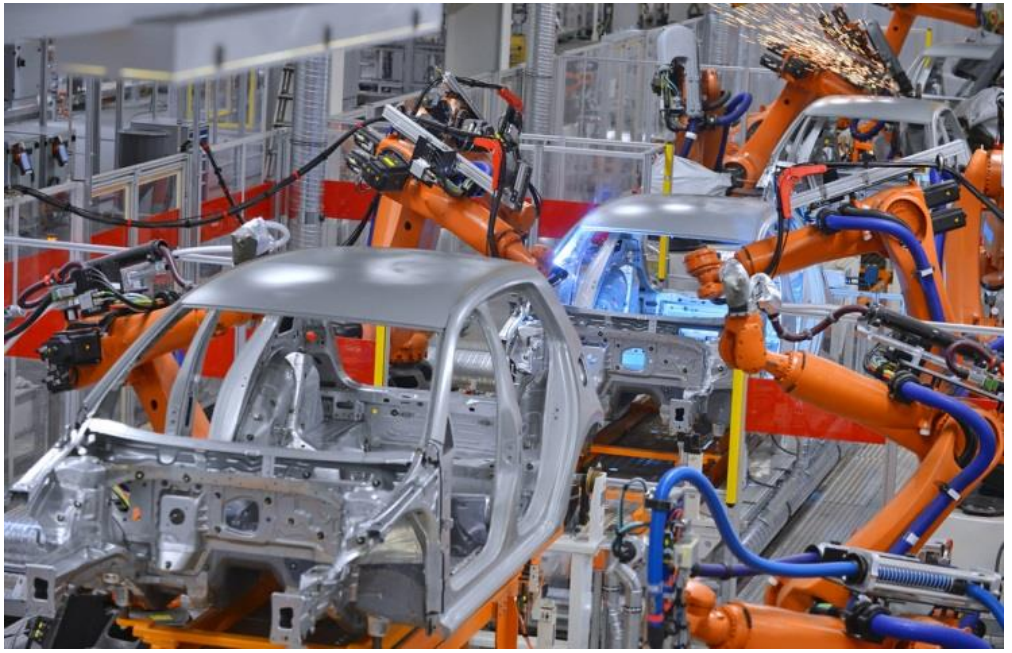
PERFORMANCE ANALYSIS OF WIRELESS INDUSTRIAL NETWORKS – CHALLENGES AND TRENDS

Neda Petreska

ETAI 2018

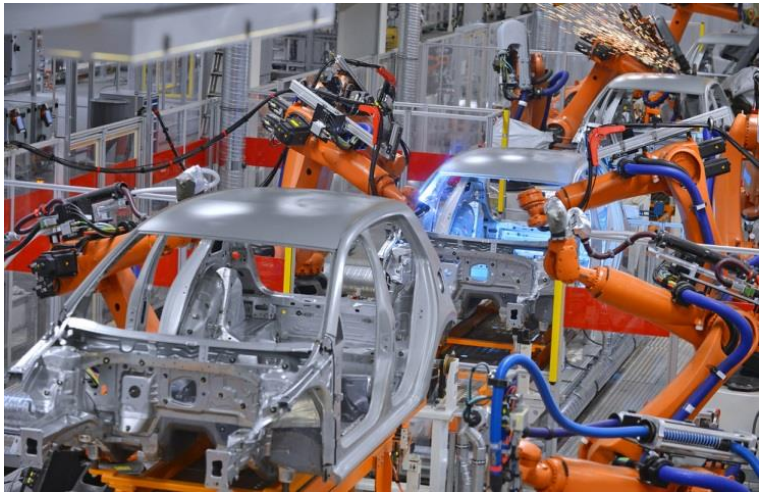
Struga, 21.09.2018



Fraunhofer ESK

Benefits of Wireless in Industrial Automation

- Fast installation
- Hardly accessible areas
- Flexibility and maintenance
- Moving machines and machine parts



