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IKT-Tag

Cyber Physical Energy Systems-
Die Bedeutung zuverlässiger Kommunikationsnetze für das Smart Grid

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Cyber Physical *Energy* Systems

Smart Market

Liberalization of energy market:

- *Explosion of number of market participants → prosumers*
- *More competition*
- *Differentiated Pricing*

→ ***Production and demand needs to be balanced <u>at the end of the day</u>!***

→ ***Mainly background traffic***

Smart Grid

Physical transformation of energy systems

- *Explosion of number distributed energy resources*
- *Highly volatile energy production*

→ ***The „50-Hz beat“ needs to be maintained <u>at all times!</u>***

→ ***Partially critical foreground communication traffic***

Current hot topic: what are the right communication networking solutions for Cyber Physical Energy Systems?

Smart Market

Smart Meters

Virtual Power Plants

Smart Grid

Wide-Area Monitoring, Protection & Control (WAMPAC)

Specific challenges

Mass market → potentially every household → ***low cost (Smart Market)***

Extended coverage needed → ***even in basement***

Real-time Control → ***worst case boundaries (Smart Grid)***

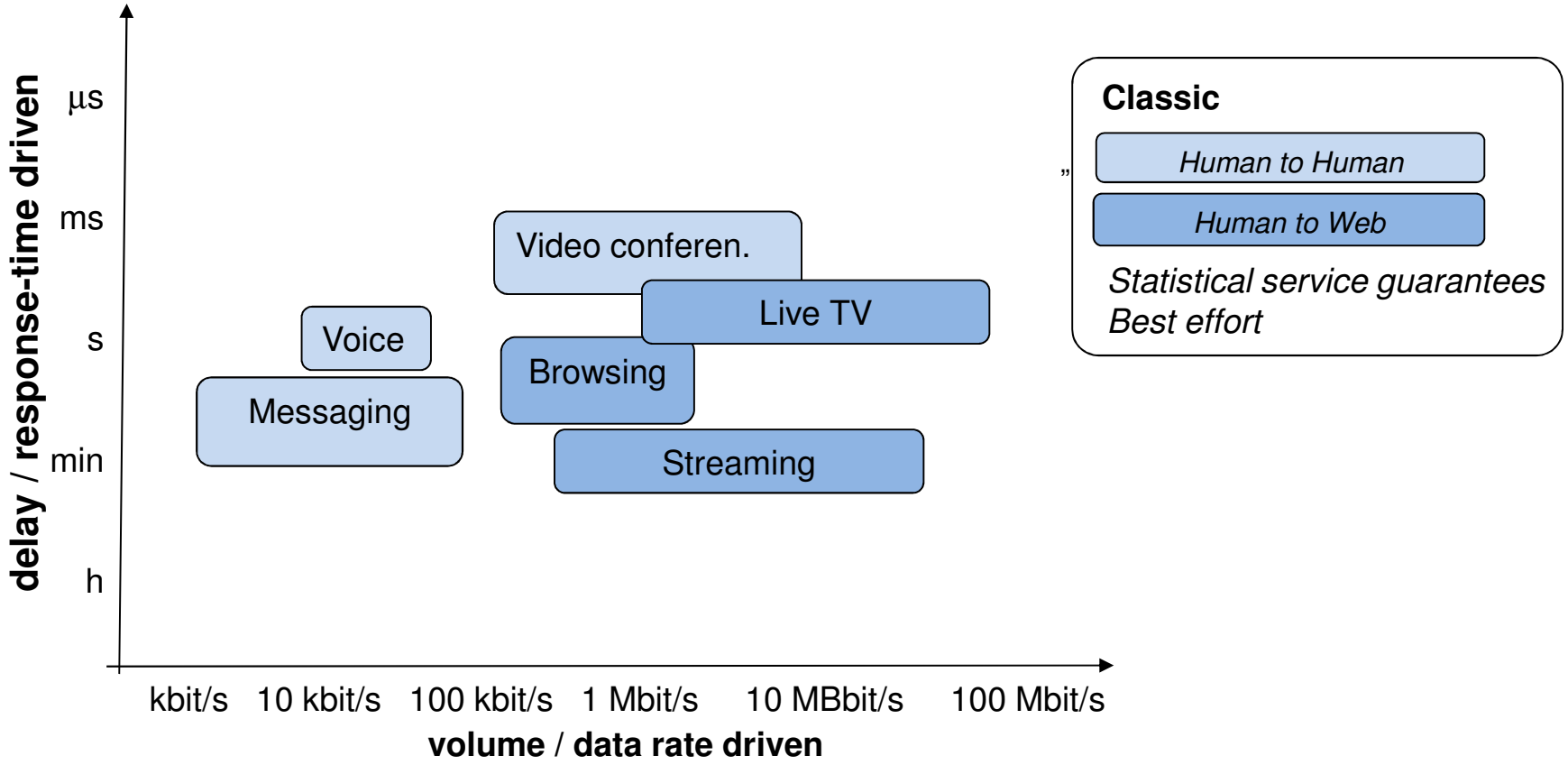
Blackout resilience → ***battery-buffered power supply for several hours***

