in 6G: Integrating Theoretical Knowledge into Deep Learning”, Arxiv, September 2020.

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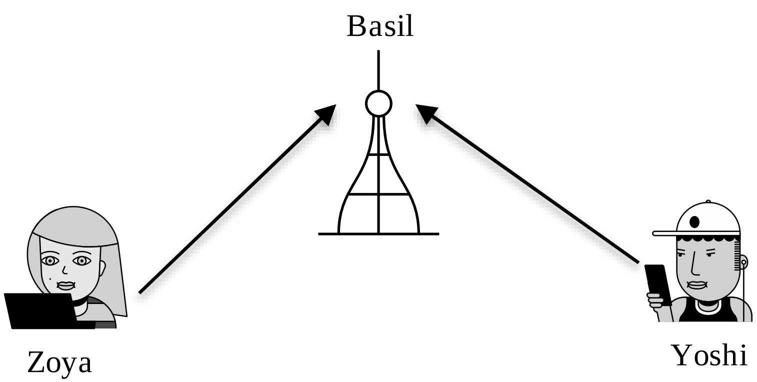
“infinite spectrum capacity”

the first topic listed in EU Commission call for projects
5G PPP – Smart Connectivity beyond 5G

“Provision of seemingly infinite network capacity including innovative spectrum use and management …”

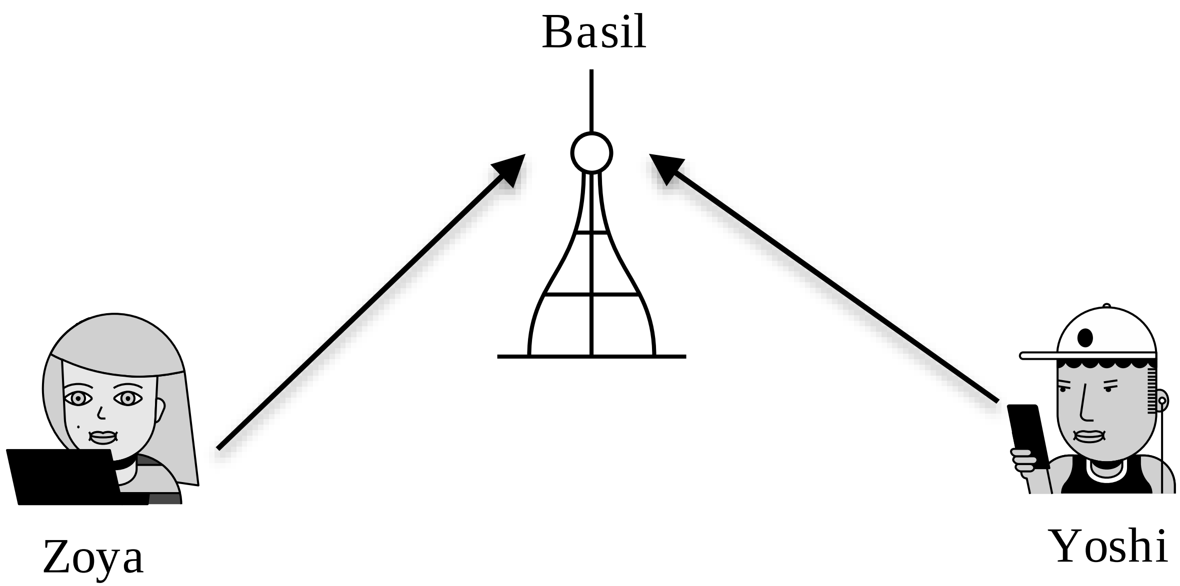
but how do we measure the spectrum capacity when one user wants a high rate and another one wants a fixed rate, low latency and high reliability?



