Optimization in Communication Networks Lecture 1: Course Introduction

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Course Webpage

- All course-related materials can be downloaded at http://klms.kaist.ac.kr
- Please regularly check!
- Please make sure that your e-mail address used by klms is correct.

Instructor and Class Information

- Instructor: Yung Yi, Office: N1, 810
- Education 3.0 course: Lecture videos will be uploaded, and required to see them before the class
- In the class, we will discuss problems, questions, etc.
- T.A.: Hyeryung Jang, hrjang@lanada.kaist.ac.kr, Jaeyoung Choi, jychoi@lanada.kaist.ac.kr
- Location and Time: Mon, 7:00 PM - 10:00 PM, N1, EDU 3.0 lecture room
- Office Hours: To be announced
- Please check regularly for new updates, questions, and answers!
- See syllabus for more detailed information
- Please actively correct typos and errors in the lecture slides!

What This Course Is About

- "A" Modeling and analysis of networking and communication problems
- Theory-driven algorithm and protocol development
- Main focus: problems that need optimization and stochastic theory
- Final message that the student can take away with, I hope:
  - "Now I can model and analyze my research problems."
  - "What papers do I have to see?"'
  - "What books do I have to see?"
  - "I can read many papers on networking and communication analysis! I don't worry about equations."

What Is Modeling and Analysis?

- Evaluate performance of existing protocols, algorithms, and system, and further motivate us to develop new algorithms
- One way: Empirical data from field trials and deployments, test-bed operations, computer simulations/emulations
- Another way: do math! - obtain provable clues: Why working, Why not working, How to modify?
- Needs assumptions: not too restrictive, not too detailed (tractability is the key)
- Key of successful modeling and analysis: plausible assumptions, nice analysis with good tools: cannot be done in a short time, and needs practice
- This course: practice how to model, practice how to make assumptions, and practice maths.

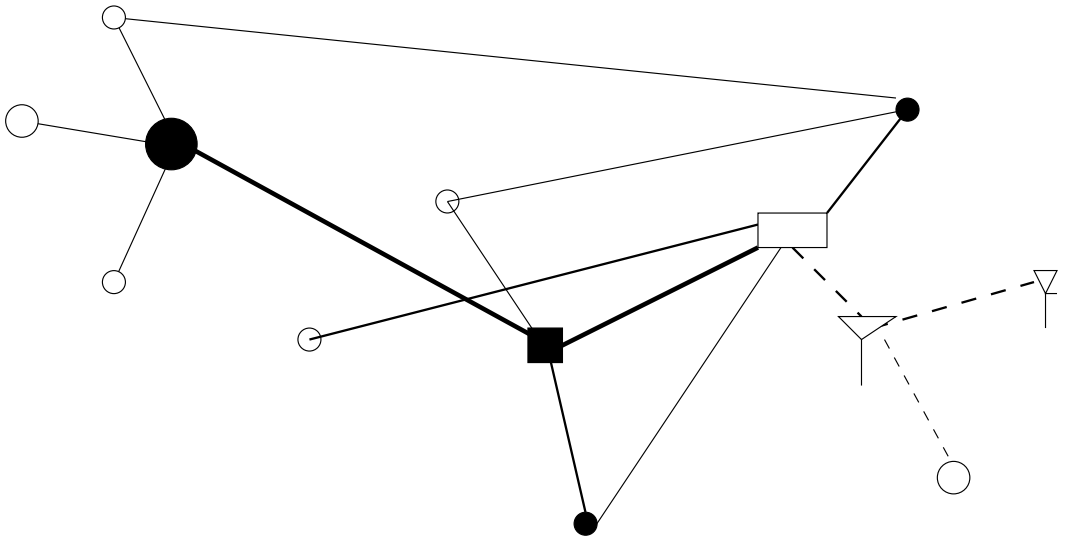
Tools

- Many tools for modeling, design and analysis of communication networks
- Main theory: optimization and stochastic theory (not that deep, but needs some serious thinking)
- Supporting theory: information theory, game theory, communication theory, other probabilistic tools, graph theory, economic modeling, physics/biology modeling ...
- What is required from the students
  - Willingness to learn
  - Willingness to practice with hands
  - Willingness to think about problems for a long time
  - Willingness to prove things
  - Willingness to see big pictures first
- Please note the grading policies and rules!