Security constraints → ***no broadcast possible***

Long lifecycle → ***10-15 years***

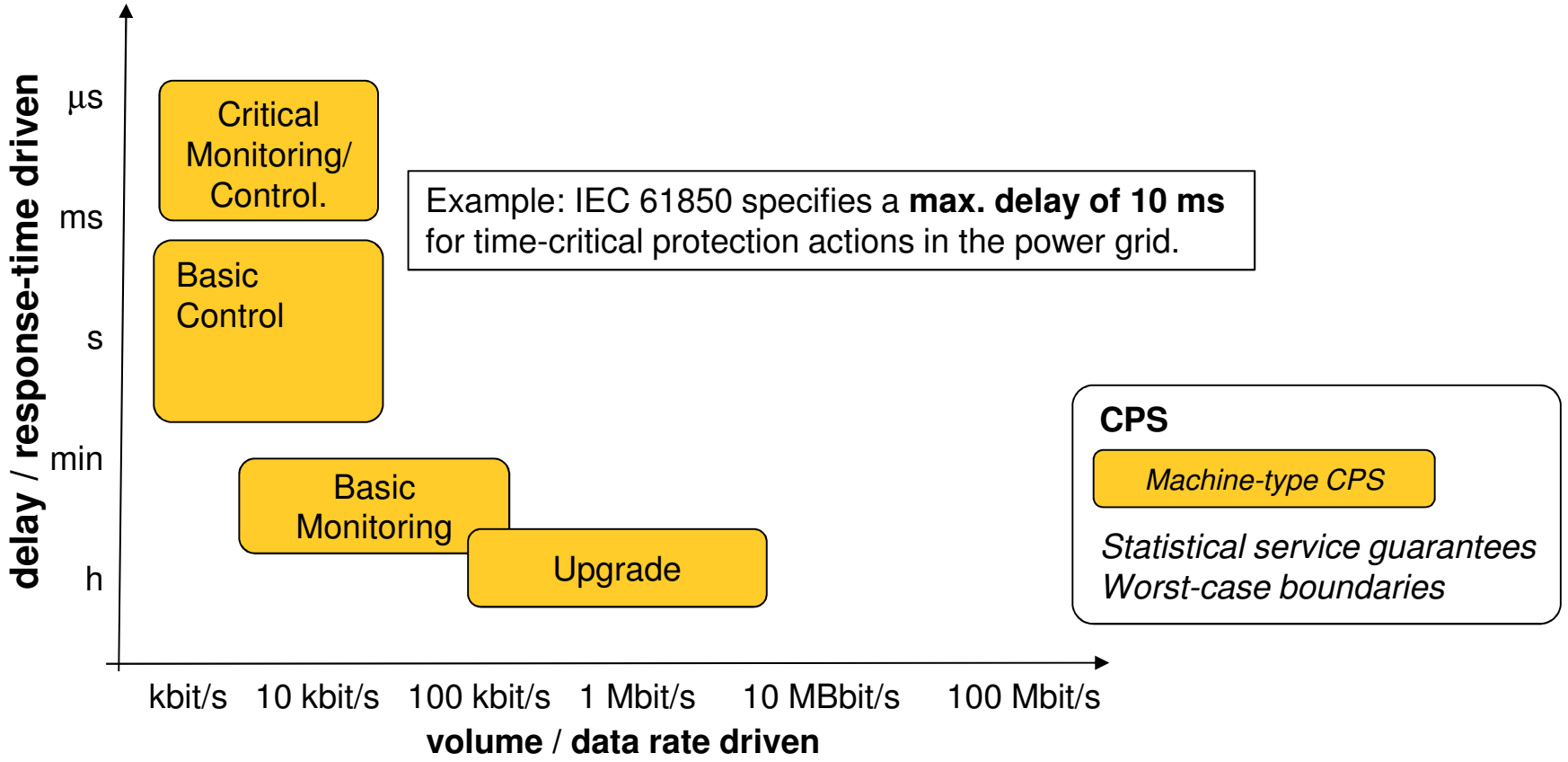
→ Which communication technologies are most suitable?

Human-to-Human/Web vs. Cyber Physical Systems services



- **Human-to-Human/-Web traffic mainly volumen/data rate driven**
- ***Best effort* plus *statistical service guarantees* are sufficient.**