broadband connectivity

low-latency critical connectivity

toy example on wireless slicing

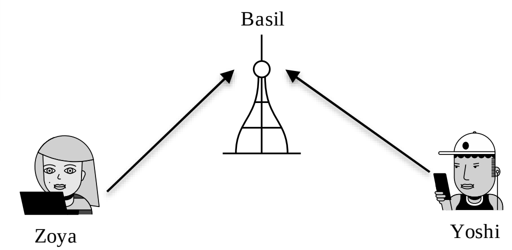


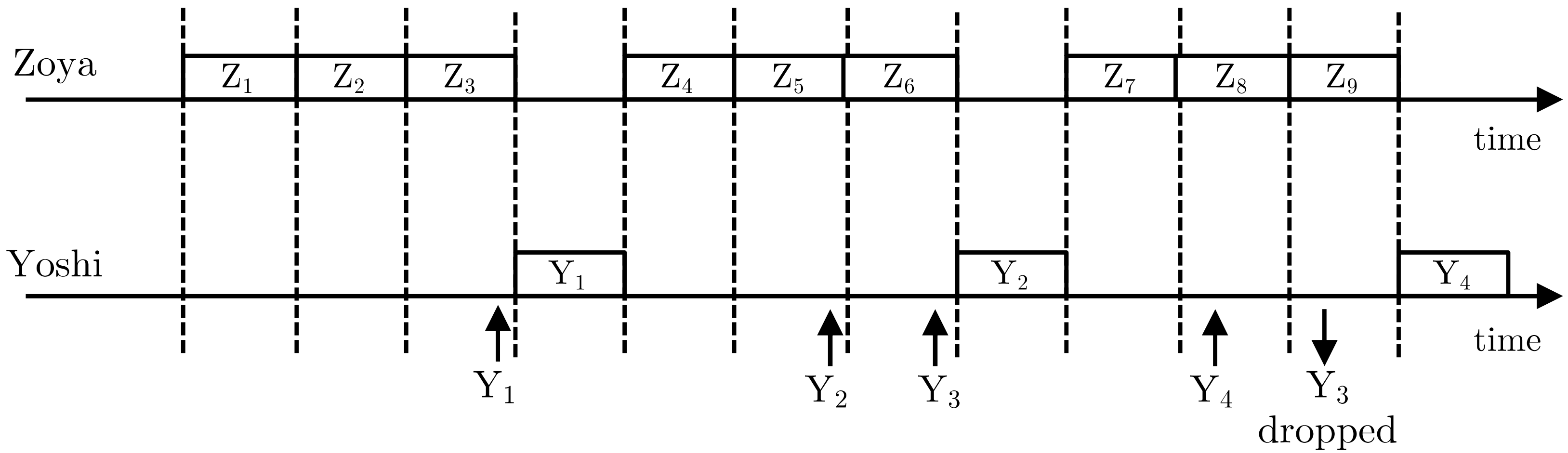
- broadband connectivity
- continuous transmission
- example: video stream
- target rate

- low-latency connectivity
- intermittent transmission
- example: reliable control
- target latency/reliability

[6] P. Popovski, *Wireless Connectivity: An Intuitive and Fundamental Guide,* Chapter 4, Wiley, 2020.