What This Course Is Not About

- Not a math course on probability or convex analysis (not many rigorous proofs)
- Not an OR course on queueing or optimization theory (only basic topics)
- Not an EE course on digital communication (cover only selected topics)
- Not a EE/CS course on networking (cover only selected topics)
- Not a CS course on algorithms (a little bit of computational complexity analysis)

Communication Networks

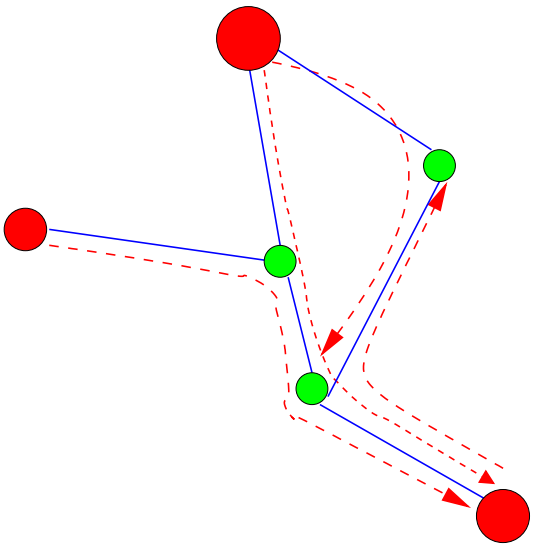


How to send information from one point to another (and for other source-destination configurations) over a medium?

Main Questions in Communication Networks

- How to meet requirements from applications (e.g., accuracy, throughput, latency, jittering, mobility support...)?
- How to represent and use the information?
- How to utilize the communication medium?
- How to connect users?
- How to reach one point from another?
- How to coordinate among the transmitters and receivers?
- How to regulate competition among users?
- How to make the system robust to failures, attacks, variations, growth across space and over time?

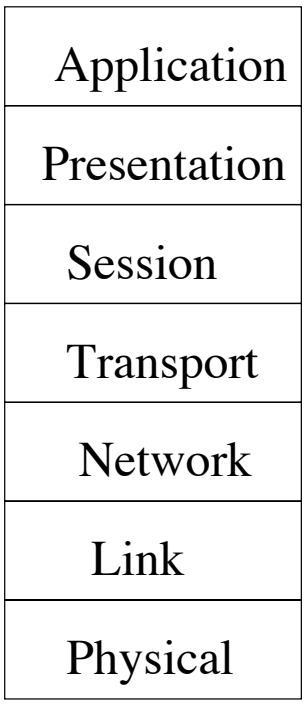
Communication Networks



- Fixed or dynamic topology? Who are transceivers and who are relays?
- Direct link or switched architecture? Circuit switch or packet switch or something else?
- How to divide into (possibly different types of) subnetworks?
- End-to-end control or hop-by-hop control?
- How to get on the communication medium?
- How to get from one point to another?
- How to monitor and adjust overall state of the network?
- How to ensure accurate, secure, dependable, timely, and usable transfer of information across space among competing users?

Layered Architecture

- Divide and conquer: break the overall big problem into smaller ones with standardized interfaces
- Each layer provides a service to upper layers and utilizes the services provided by lower layers
- Performance may not be 'optimal', but makes the architecture simple and flexible



Optimization mentality is one way of model, analyze, and design such systems.

Optimization, Convexity

$$\begin{array}{rl} \text{minimize} & f(x) \\ \text{subject to} & x \in \mathcal{X}, \end{array}$$

where $f(x)$ is a convex function, and $\mathcal{X}$ is a convex set.

- Why optimization?

  Efficiency of a mechanism: measured by "how far from optimal?"

  Throughput maximization, delay minimization, energy minimization

  What is the way to make my boy/girl friend maximally happy with my limited amount of money? That's what we are doing in communication networks

- Why convex optimization?

  Easy to solve!

  Locally-optimal is globally optimal!

  Zero duality gap!, Largrange duality theory

  Easy to develop distributed solutions!

- What happens, if non-convex?

  We will see...

Questions in Optimization Mentality

- How to describe the constraint set?
- Can the problem be solved globally and uniquely?
- What kind of properties does it have? How does it relate to another optimization problem?
- Can we numerically solve it in an efficient, robust, and distributed way?
- Can we optimize multiple objectives simultaneously?
- Can we optimize over a sequence of time instances?
- Can we find the problem for a given solution?

