The future of URLLC in the 6G era

Contribution to 6G RESEARCH VISIONS WEBINAR SERIES:
Deep Dive into Machine Type Communications Towards 6G

Christian Wietfeld
christian.wietfeld@tu-dortmund.de

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Faculty of Electrical Engineering and Information Technology
Communication Networks Institute
Prof. Dr.-Ing. Christian Wietfeld
Latest 5G measurements demonstrate excellent performance…
… which will be further improved with future 3GPP releases

5G Ultra-Wide Band mmWAVE

1.8 Gbit/s

6 ms Latency

Loss 0.0%

Will be further improved with latest 3GPP releases

Measurements in Downtown San Francisco

Screen shot from: https://www.youtube.com/watch?v=oUvGoexmCqk

Yet we cannot expect these high-end solutions to be available everywhere anytime soon.
Mission-critical MTC reaches beyond city centres ….

A broader, *multi-network, multi-technology* approach is needed
6G White Paper on MTC:
*Predictability should be a key criteria for MTC service classes*

Adapted from Figure 8

**„Predictability“ determined by application**

- **uniform**: Cost-efficient, Well-planned MTC transmission patterns
- **Gauss**: Stochastic nature with "classical" distributions
- **Poisson**: Rare events without any obvious predictability
- **"unknown"**: Most challenging and costly

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6G White Paper on MTC:
Mission-Critical MTC Solution Components towards 6G

Mission-Critical MTC Mgmt. Function
- Dynamic Coexistence & Resource Assignment
- Operator-independent MC-MTC broker
- End-to-end admission control
- Digital twin of MTC device and network

Resource Awareness [Monitoring, Prediction]
- Spectrum
- Energy

Multi-X [Link, Band, RAT] Scheduling
- Multi-RAT
- Multi-Network
- Multi-Band

Programmable Wireless Environment
- Reconfigurable Intellig. Surfaces
- New Antenna Techniques
- Relaying Concepts

Based on Figure 9

Mission-Critical MTC Solution Components towards 6G

- **Mission-Critical MTC Mgmt. Function**
  - Dynamic Coexistence & Resource Assignment
  - Pro-active Mitigation of interference
  - End-to-end admission control

- **Cross-network MC-MTC broker**
- **Digital twin of MTC device and network**

- **Resource Awareness [Monitoring, Prediction]**
  - Spectrum
  - Energy

- **Multi-X [Link, Band, RAT] Scheduling**
  - Multi-RAT
  - Multi-Network
  - Multi-Band
  - Single network
  - strict partitioning
  - Time-Sensitive Networking
  - Semi-Persistent Scheduling

- **Programmable Wireless Environment**
  - Reconfigurable Intellig. Surfaces
  - New Antenna Techniques
  - Relaying Concepts

- **AI in MTC to uncover hidden characteristics**

Three potential multi-network solution approaches for mission-critical MTC

Do not treat all networks the same with a preplanned scheme, but learn from the actual, real-life behavior of each network to make opportunistic choices.

Do not trust a single public network, but combine independently planned public networks, and mix with private networks in order to instantly mitigate issues.

Do not trust statistics and learning from historical data, but run realistical models in parallel to the real-life execution to anticipate upcoming issues.

AI-enabled resource awareness and scheduling

Cross-Network MTC Broker

Real-time Predictive Network Twins
AI-enabled resource awareness and scheduling on **Client-side**

**ML-enabled opportunistic scheduling decisions**

- Learning the complex behaviour of mobile networks
- Flexible scheduling leads to **higher data rates**
- Additionally **lower battery consumption**
- Usable not only for Smart Phones, but also **tiny IoT devices**

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**Datarate prediction with passive indicators using Random Forests**

**Opportunistic choice of application-level scheduling using Reinforcement Learning**

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Dynamic Mixed-Critical Network Slicing

AI* enables tailored Network slicing for URLLC slices

Examples for 5G Network Slices

5G Service Dimensions:
URLLC – Ultra-Reliable Low Latency Communications
eMTC – evolved Machine-Type Communication
eMBB - enhanced Mobile Broadband

Without Slicing:
Latency requirement violated

- 97 %

Dynamic Slicing with AI:
Latency requirement fulfilled, yet more efficient

- 28 %

With static slicing:
Latency requirement fulfilled, yet inefficient

The SKATES approach: an example cross-network MTC broker

- Usage of multiple network links for increased reliability
- Multi-Connectivity implemented using MTPCP
- Wireguard based VPN for NAT traversal and firewall passing
- Open source extension to exploit multiple interfaces of MTPCP


The SKATES approach: Experimental evaluation of MTC broker concept

Independent MTC-Broker managing the following networking options:
- 2 public LTE
- 1 private long-range LTE
- 1 private SA 5G
- 1 WiFi6

In different configurations

October 2019 search and rescue exercise @ Baltic sea

October 2020 with 5G @ German Rescue Robotics Centre

March 2020 during COVID lockdown @ TU Dortmund


On-going: Real-time Predictive Digital Network Twins

Example: anticipate mobility to allow for mmWAVE beam selection and steering

Based on:
- Light-weight ICT-centric Mobility Simulation **LimoSIM**
- **Lean 3D channel model** derived from experiments
Summary

• Verticals requiring URLLC move towards 5G technology, yet in many cases various options for network design and operations are still considered…

• Potential solutions for mission-critical MTC towards 6G:
  • AI-enabled resource awareness
  • Mixed-critical AI-enabled scheduling for dynamic network slices
  • Cross-network MTC brokers supported by
  • Real-time Predictive Network Twins

Thank you very much for your attention!

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