Mathematics of Bandwidth Sharing
&
Basic Research for the Future Internet

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Summary

- Bandwidth sharing through "Statistical Networking"
  1. Interaction of Applications in the Internet
  2. Interaction of Applications in a Wireless Access Network

Statistical Networking

- State of the art: Conservation Laws: empirical or mathematically proved formulas linking two or more unknown quantities of a network e.g.:

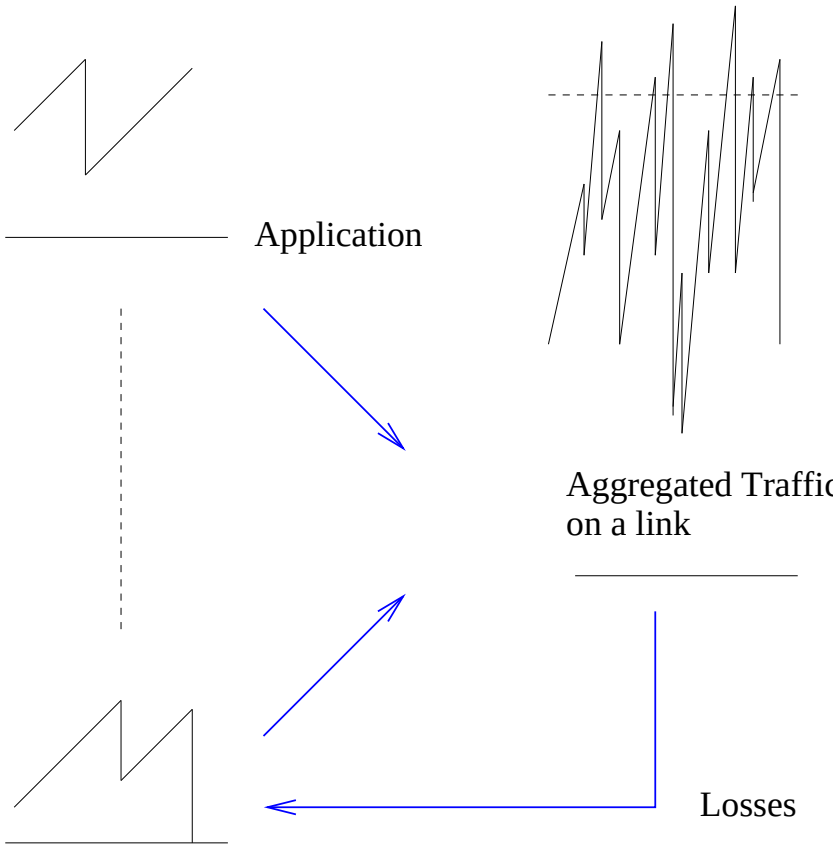
$$T = \frac{K}{R\sqrt{p}}$$

  or unproved claims.

- Need Statistical Networking: large scale interaction of applications with random characteristics in networks where they share resources:
  - start from a microscopic description of the interaction of applications through protocols & network elements
  - compute the law (mean and typical fluctuations) of macroscopic quantities like p and R and T.

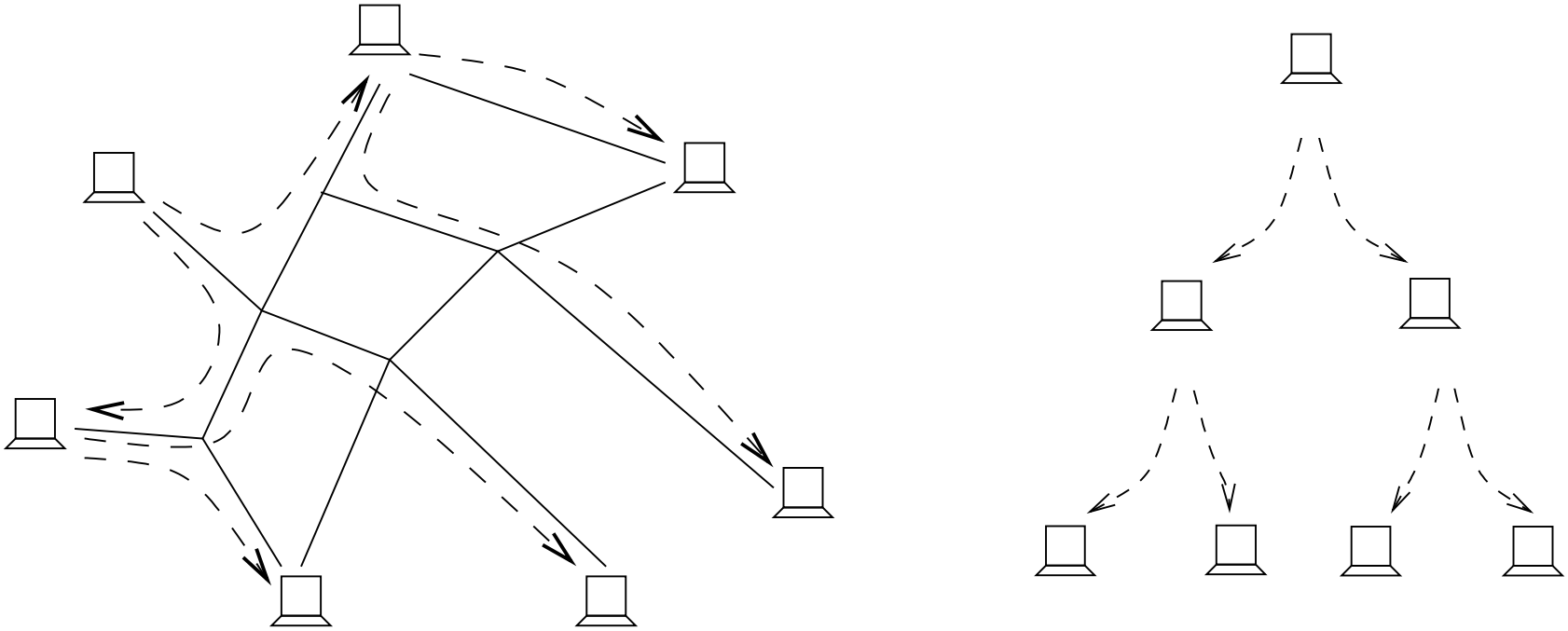
I Wired Networks: Flow Competition

- The instantaneous throughput of a session depends from losses, which result from the competition with other sessions sharing the same links.
- Mean field analysis possible in the single link case.