Optimization of Communication Networks

Three meanings of 'optimization of communication systems':

- Formulate the problem as an optimization problem
- Interpret a given solution as an optimizer/algorithm for an optimization problem
- Extend the underlying theory by optimization theoretic techniques

A remarkably powerful, versatile, widely applicable and not yet fully recognized viewpoint

Applications in communication systems also stimulate new developments in optimization theory and algorithms

Two Views

- Network to be optimized

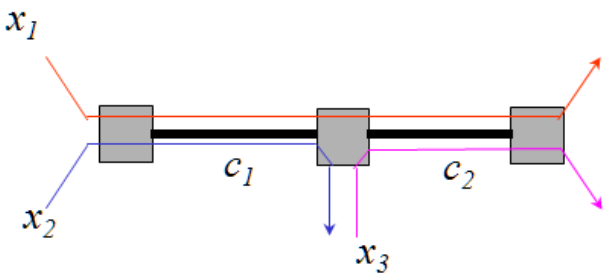
  Optimization is a tool

- Network as an optimizer

  Optimization is a mentality and language

TCP and Optimization

- Network Utility Maximization
- Congestion Control $\approx$ Maximizing Network Utility
- Frank Kelly's Seminal Paper in 1998 $\rightarrow$ Cross-layer optimization in wireless networks



$$x_1 + x_2 \leq c_1$$
$$x_1 + x_3 \leq c_2$$

$$\max \sum_{r \in R} U_r(x_r)$$

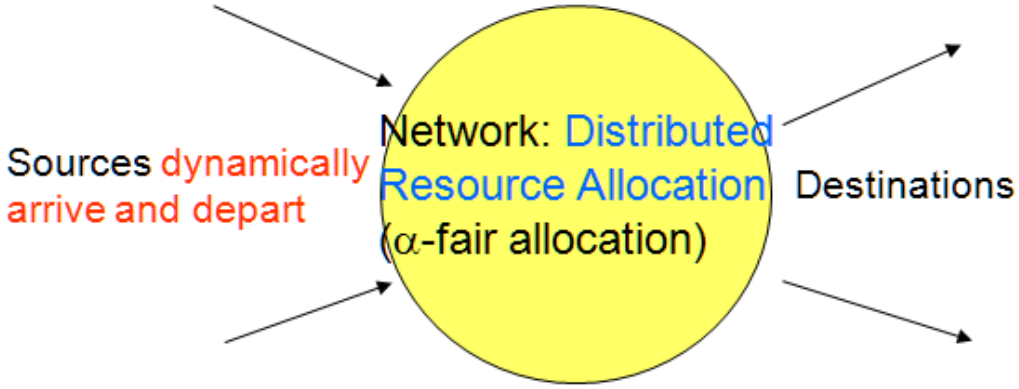
subject to

"Resource Constraints",

where $U_r(x_r)$ is the utility function of the user r with rate x_r

Differential Equation Based Distributed Congestion Control Algorithm

Bandwidth Sharing in the Internet



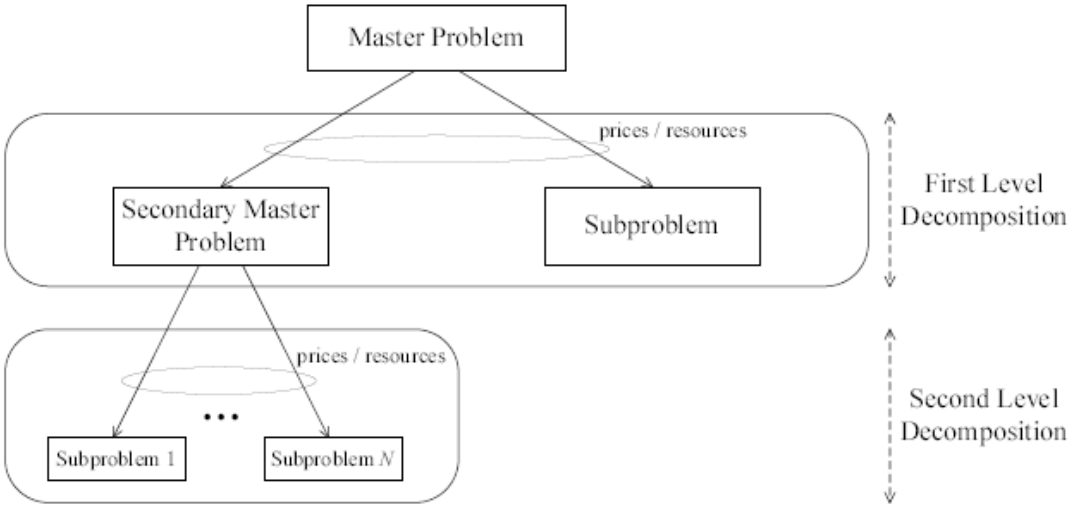
Assuming that NUM is used as a resource allocation mechanism (i.e., congestion control),