Human-to-Human/Web vs. Cyber Physical Systems services

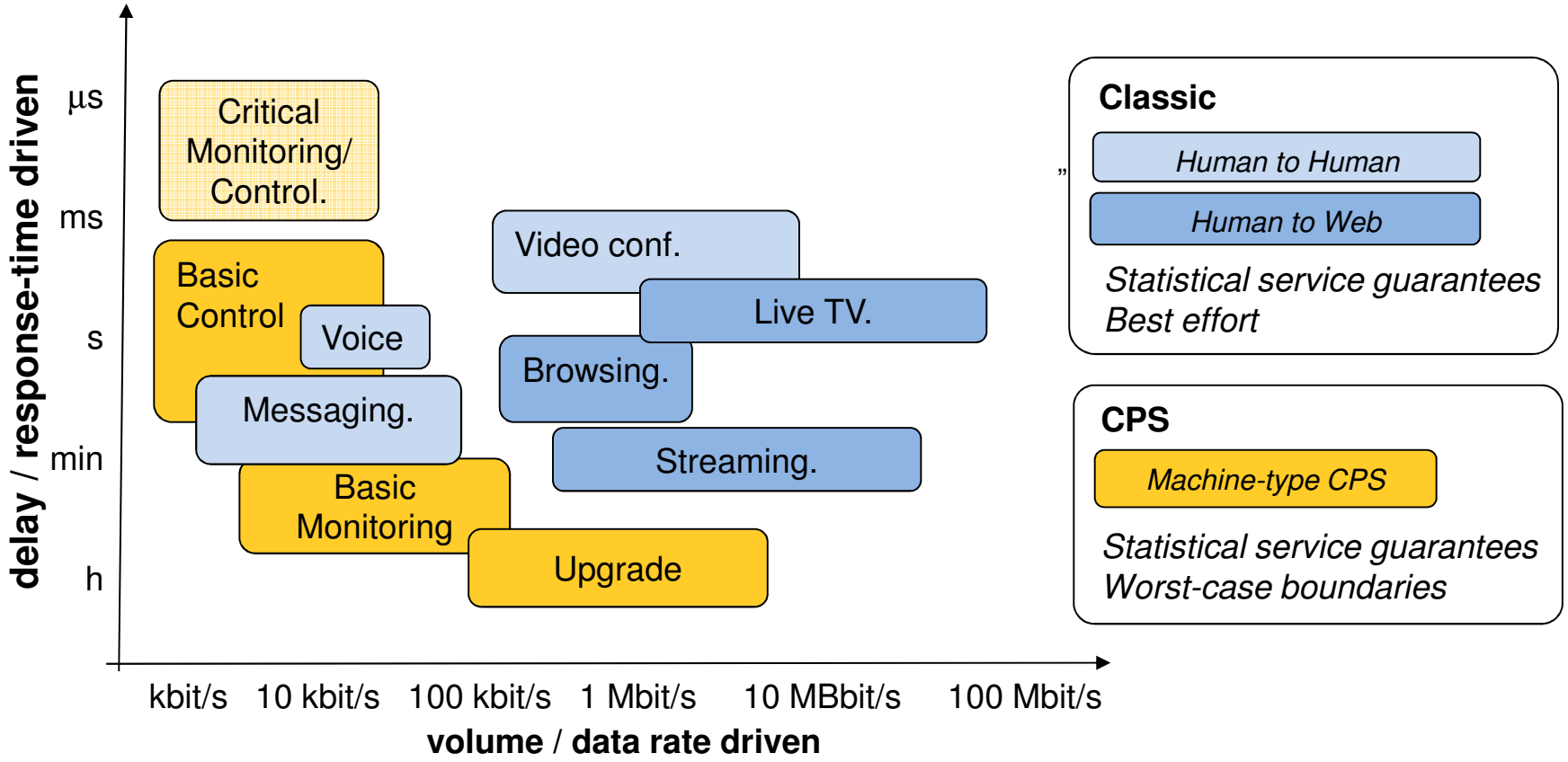


CPS traffic in parts also *volumen / data rate driven*,

but also *delay/response-time driven*

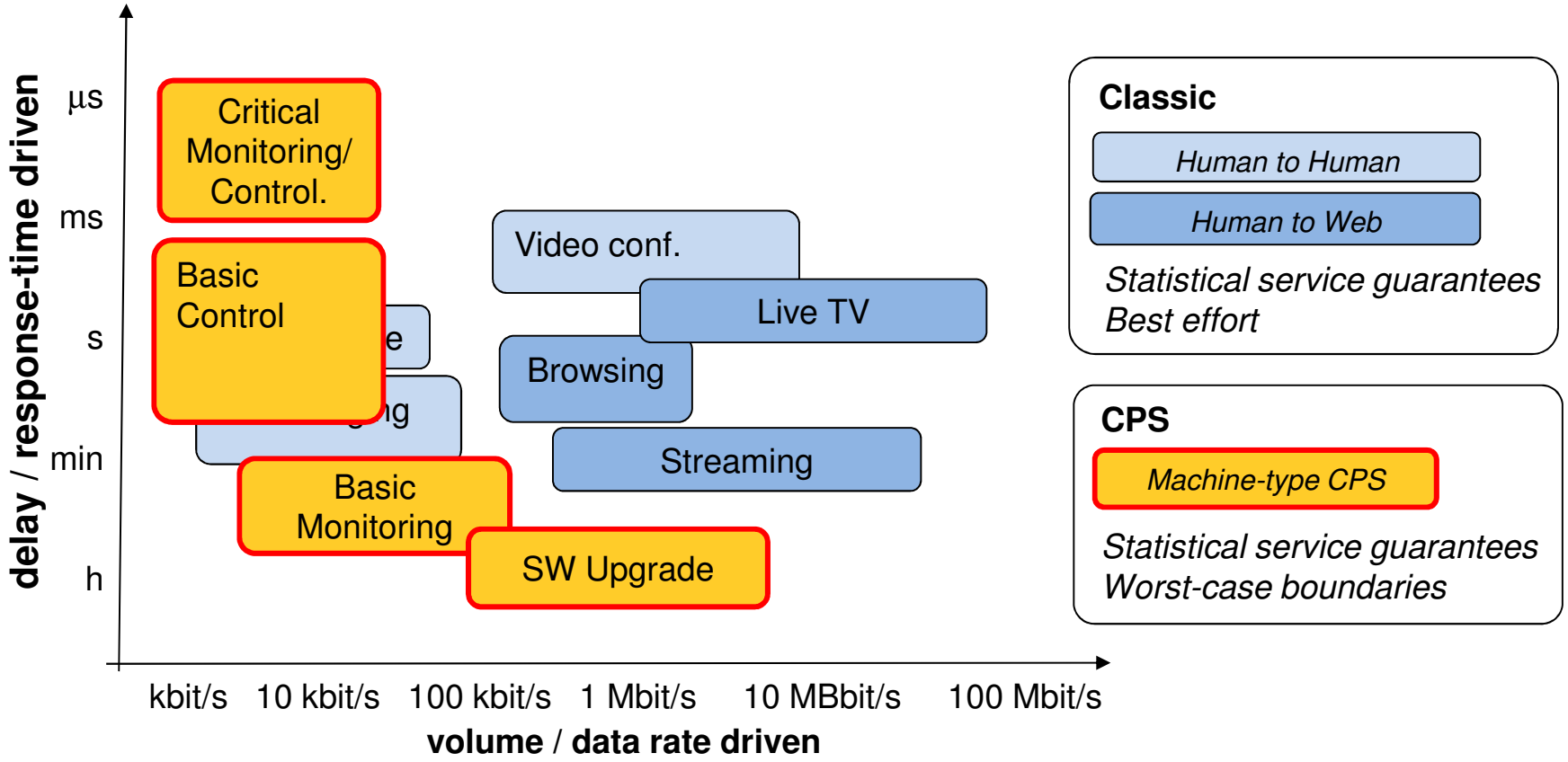
(plus *worst-case boundaries*)

Human-to-Human/Web vs. Cyber Physical Systems services



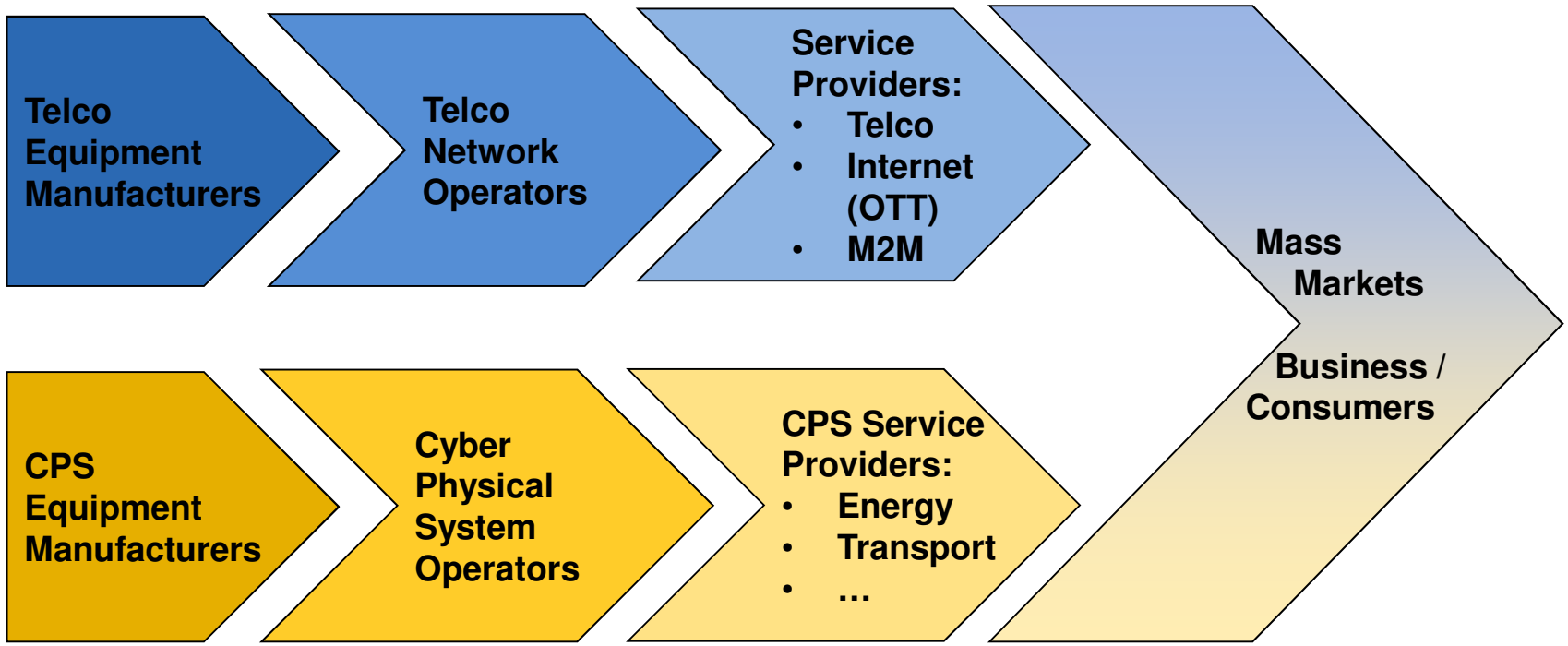
- CPS network infrastructures need to be **100% ready when needed**:
  - **Normal operation**: CPS Monitoring and Control in ***background***