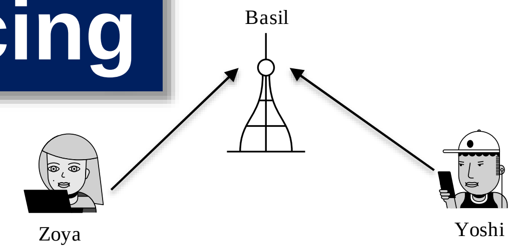
toy example: orthogonal slicing

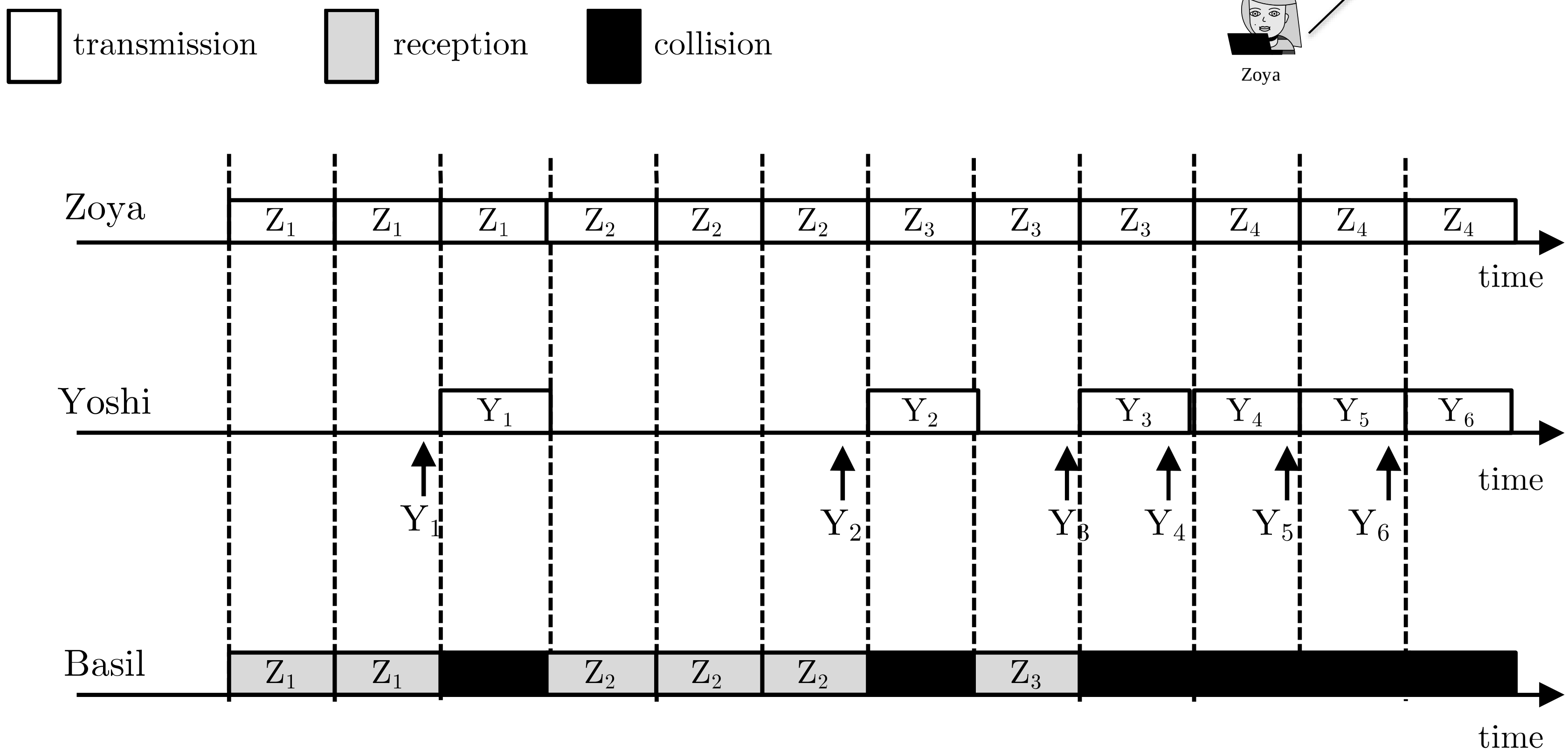




- L-th slot allocated to intermittend
  - he waits at most L slots to deliver the packet
- the broadband goodput is $G_Z = \frac{L-1}{L} R$
- intermittency does not affect the broadband goodput of

toy example: non-orthogonal slicing





- broadband repeats each packet 3 times
- Successive Interference Cancellation

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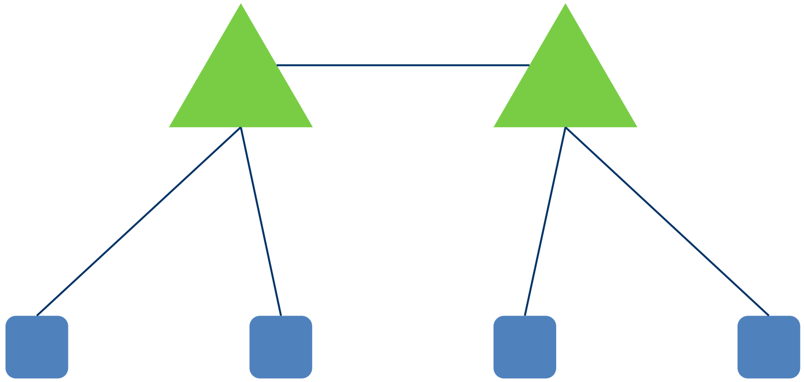
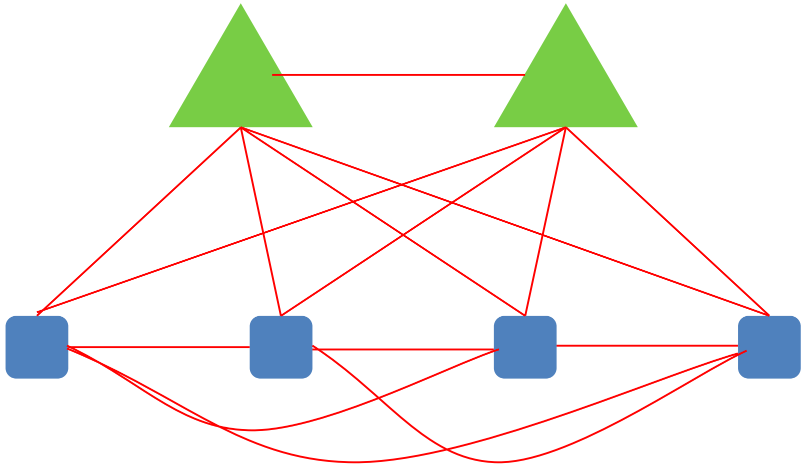
blockchains and wireless IoT connectivity