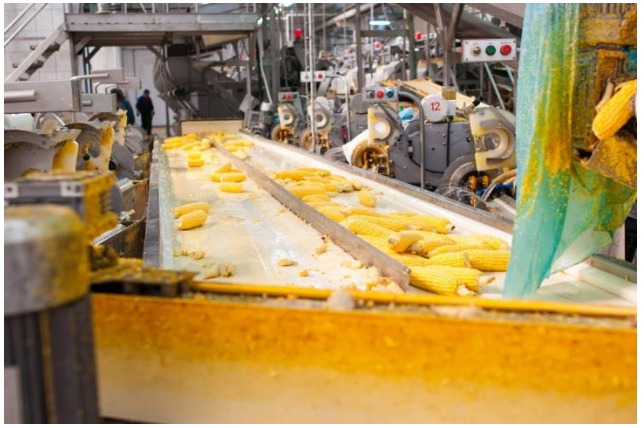
Source: www.bildagentur.pantermedia.net

Smart Manufacturing

- Slip rings
- Food industry
- Chemical processes and dangerous areas

© panthermedia.net / 06photo

© panthermedia.net / monstArrr



© panthermedia.net / kreatorex

Fraunhofer ESK

Requirements

- Coexistence with other wireless networks and technologies
- Energy efficiency, long battery life
- Enhanced coverage → multi-hop communication

Requirements

- Coexistence with other wireless networks and technologies
- Energy efficiency, long battery life
- Enhanced coverage → multi-hop communication

Application type	Latency	Outage Prob.	Technology
Process automation	50 ms – X s	> 10^{-5}	WirelessHART, ISA100.11a
Augmented reality	10 ms	10^{-5}	WLAN, LTE
AGV	15-20 ms	> 10^{-6}	LTE
Factory automation	1-10 ms	10^{-9}	Wireless IO Link
Functional safety	10 ms	10^{-9}	Wireless IO Link

“Funktechnologien für Industrie 4.0”, VDE Positionspapier, 2017

Challenges

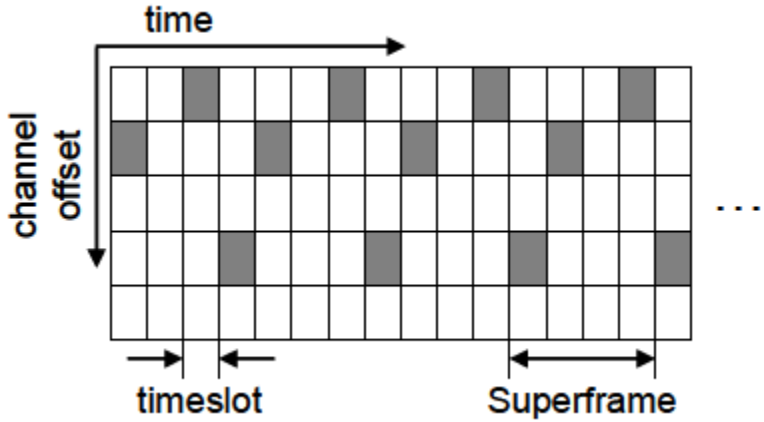
- Express the end-to-end delay violation probability of wireless industrial networks
  - Multi-hop networks ⇨ end-to-end performance guarantees
  - Analytical definition
  - Consider fading and queueing effects
  - Enable coexistence
- Which methods should be used?
- How well do these methods perform?
- Can we provide optimal resource allocation?
- Does the analytical optimum resemble the real system optimum?

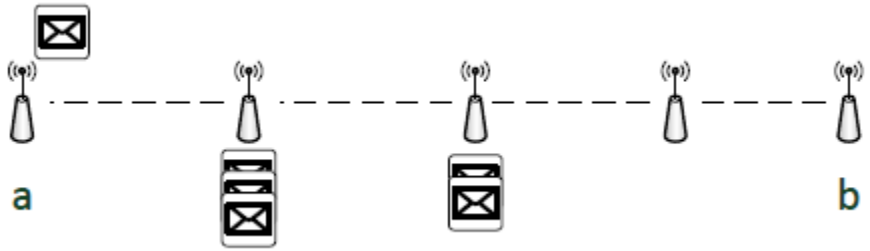
System Model

- Multi-Hop Path
- IEEE 802.15.4 PHY
- IEEE 802.15.4e TSCH MAC:

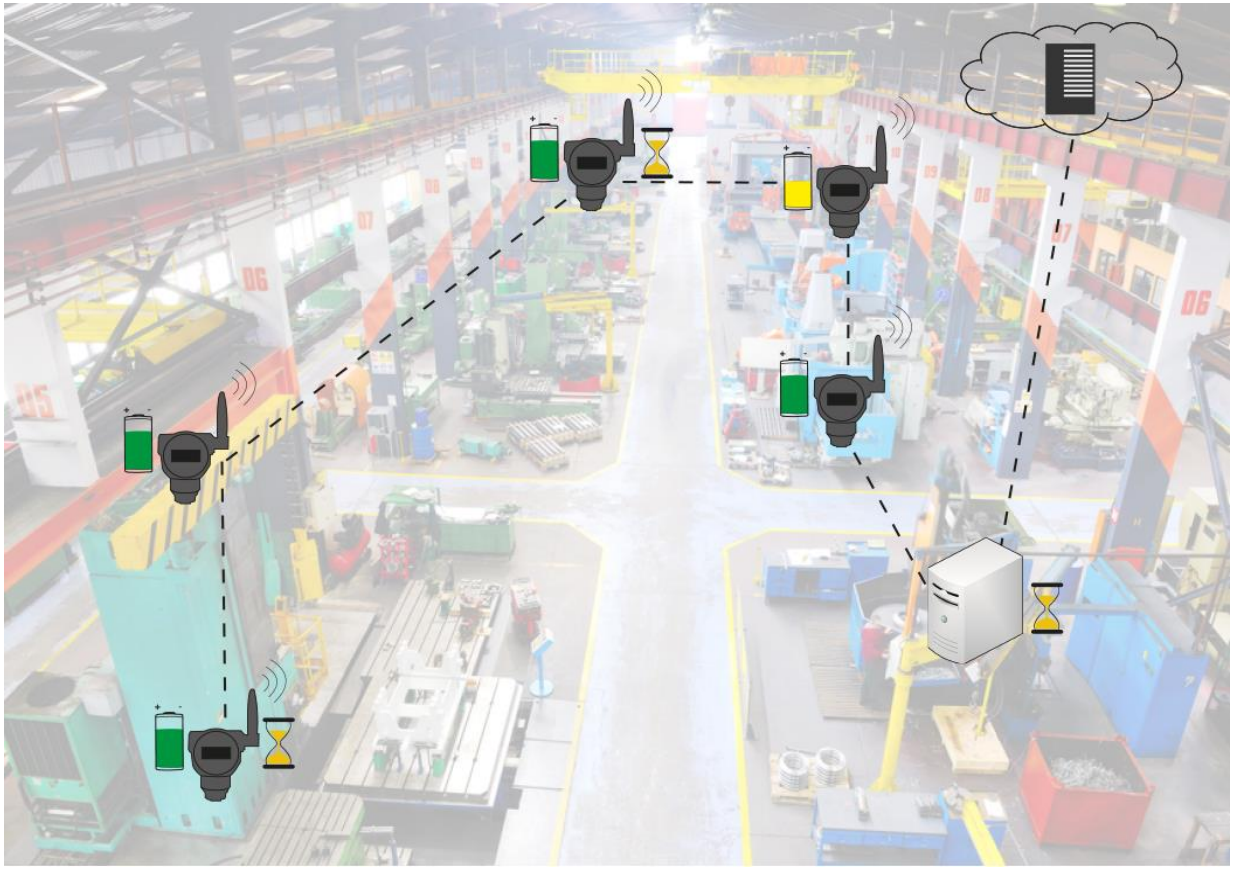
  Time Synchronized Channel Hopping
- Block fading channels with statistically independent, but

