Algorithms for Optimal Power Allocation of Wireless Multi-Hop Heterogeneous Networks under Statistical Delay Constraints

Neda Petreska
(joint work with J. Gross and H. Al-Zubaidy)

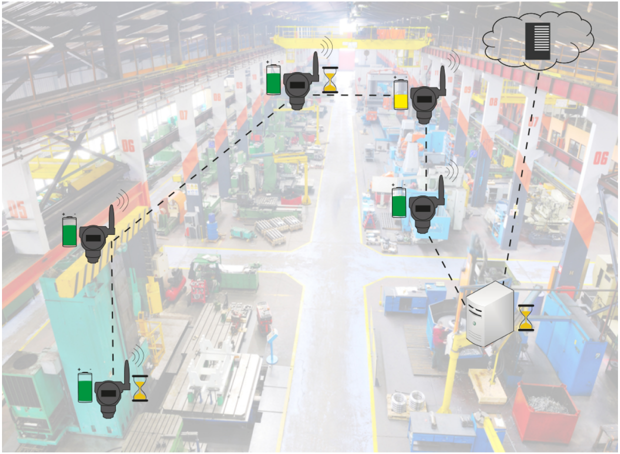
Fraunhofer Institute for Embedded Systems and Communication Technologies ESK

WoNeCa 2018

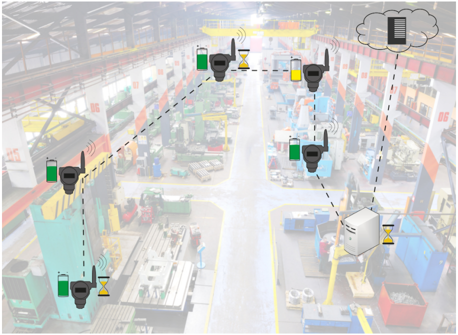
Erlangen, 28.02.2018

Fraunhofer ESK

Wireless Industrial Sensor Networks



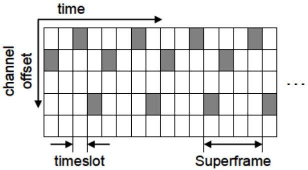
Wireless Industrial Sensor Networks

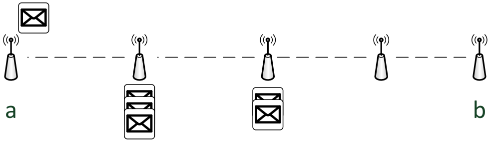


- Provide e2e delay guarantees
- Maximize battery lifetime
- Minimize interference

System Model

- Multi-hop path
- Time slotted system
- Block-fading channels with non-identically distributed, but statistically independent channel gains





Open Questions

- How to analytically define the end-to-end performance guarantees for wireless industrial networks?
  $\Rightarrow$ Consider fading and queuing effects.
- Is an optimal transmit power allocation possible?
- Does the analytical optimum resemble the real system optimum?

Used Method: Stochastic (min,x) Network Calculus

SNR domain

$$\mathcal{S}(\tau, t) = \prod_{i=\tau}^{t-1} g(\gamma_i)$$

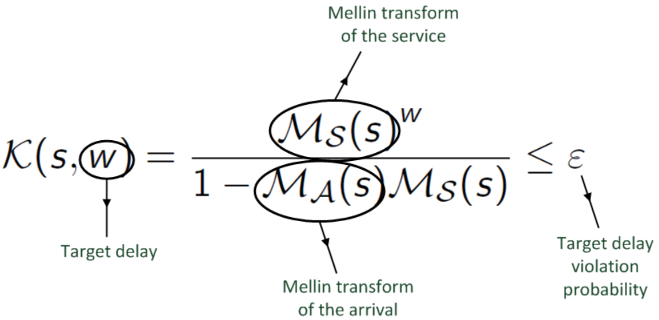
$e^{S(\tau,t)}$

$\log(\mathcal{S}(\tau, t))$

Bit domain

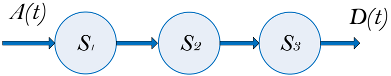
$$S(\tau, t) = \sum_{i=\tau}^{t-1} \log g(\gamma_i)$$