- blockchains and distributed consensus fundamentally change the communication traffic
- improved security adds an additional overhead



IoT without blockchain

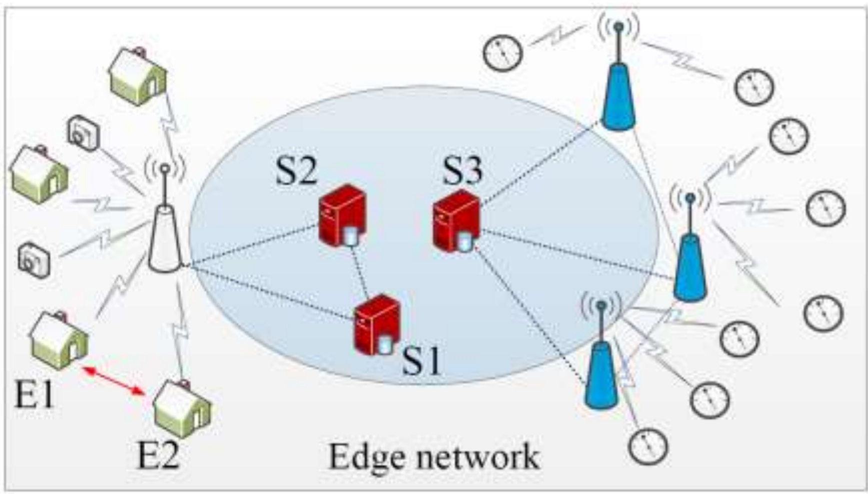


IoT with blockchain

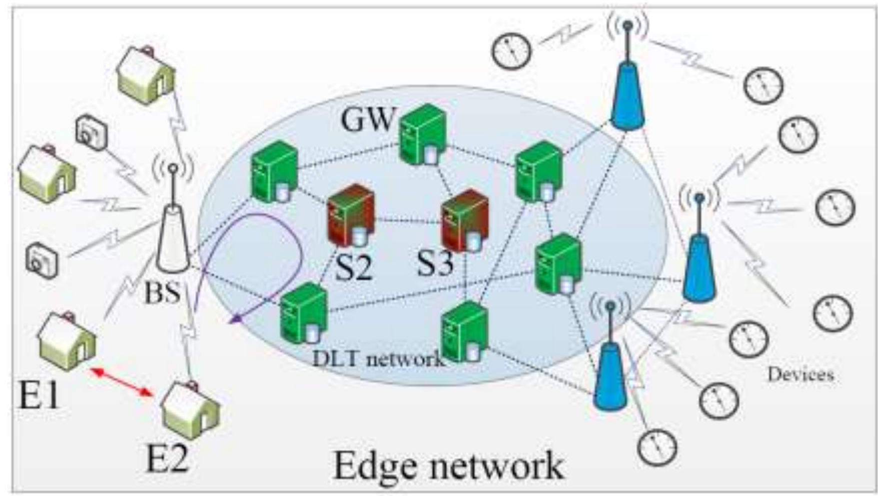
fitting DLT to mMTC and URLLC

- capabilities and requirements of mMTC and URLLC devices quite different
- the challenge in mMTC is computational requirements and protocol overhead
- the challenge in URLLC is transaction finalization delay
  – new definitions and requirements on latency

distributed trust architecture



Legacy System Architecture



Distributed Trust Architecture

outlook

- interaction among different generic traffic types
- better understanding of models will lead to generalization of the notions of timing and reliability
  - IoT traffic may be significantly changed by smart contracts and distributed ledgers.
- ML is must-have for guaranteeing and measuring ultra-reliability
- spectrum allocation and usage to be revised from "spectrum efficiency only" to conform to the requirements of different generic types