Queuing Analysis of Wireless Systems: Waste of Time?

Dagstuhl Seminar “Network Calculus”
March 9th, 2015

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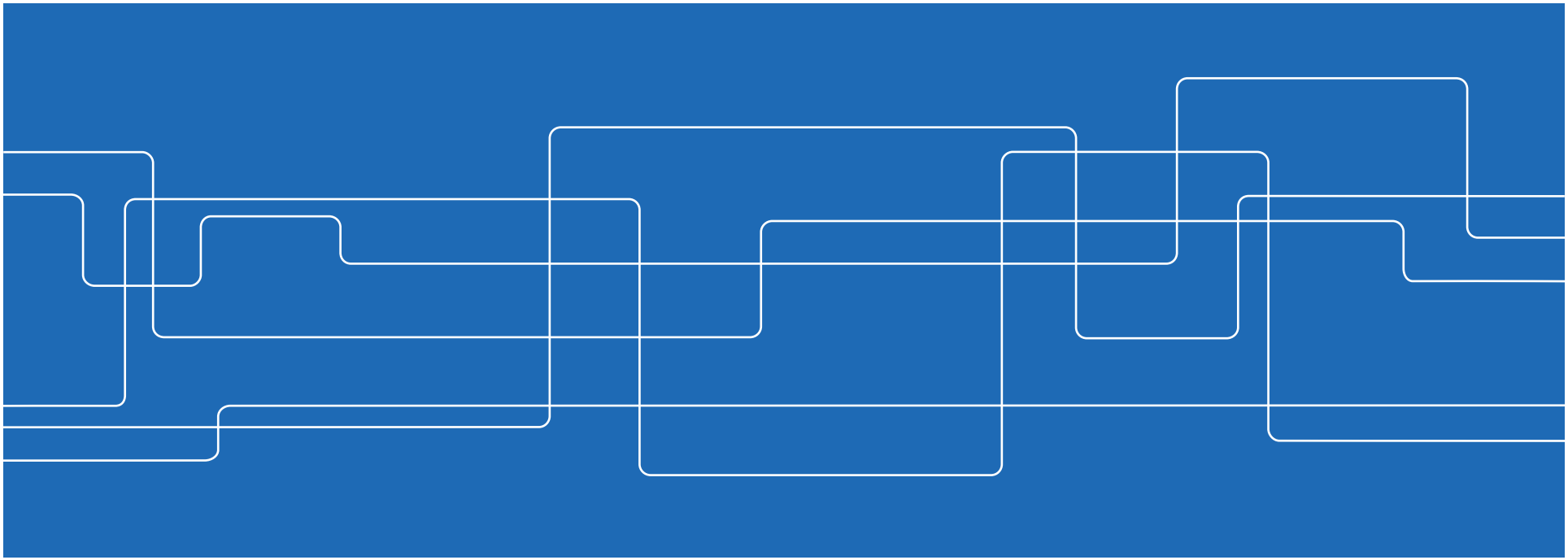


Outline

- Some Facts: Personal Endeavors
  - Outdated CSI Analysis
  - Cellular Systems
  - Relaying and Energy-Efficiency
- Some Speculations:
  - What is going wrong?
  - And how to fix it?

Motivation

Much effort spent to improve wireless spectral efficiency:

- Multi-antenna systems
- Dynamic spectrum allocation
- Interference coordination / alignment
- Network coding, Relaying

Primary focus: Physical layer performance

- Shannon capacity, outage-limited capacity etc.
- Driven by information- or communication-theoretic community

What about queuing performance of these approaches?

- Seemingly important question due to applications …

Method of Choice: Effective Capacity

Single-hop queuing approximation introduced by Wu [1]:

- Q denotes random steady-state queue length
- From Chernoff bound we get the bound approximation

$$\Pr.\{Q > x\} \approx K \cdot e^{-\theta \cdot x} \quad \Rightarrow \quad \Pr.\{D > d\} = \mathcal{P} \approx K \cdot e^{-\theta \cdot r \cdot d}$$

- K is the probability that the queue is not empty
- θ is the QoS exponent such that $r \leq \alpha(\theta) = -\frac{\Lambda(-\theta)}{\theta}$ with $\Lambda(\theta) = \lim_{i \to \infty} \frac{1}{i} \log \mathrm{E}\left[e^{\theta \cdot (S[i] - S[0])}\right]$ as the log-moment generating function and $\alpha(\theta)$ as the effective service capacity

Tricky aspect: Determine $\alpha(\theta)$ for a given wireless system !

[1] D. Wu, R. Negi, „Effective Capacity: A Wireless Link Model For Support of QoS,“ *IEEE Trans. Wireless Commun.*, vol. 2, no. 4, pp. 630–643, 2003

Method of Choice: Effective Capacity II

"M/G/1" Rule of Eff. Cap. introduced by Soret [2]:

- With central limit theorem (if service process increments are i.i.d)

$$\alpha(\theta) = \mathrm{E}\left[s_j[i]\right] - \frac{\theta}{2}\mathrm{Var}\left[s_j[i]\right]$$

- Max. sustainable rate:

$$r_j^* \approx \tfrac{1}{2} \cdot \left(\mathrm{E}\left[s_j\right] + \sqrt{(\mathrm{E}[s_j])^2 + \frac{2 \cdot \ln(\mathcal{P}_j)}{d_j} \cdot \mathrm{Var}[s_j]}\right)$$

[2] B. Soret, M. C. Aguayo-Torres, and J. T. Entrambasaguas, "Capacity with Explicit Delay Guarantees for Generic Sources over Correlated Rayleigh Channel," *IEEE Trans. Wireless Commun.*, vol. 9, no. 6, pp. 1901–1911, 2010.