  non-identically distrbuted channel gains



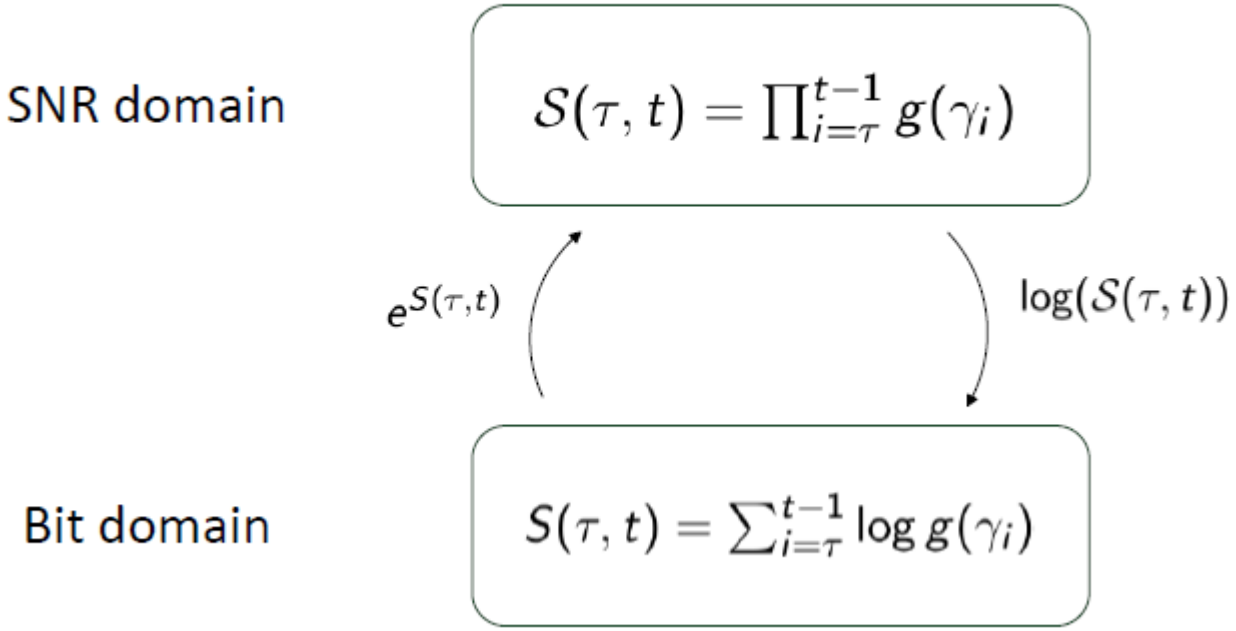


Example: Monitoring Application



Fraunhofer ESK

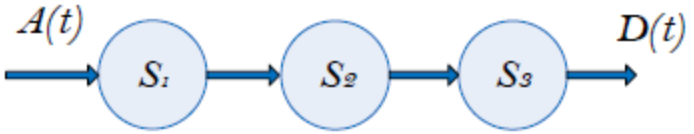
Service Curve in the SNR Domain



H. Al-Zubaidy, J. Liebeherr, A. Burchard, "Network-Layer Performance Analysis of Multihop Fading Channels", IEEE/ACM Transactions on Networking, 2014

End-to-End Delay Bound

$$\mathbb{L} = \{1, 2, 3\}$$



Probability, that the target end-to-end delay w is violated:

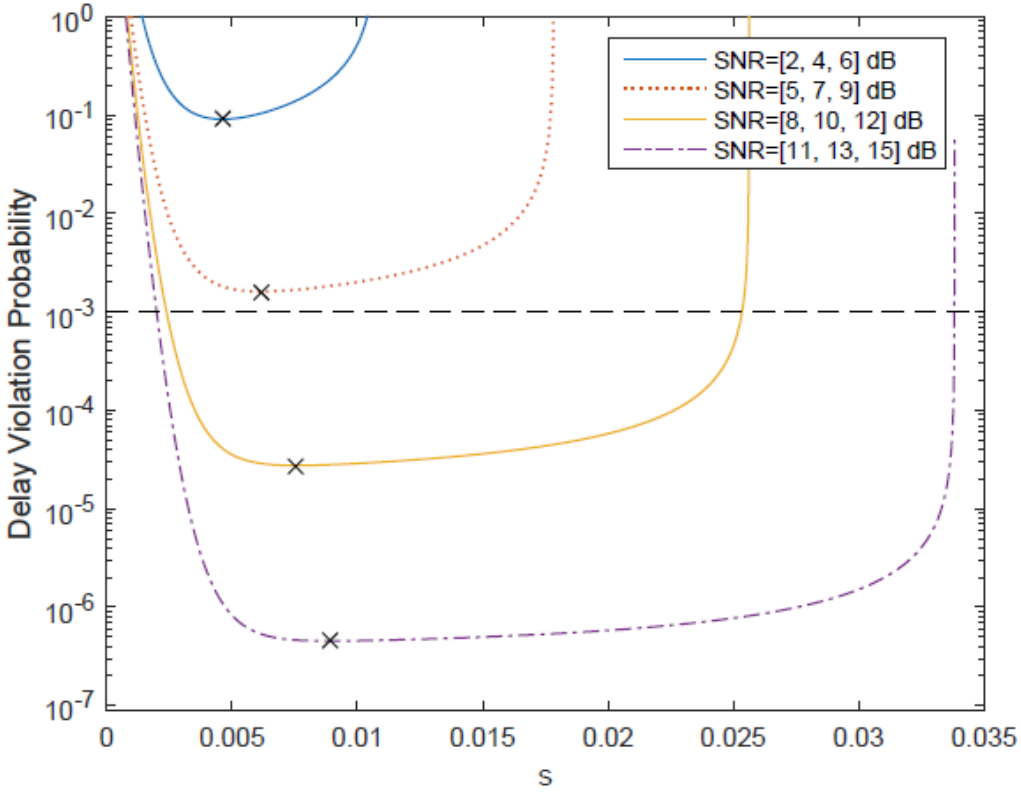
$$\mathcal{K}^{\{1,2,3\}}(w) = \frac{S_2}{S_2 - S_3} \cdot \mathcal{K}^{\{1,2\}}(w) + \frac{S_3}{S_3 - S_2} \cdot \mathcal{K}^{\{1,3\}}(w)$$

Kernel of a 3-hop path

Service curve of link 3

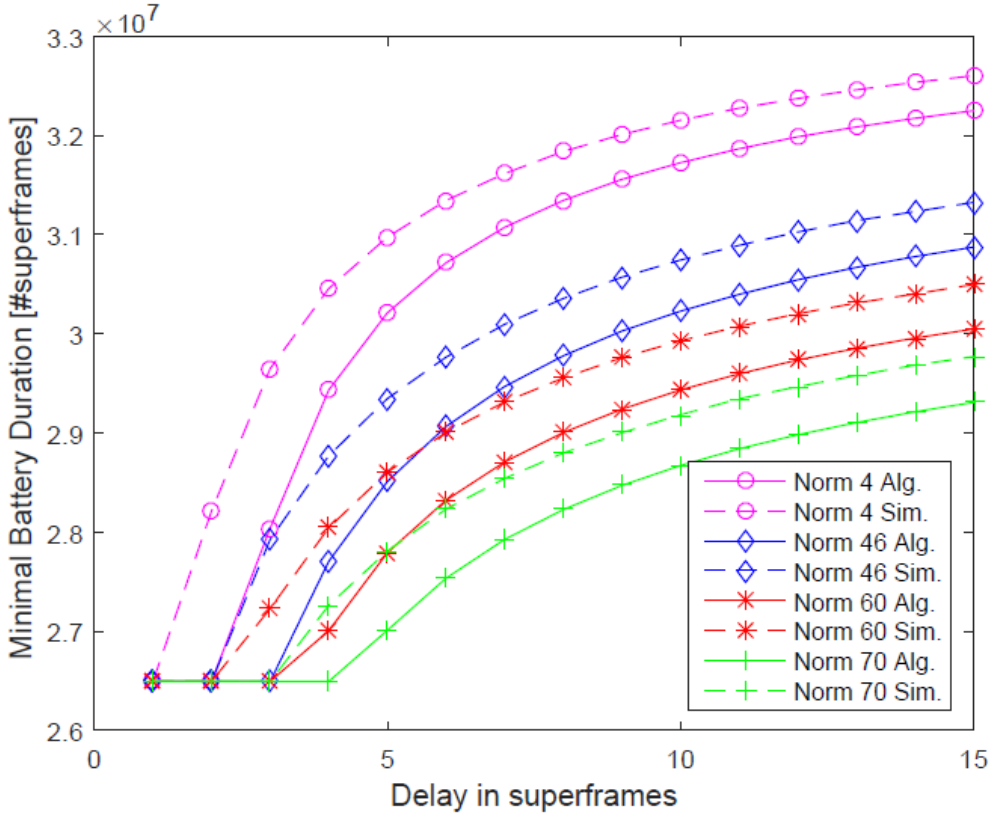
N. Petreska, H. Al-Zubaidy, J. Gross, "On the Recursive Nature of End-to-End Delay Bound for Heterogeneous Wireless Networks", IEEE International Conference on Communications, 2015