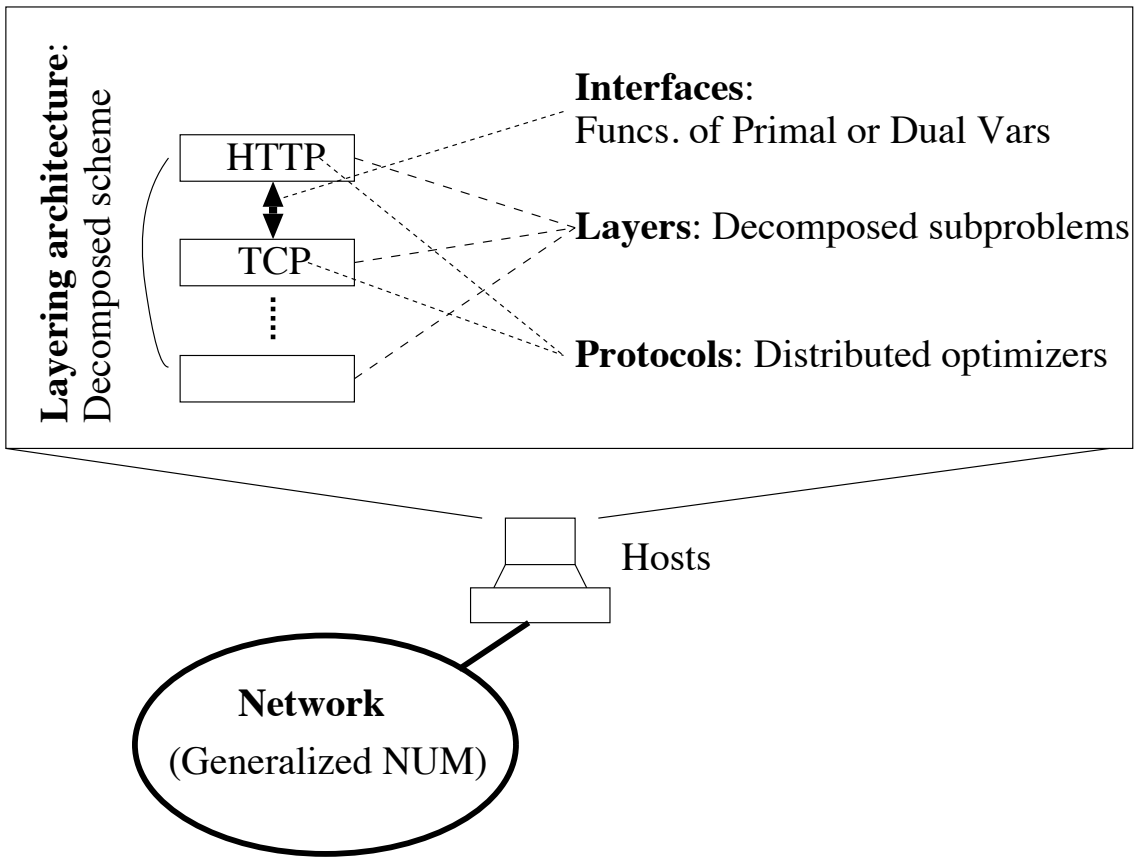
- What happens to the network for dynamically arriving and departing TCP sessions?
- What are the session-level performance metric?
- How does the session-level performance depend on the specific NUM (i.e., different utility functions)?
- NUM: Faster-time scale resource allocation, This topic: Slower-time scale session-level dynamics