Human-to-Human/Web vs. Cyber Physical Systems services



- CPS network infrastructures need to be **100% ready when needed**:
  - **Normal operation**: CPS Monitoring and Control in ***background***
  - **Incident mitigation**: CPS Monitoring and Control in ***foreground***

Two strong value chains meet with different expectations….



Different viewpoints:

- Telco industry may understand CPS operators as „another M2M customer“
- CPS operators understand telco services as „**essential component they need to fully control**“ in order to run their systems properly….

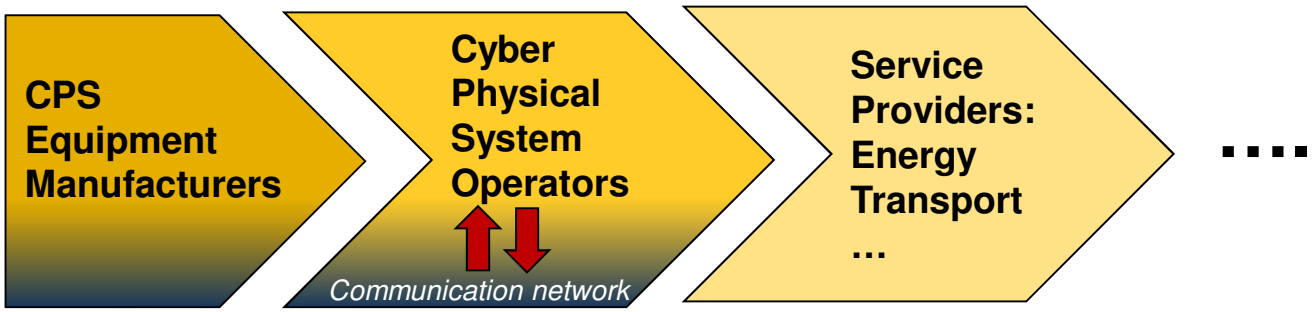
Control: *Service priorities, QoS guarantees, network planning, life-cycle support, etc.*

CPS operators face a „Make or Buy“ decision

CPS operators take over the control

Telecommunication network operated by CPS operator himself (or subcontracted)

MAKE

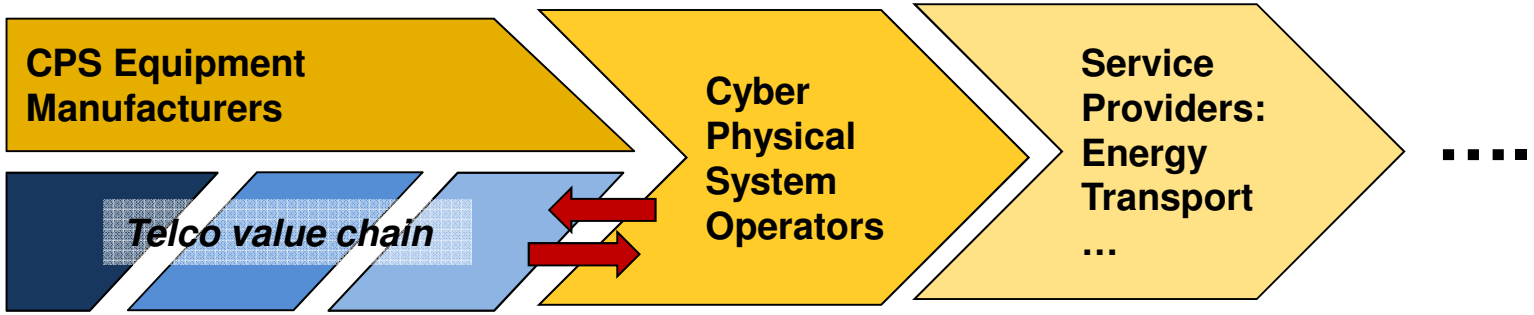


vs.

CPS operators relies on control interfaces offered by telco networks

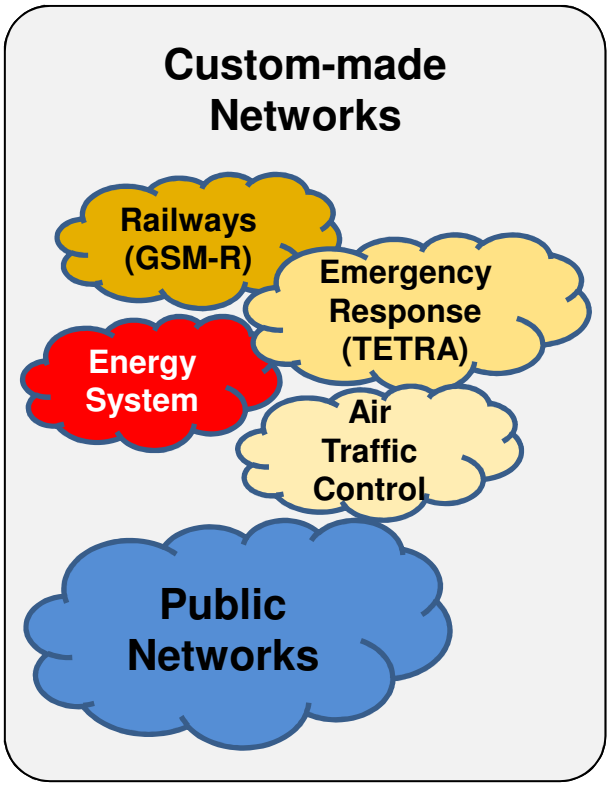
Telecommunication services provided by telco service provider