Analytical Delay Bound



Recursive End-to-End Delay Bound

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



Violation probability of the target end-to-end delay w:

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

N.Petreska, H.Al-Zubaidy, R.Knorr, J.Gross, "On the Recursive Nature of End-to-End Delay Bound for Heterogeneous Wireless Networks", ICC, 2015

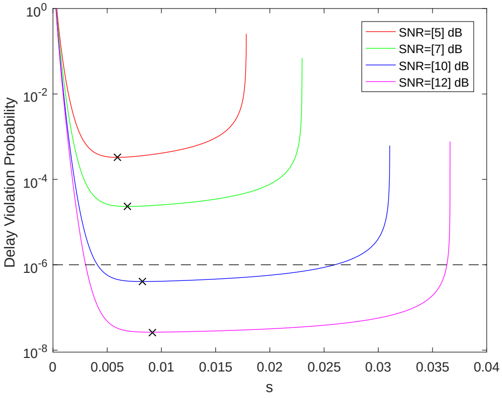
Transmit Power Minimization Algorithm

Enable delay-aware dynamic power management to

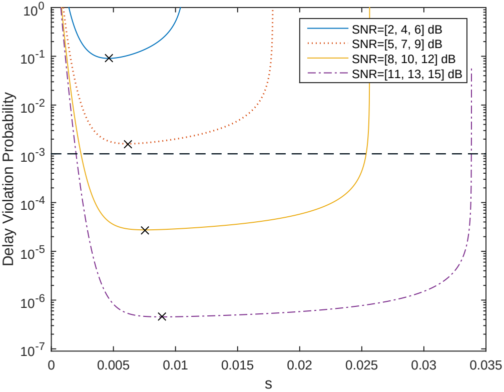
- Extend battery ⇒ node ⇒ network lifetime
- Reduce interference
- Enable coexistence of several wireless technologies

Use delay bound convexity

Convex Delay Bound: One Hop

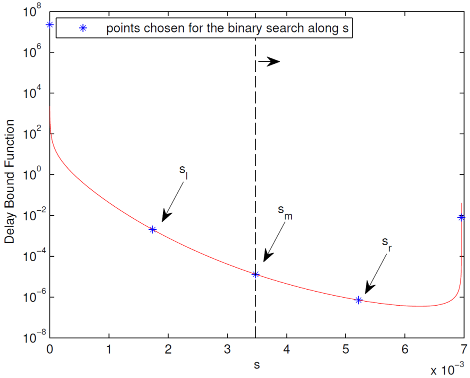


Convex Delay Bound: Multi-Hop



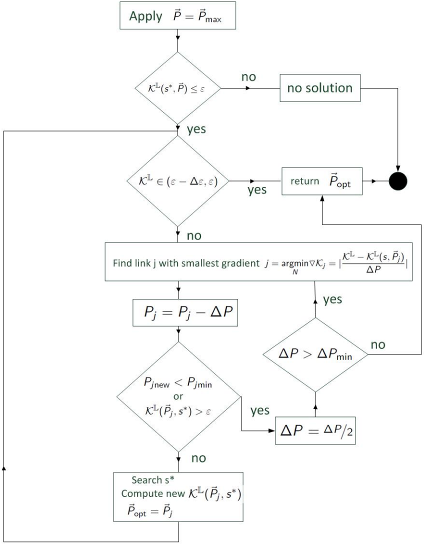
N.Petreska, "End-to-End Performance Analysis for Industrial IEEE 802.15.4e-based Networks", Fachgespräch für Sensornetze, 2017