Basically Unsolved Problem in the Multi Link, Multi Application Case

Flow Competition and Collaboration in Large Overlays



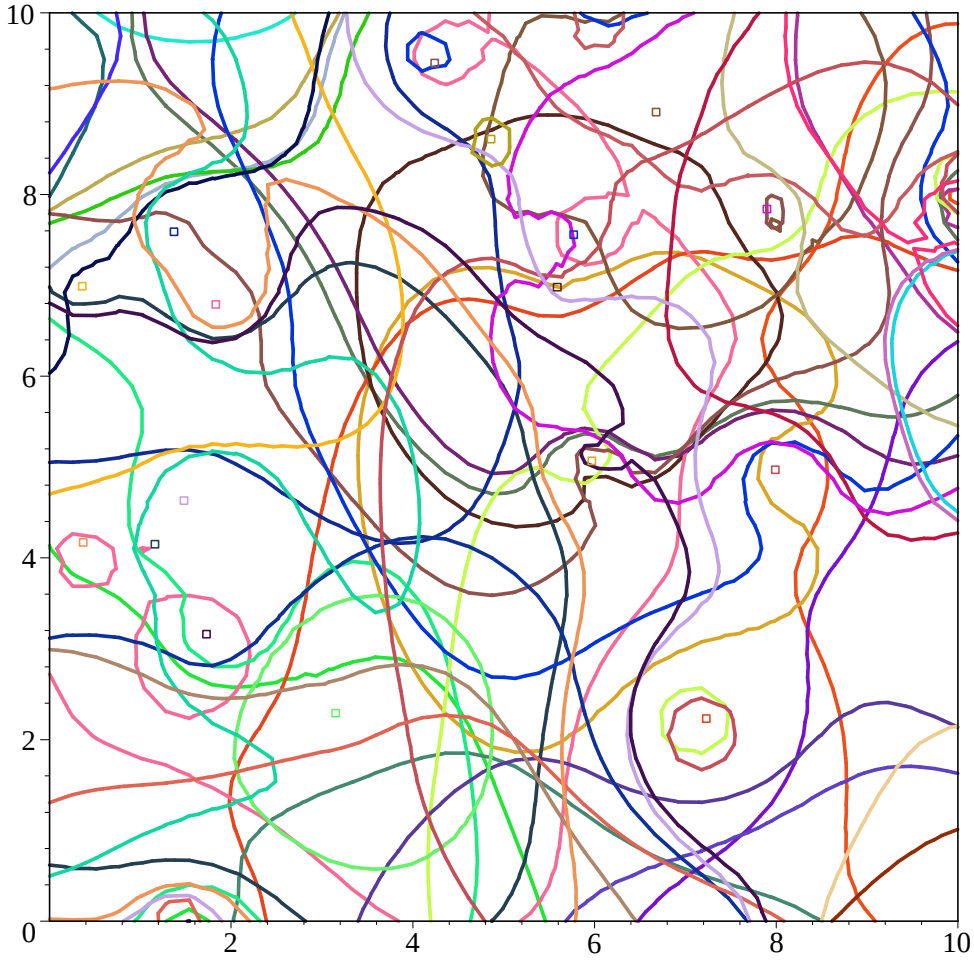
New research direction: Bandwidth of Overlays with Multihoming, Split, Splice, Series, Networks of TCP connections

II Wireless Access

- The Internet will more and more be accessed through a variety of co-existing wireless technologies: WIFI meshes, WIMAX, 3G/LTE, cellular etc.
- Rates depend on interference which depends on geometry. Key role played by the interplay between IT and geometry for understanding bandwidth sharing in this context.

II Wireless Access (*continued*)

- Bandwidth sharing in CDMA
- SINR coverage at a given bitrate for UDP flows



Why is the Understanding of Bandwidth Sharing Important?

- Clean slate design
  - For new distributed congestion control algorithms with predictable statistical behavior;
  - For the control of overlays
  - For wireless access, where there is a need for the design of scalable user association/split, power control, access scheduling and congestion control mechanisms.

Why is the Understanding of Bandwidth Sharing Important? (*continued*)

- Basic Engineering Default option of good sense: all systems are monotone and convex! But feedback systems may challenge engineering sense and TCP is a feedback system
  - Example 0: Oscillations of AQM.
  - Example 1: TCP under Congestion & Transmission Losses: adding random transmission losses on top of congestion losses may increase throughput.
  - Example 2: TCP/UDP interaction: shaping some UDP flows may decrease TCP throughput.

Conclusion

- The maths of bandwidth sharing is an essential ingredient
  - For the design of new distributed congestion control algorithms with predictable statistical behavior;
  - For solving inverse problems what is observable from end 2 end measurements? what is an anomaly?
  - To complete the Levy-Vehel–Riedi, Willinger, Abry–Veitch, Taqqu program: identify the causes of the spectrum of Internet traffic.
- The maths of spatial bandwidth sharing
  - has a major role to play within the context of wireless access;
  - might be one of the original scientific tools (information theoretic geometry) of networking.