BUY



Control: *service prioritization, QoS guarantees, life-cycle support, etc.*

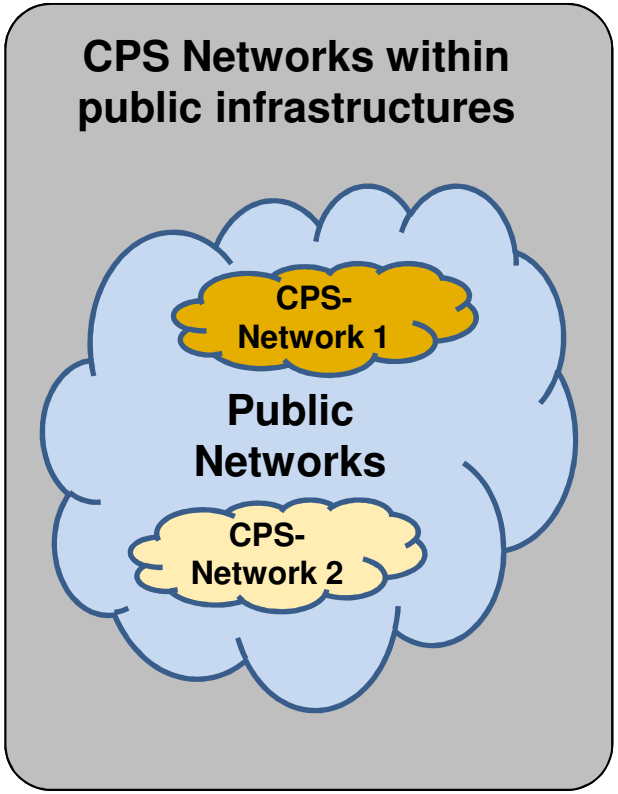
Network Realization Options for CPS applications (1)



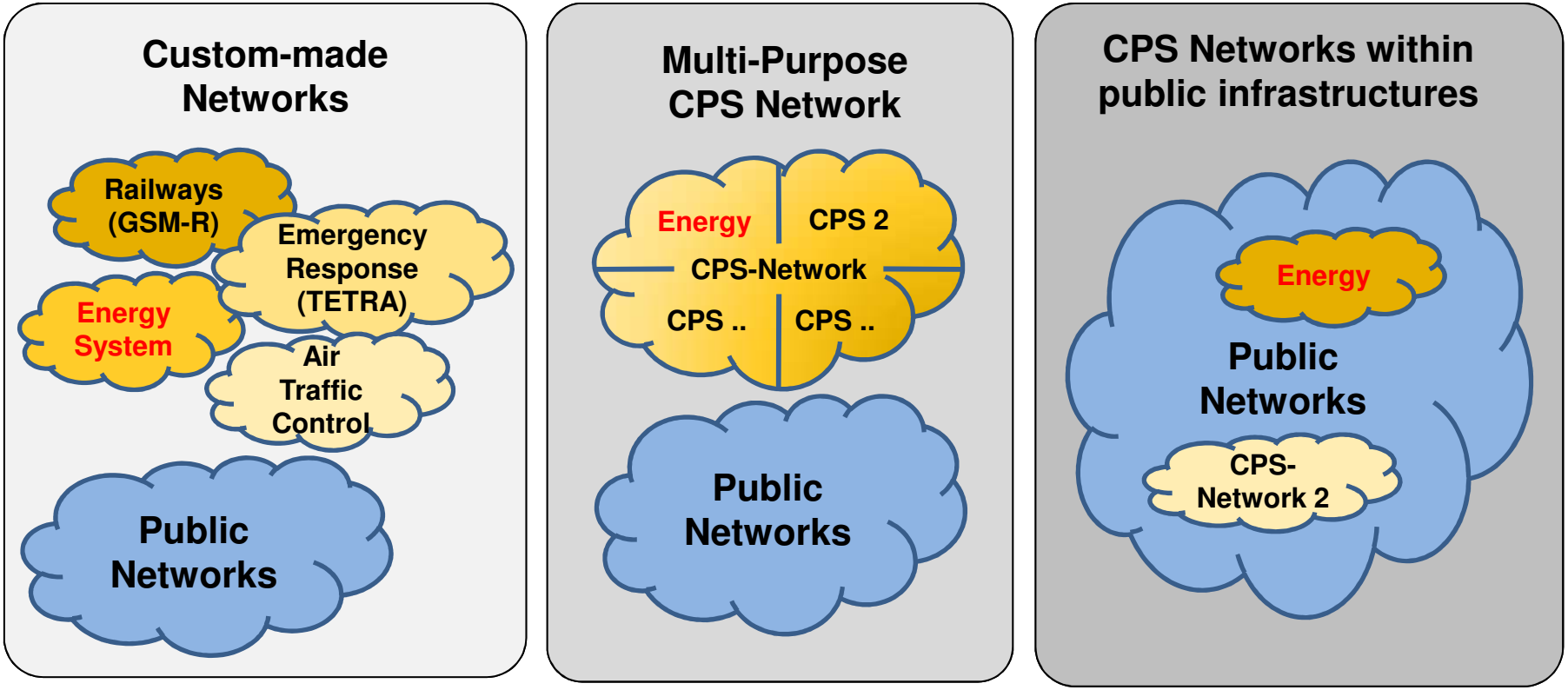
- **Traditional option: built and operate own network:**
  - Separate frequency bands
  - Partially: entirely own technology (TETRA) or technology adaption (GSM-R)
- **Lessons-learned:**
  - ☺ **Technically feasible**
  - 😐 **Implicit security value-add:** details of technology implementation known only by few specialists
  - ☹ **Slow integration of State-of-the-Art**
  - ☹ **Coverage limitations:** public networks still used in addition to dedicated network
  - ☹ **Economic issues:**
    - Market size
    - Costs