Convex Delay Bound in IEEE 802.15.4e-based Networks



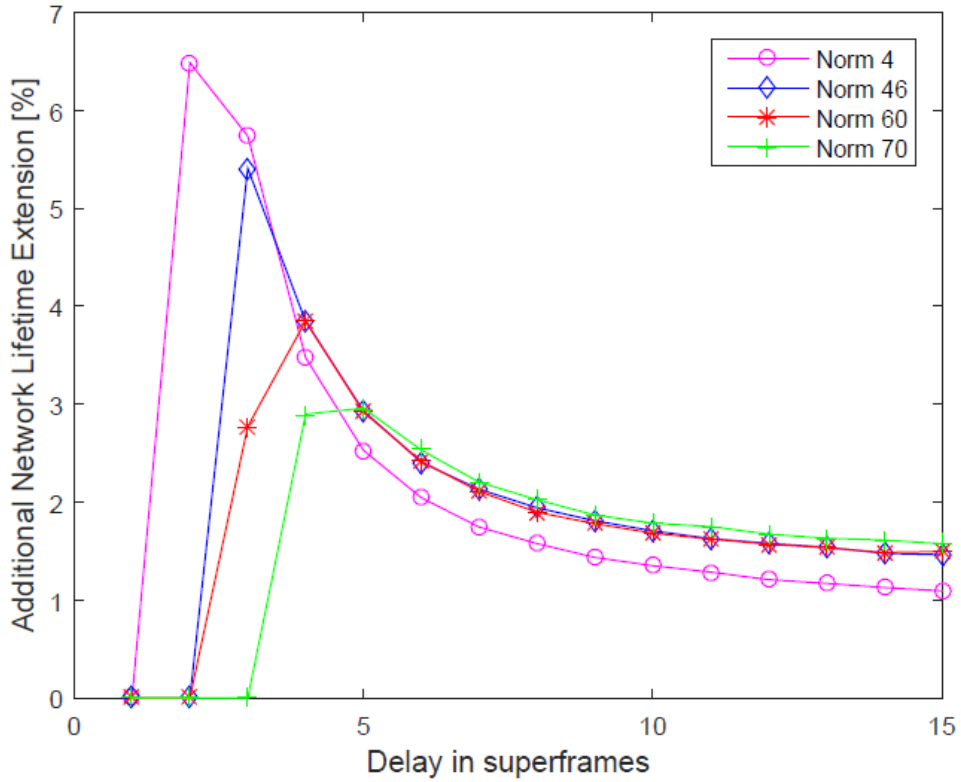
N. Petreska, "End-to-End Performance Analysis of Industrial IEEE 802.15.4e-based Networks", Fachgespräch für Sensornetze, 2017

Bound-Based vs. Real System Optimum



N. Petreska, H. Al-Zubaidy, J. Gross, "Bound-Based Power Optimization for Multi-Hop Heterogeneous Wireless Industrial Networks under Statistical Delay Constraints", to appear in Computer Networks, 2018

Additional Lifetime Extension



N. Petreska, H. Al-Zubaidy, J. Gross, "Bound-Based Power Optimization for Multi-Hop Heterogeneous Wireless Industrial Networks under Statistical Delay Constraints", to appear in Computer Networks, 2018

Outlook

- Performance analysis is an important and necessary step in the process of network design and planing of industrial networks
- The presented research enables optimal resource allocation while providing statistical delay guarantees
- Current work
  - Routing algorithm with performance guarantees
  - Project ZEPOWEL: Build a multi-hop network prototype with Contiki OS using the TSCH MAC mode. Minimize transmit power along the path.
- Further research topics
  - Transient analysis
  - Integrate machine learning concepts

Zolertia motes