Own Efforts

Queuing analysis of various wireless systems

- SISO system with outdated CSI [3]
- Cellular (interference-limited) networks [4]
- Cooperative ARQ protocols [5]

Goals:

- Establish effective capacity for these systems
- Performance analysis for different QoS constraints
- Devise admission control rules for real systems

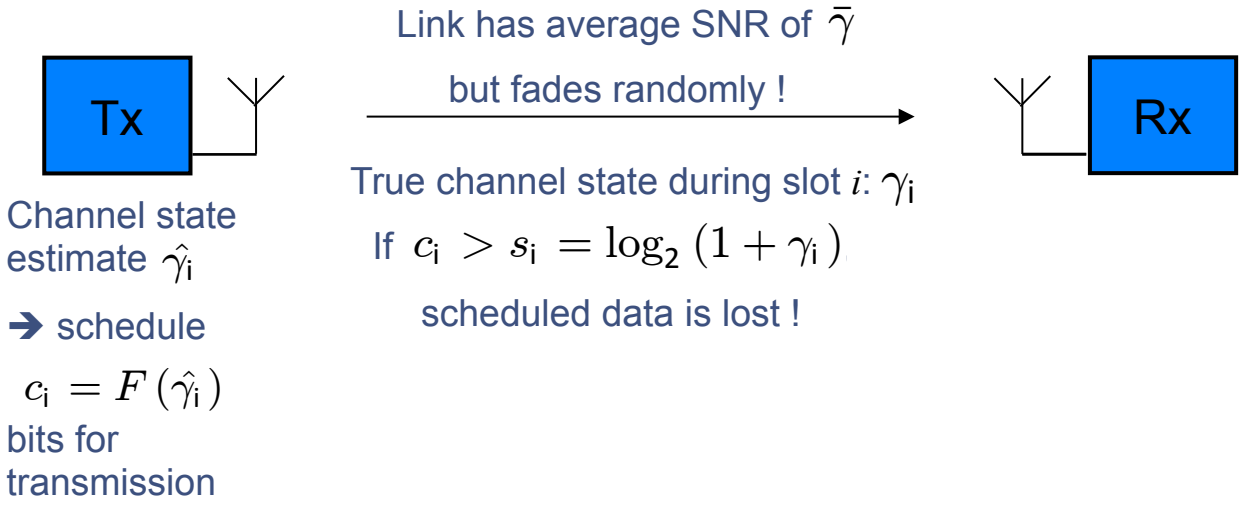
[3] J. Gross, „Scheduling with outdated CSI: Effective Service Capacities of Optimistic vs. Pessimistic Policies “, *Proc. IEEE IWQoS 2012*.

[4] M. Weyres, J. Gross, „Effective Capacity Analysis of Interference-limited Multi-Carrier Systems“, *Proc. European Wireless 2013.*

[5] Y. Hu, A. Schmeink, J. Gross, „QoS-Constrained Energy-Efficiency of Cooperative ARQ in Multple DF Relay Systems,“ *IEEE Trans. Veh. Tech.*, in press – available online

Example: Outdated CSI

Investigate different scheduling policies: Given a channel state estimate, should the system adapt?



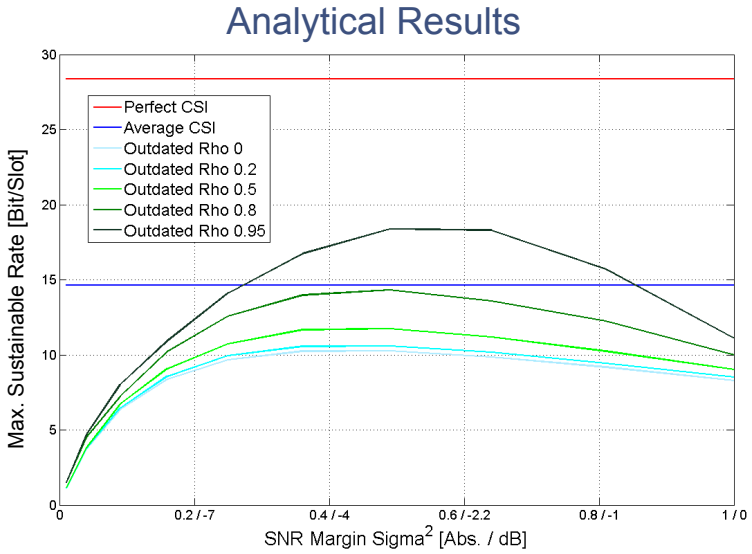
In particular, improve performance by SNR margin?

Example: Outdated CSI

Target delay: 10 slots, target outage prob. 0.1

Link has average SNR of 10 dB

What is the max. source rate that can be supported?



Some observations

- Even using Soret's simplification, EC is usually tricky to determine
- Although there are optimal configurations, they typically can not be derived
- Overall, the obtained results are typically boring: Systems with a better ergodic capacity also have a better EC
- Nobody cares

Speculations: What is going wrong ?

Trend in academia: Observe what is “hot” in information/ communication theory, do the corresponding queue analysis

- Failsafe method for a paper …
- **But: Has limited contribution, as the “genuine act” has typically been already achieved, queuing analysis does not provide surprising additional insights!**

Trend in industry: No need for queuing-theoretic models

- Static assignment of resources, drop session if QoS degrades
- Mismatch between real performance and modeled systems

Some possible ways out

- New services will force industry to focus on QoS ?
  - Low latency wireless for control services …
- Address the mismatch between models and real systems?
- Think black/white (i.e. better/worse): Where can queuing analysis provide a system statement that is counterintuitive ?