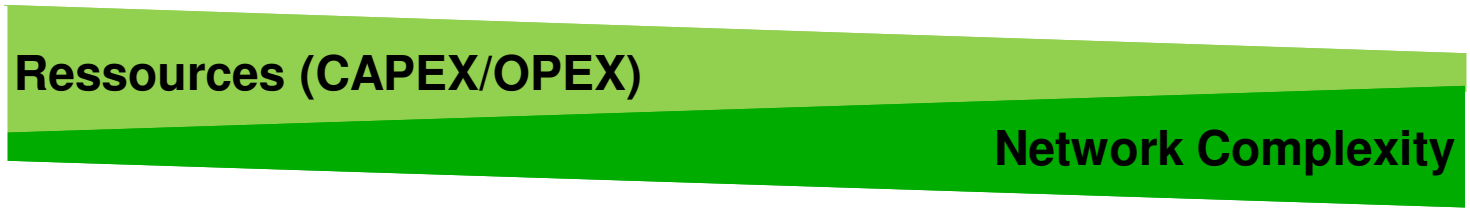
Network Realization Options for CPS applications (2)

- **Options for the future:**
  - **Leverage main-stream** networking technologies, i.e. LTE
  - **Complement features** where needed to meet additional requirements plus hardening
- **Manage interdependence between „classic“ H2H/H2W and CPS traffic:**
  - **Dedicated CPS QoS support**
    - Statistical service guarantees
    - Issue: Trust of CPS operator
  - **Use exclusive physical resources**
    - Clean solution
    - Issues: Spectrum limitations, Economic viability
  - **Leverage virtualization technologies**
    - Enables trade-off between ressource-efficiency and effective QoS guarantees
    - On-going development



Network Realization Options for CPS applications





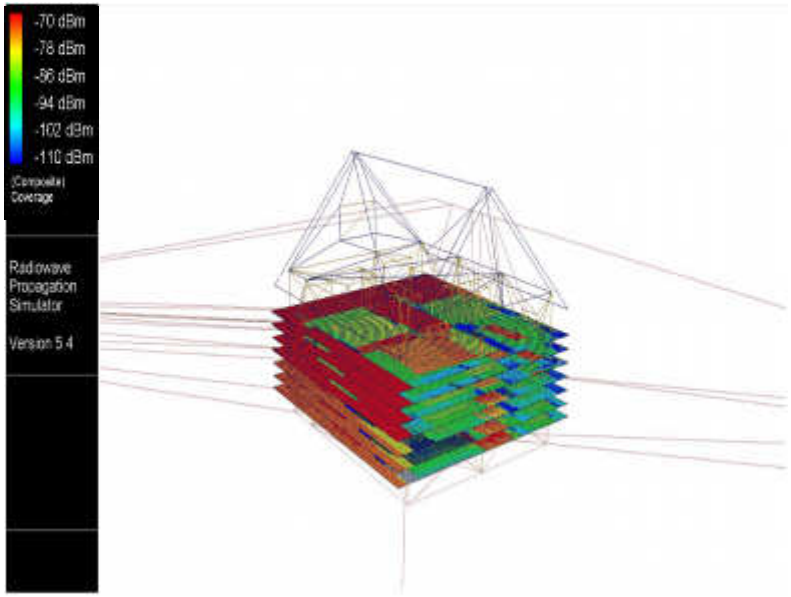
Solution approaches for Cyber Physical Energy Systems

- **Power Line Communications:**
  - Leverages existing power line infrastructure → full control
  - Large-scale Smart Meter deployments (e.g. in Italy)
  - Issues: interference, capacity, *coverage* (especially in rural areas)
  - New OFDM-PLC standard (G3) / Broadband PLC address some issues
- **2G-Cellular Systems**
  - Almost 100% outdoor coverage → suited for rural areas
  - Issues regarding indoor/ basement coverage and *capacity*
  - Long-term availability → Dependency on overall telco business case
- **Dedicated networks in sub-GHz bands (CDMA, TETRA, Mesh)**
  - Full control of network deployment
  - Larger-scale deployments in place
  - Issues: License ownership (country-specific rules), long-term availability of technology, *capacity*

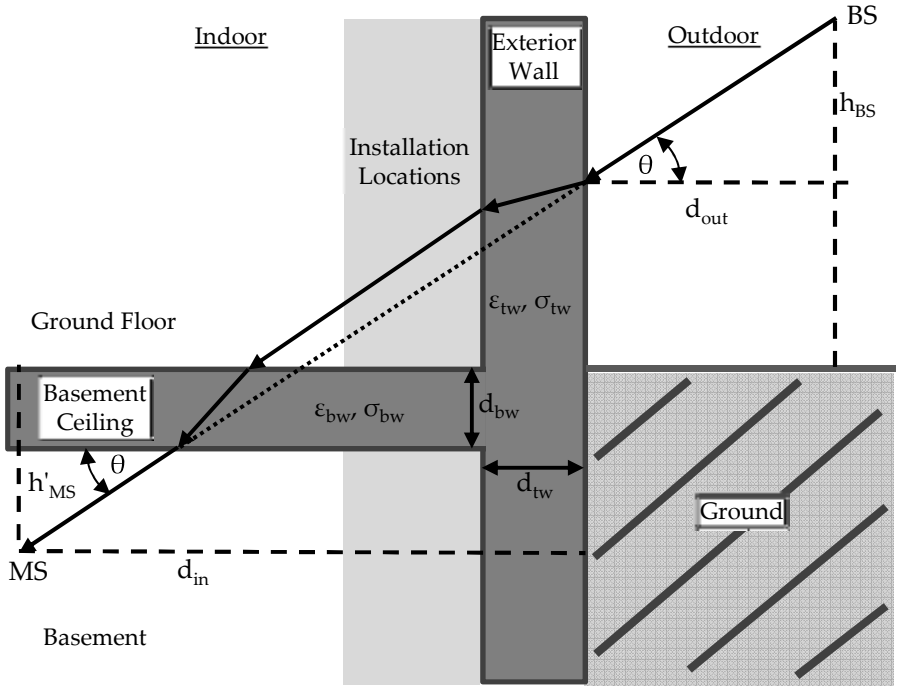
How can LTE fit in?