Basic Theories

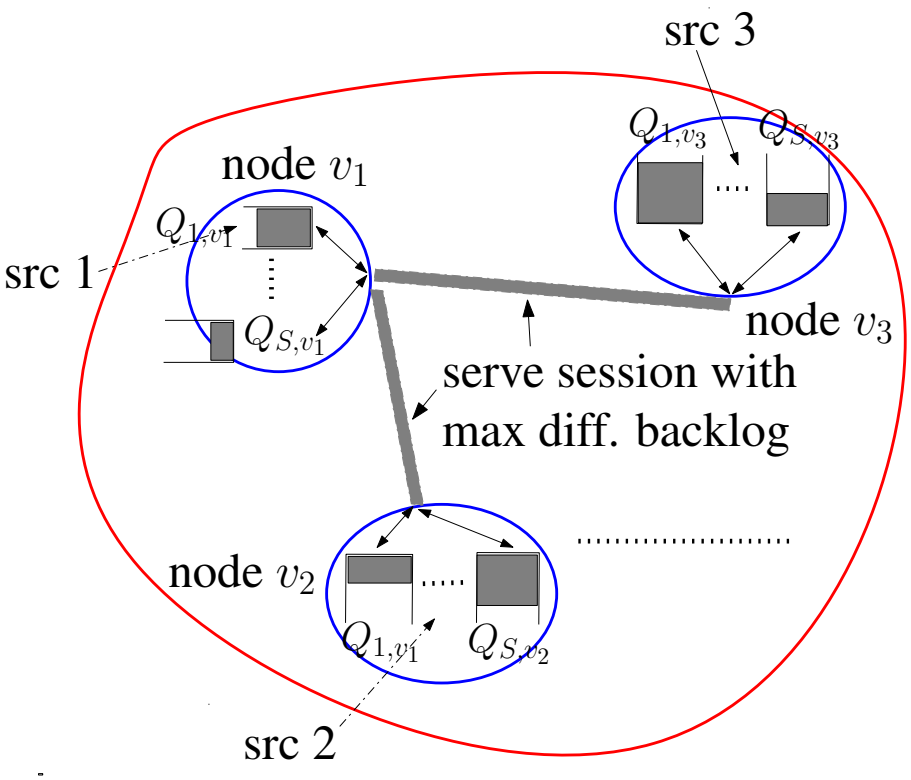
- Markov chain: how to measure throughput, measured by stability?
- Pareto-optimal allocation
- Fluid-limit: Very useful tool to prove stability
- Poisson process, gradient algorithm, distributed algorithm, convergence, rate of convergence, etc
- Modes of convergence of the sequence of random variables
- etc.

LAD (Layering As optimization Decomposition)





Multi-hop: TCP/IP/MAC/Physical

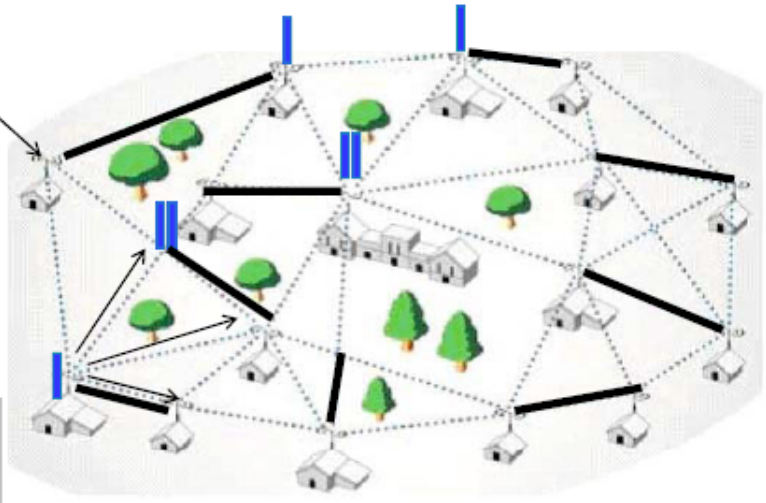


At each slot t, we have to decide:

Scheduling:
Which links to activate?