Binary Search Algorithm

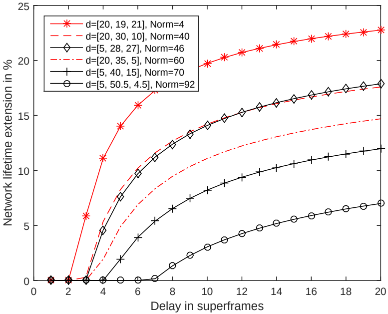


N.Petreska, H.Al-Zubaidy and J.Gross, "Power Minimization for Industrial Wireless Networks Under Statistical Delay Constraints", ITC, 2014

Power Minimization Algorithm



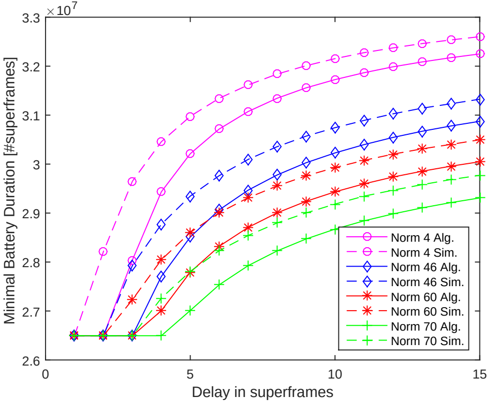
Link Heterogeneity



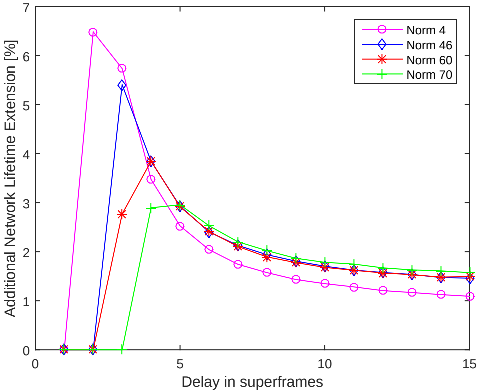
- Target delay violation probability $\varepsilon = 10^{-3}$.
- Payload size 10 B.
- Transmit power used as a comparison $P_{\text{tx}} = 4$ dBm.
- Duration of superframe 30 ms.

Bound-Based vs. Real System Optimum

How well the NC-based power optimization reflects the real system optimum?



Additional Network Lifetime Extension

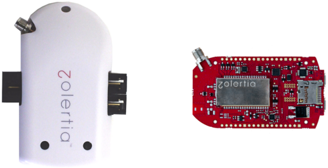


Conclusions

- Latency, reliability and energy efficiency - crucial requirements for industrial applications
- Using the (min,x) network calculus we provide
  - a closed form expression for the end-to-end delay bound in multi-hop wireless heterogeneous networks
  - a bound-based optimal power allocation algorithm
- Bound-based power allocation can be used to design reliable and power-efficient wireless industrial networks

Next Steps

- Validate the delay bound in real IEEE 802.15.4e testbed
  - Currently working with ContikiNG and Cooja simulation network
  - Build a multi-hop network prototype and test the power savings under various delay and reliability constraints
- Use the recursive behaviour of the end-to-end delay bound to define a power-efficient routing algorithm

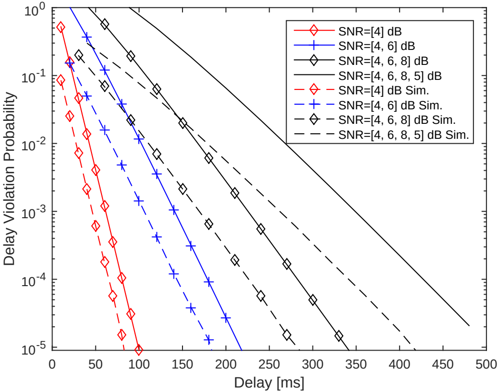


Zolertia motes

TI CC2538
System-On-Chip

Extra Slides

Validation of the WirelessHART Service Curve



N.Petreska, H.Al-Zubaidy, B. Staehle, R. Knorr and J.Gross, "Statistical Delay Bound for WirelessHART Networks", PE-WASUN, 2016