LTE can provide capacity and coverage with long life cycle ahead

Channel model extensions for basement coverage analysis (1)



Small Scale Scenario (House)

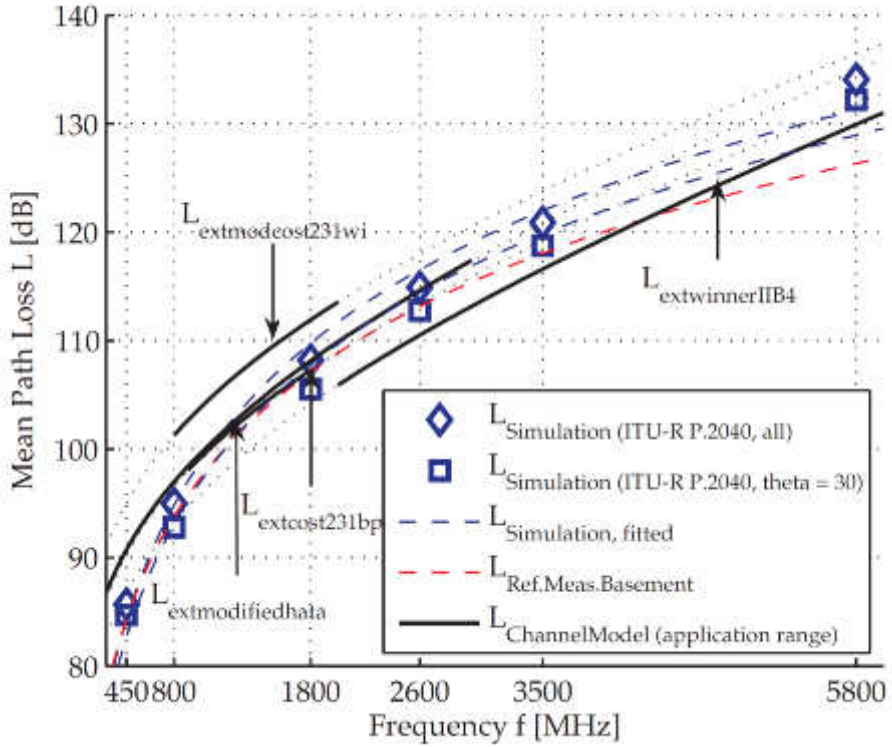


Extended Channel Propagation Modeling for new scenarios

- Performance evaluation of wireless technologies for smart metering and demand side management based on ray tracing analysis and radio propagation channel models for building penetration
- Proposed extensions depending on *base station height*, *carrier frequency* and *basement ceiling characteristics*

C. Hägerling, C. Ide and C. Wietfeld, "Coverage and Capacity Analysis of Wireless M2M Technologies for Smart Distribution Grid Services", 5th IEEE International Conference on Smart Grid Communications (SmartGridComm 2014), Venice, Italy, Nov. 2014.

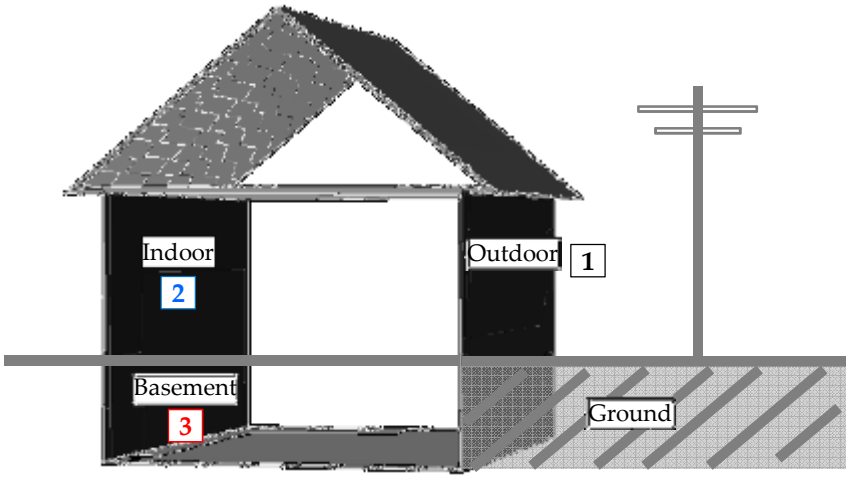
Channel model extensions for basement coverage analysis (2)



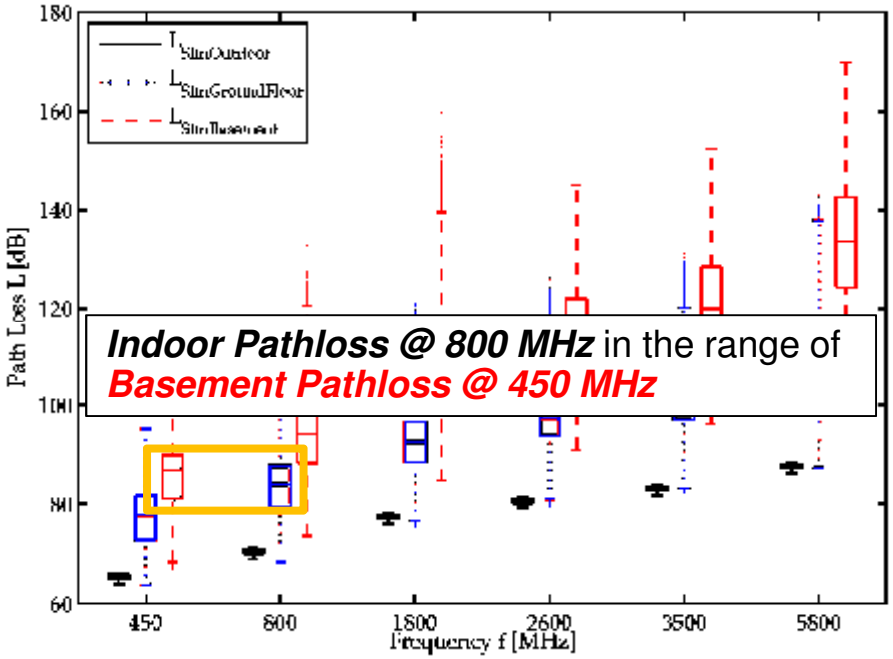
- Extensions of radio propagation channel models (HATA, WINNER, etc.) for building penetration, especially *deep indoor* and *basement coverage*
- Validation with simulation (raytracing) and measurements

C. Hägerling, C. Ide and C. Wietfeld, "Coverage and Capacity Analysis of Wireless M2M Technologies for Smart Distribution Grid Services", 5th IEEE International Conference on Smart Grid Communications (SmartGridComm 2014), Venice, Italy, Nov. 2014.