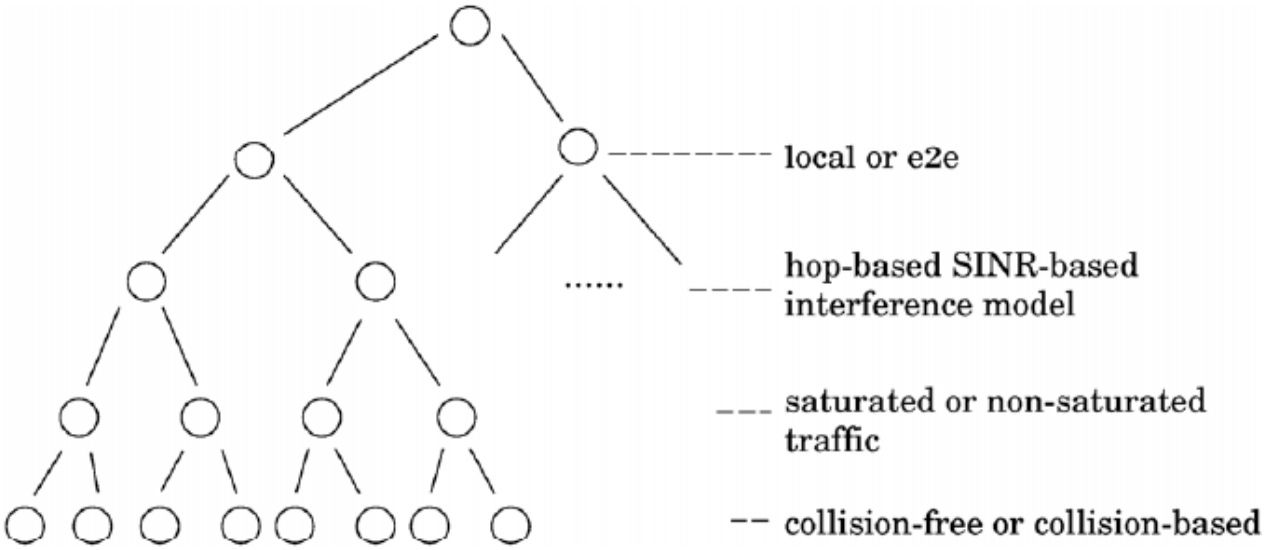
Source

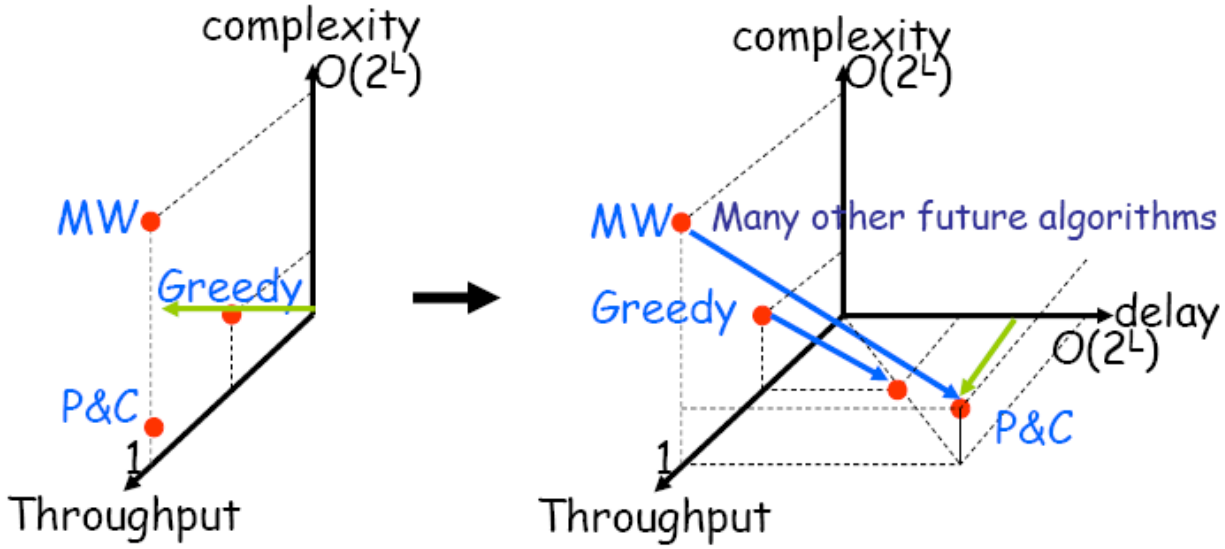
Congestion Control:
How much data the source injects into the system