Quantification of coverage advantages at 450 MHz



Installation Scenarios Smart Grid Devices



Building Penetration Path Loss (Outdoor/Indoor/Basement)

- GHz-bands not suitable for basement coverage
- Using the 450 MHz means (compared to 800 MHz):
  - No new BS sites needed (reuse existing base station sites) *or*
  - 60% less base stations

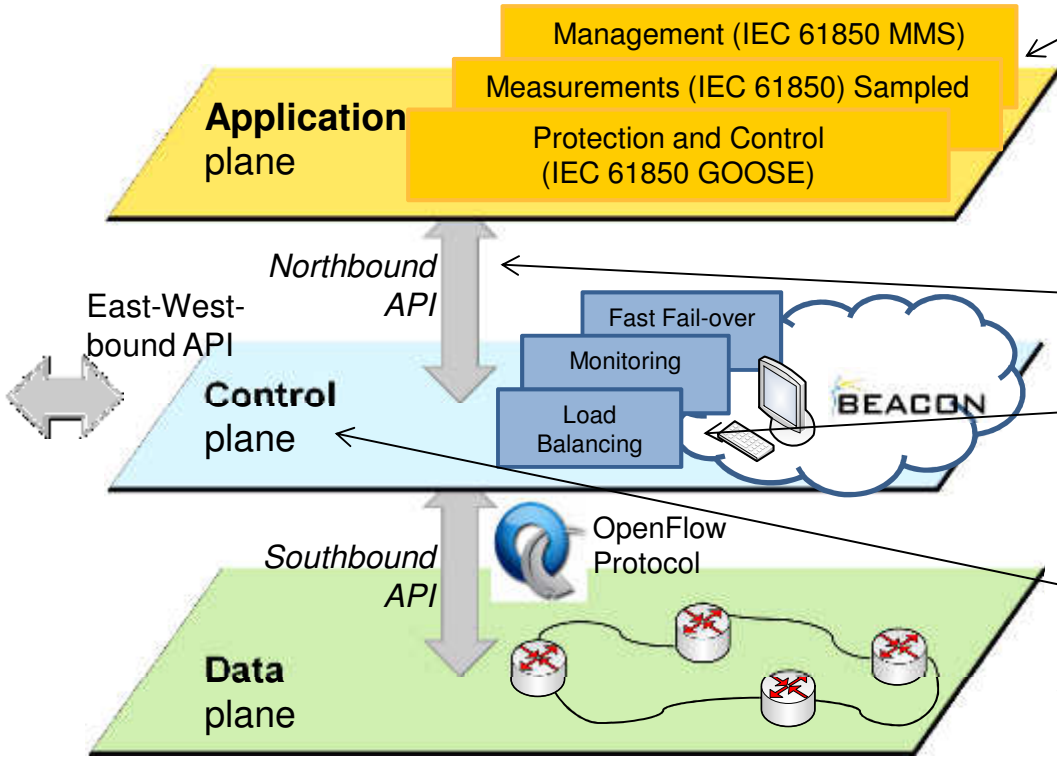
C. Hägerling, C. Ide and C. Wietfeld, "Coverage and Capacity Analysis of Wireless M2M Technologies for Smart Distribution Grid Services", 5th IEEE International Conference on Smart Grid Communications (SmartGridComm 2014), Venice, Italy, Nov. 2014.

LTE standardization targets CPS-friendly features (Rel 12)

- **Low-cost implementations for MTC:**
  - Massive MTC connections with reduced signaling overhead for frequent transmissions
- **Link budget enhancements for indoor penetration (up to 20 dB)**
  - Time diversity (→ low data rates)
  - Extensive HARQ
  - Power boosting
- **Improved system capacity**
  - Higher order modulation schemes (up to 256 QAM)
  - 3D MIMO beam forming
  - Carrier aggregation to up to 450 MHz
  - Enhancement for Coordinated Multi-Point (eCoMP) to improve the cell edge data rate

SDN-based *Industrial Internet* for *Smart Grids*

Work of DFG Research Group 1511 „Protection and Control Systems for Smart Grids “ and the EU-FP7-Project *SmartC2Net*



IEC 61850–Smart Grid Communications:
- Monitoring
- Control
- Real-time constraints (ms)

New *Northbound Interface*
→ Smart Grid specific *Flows* with differentiated QoS characteristics

SDN Controller
executes ressource reservations and error handling in a self-organized way [1]

Virtualization of *SDN Controllers* *in Edge Cloud* → high availability [2]

Validation with hybrid Energy and Communication System Simulation [3] and interdisciplinary test beds [1]

[1] Dorsch, N., Kurtz, F., Georg, H., Hägerling, C. and Wietfeld, C. "**Software-Defined Networking for Smart Grid Communications: Applications, Challenges and Advantages**", 5th IEEE International Conference on Smart Grid Communications (SmartGridComm 2014), Venice, Italy, Nov. 2014.

[2] N. Dorsch, B. Jablkowski, H. Georg, O. Spinczyk and C. Wietfeld, „**Analysis of Communication Networks for Smart Substations Using a Virtualized Execution Platform**“, IEEE International Conference on Communications (ICC), Sydney, Australia, Jun. 2014.

[3] Georg, H., Müller, S.C., Rehtanz, C. and Wietfeld, C., "**Analyzing Cyber-Physical Energy Systems: the INSPIRE Co-Simulation of Power and ICT Systems Using HLA**", IEEE Transactions on Industrial Informatics, vol. PP, no. 99, Jun 2014.

Conclusions

- Cyber Physical Energy Systems push requirements for **real-time, highly reliable communication services to a new limit**
- **Smart Grid operators demand control** of communication networks and their long-term evolution as mission-critical component of their infrastructure
- **LTE at subGHz (450 MHz)** is a strong candidate to provide sustainable wireless solutions for Cyber Physical Energy Systems
- CPS-specific LTE implementations focus on **reliability** and **QoS** and not on volume only
- **SDN** technologies are a candidate to provide appropriate control interfaces to CPS operators

Thank you very much for your attention!

Looking forward to your questions!

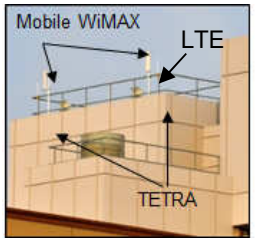
- **Acknowledgement:**
  - FP7 Project SmartC2Net
  - DFG Research Group FOR 1511
  - DFG SFB 876

- **Contact:** christian.wietfeld@tu-dortmund.de

TU Dortmund's ComNets Institute (CNI) in a nutshell

- **Team of 20+ full-time researchers** and 30 students (75 % third party funded)
- Research focus: **highly reliable wireless networks for Cyber Physical Systems** (MAC-App) in energy, transport and production/logistics

- **Model-driven** research methodology:
  - **Interdisciplinary, cross-layer** system modelling and **multi-scale system simulation**
  - **Sophisticated Lab** (2G-4G network emulators, wireless channel emulators, SDR, SDN) and **Outdoor Testing Site** with research licenses at 400MHz to 2,6 GHz



- On-going contributions to **standardization** (IETF, ISO/IEC) and **open source** projects (Omnet)
- Since 2008: 7 Int'l „Best Paper" Awards
- Award-winning **spin-off** comnovo (SME)

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