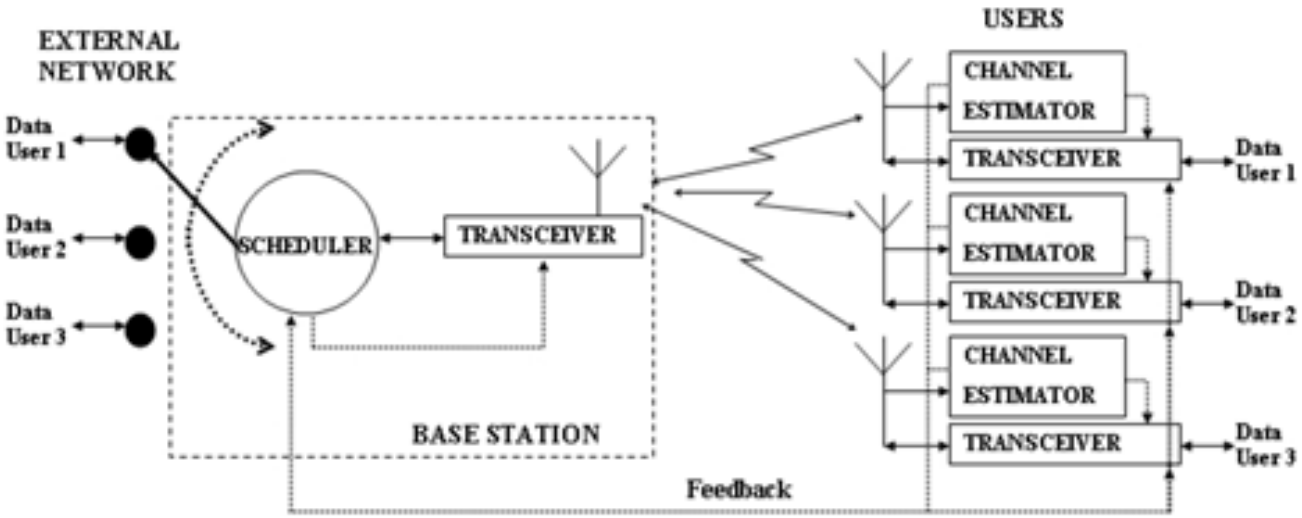
Routing:
Forward a packet to which neighbor?

MAC Scheduling

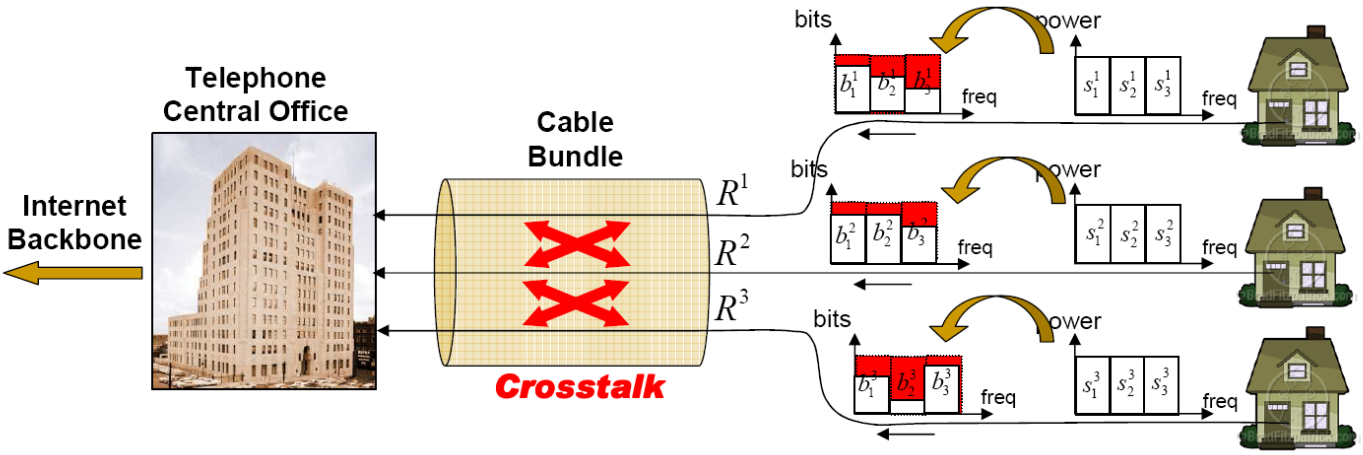




Opportunistic Scheduling: Wireless Cellular

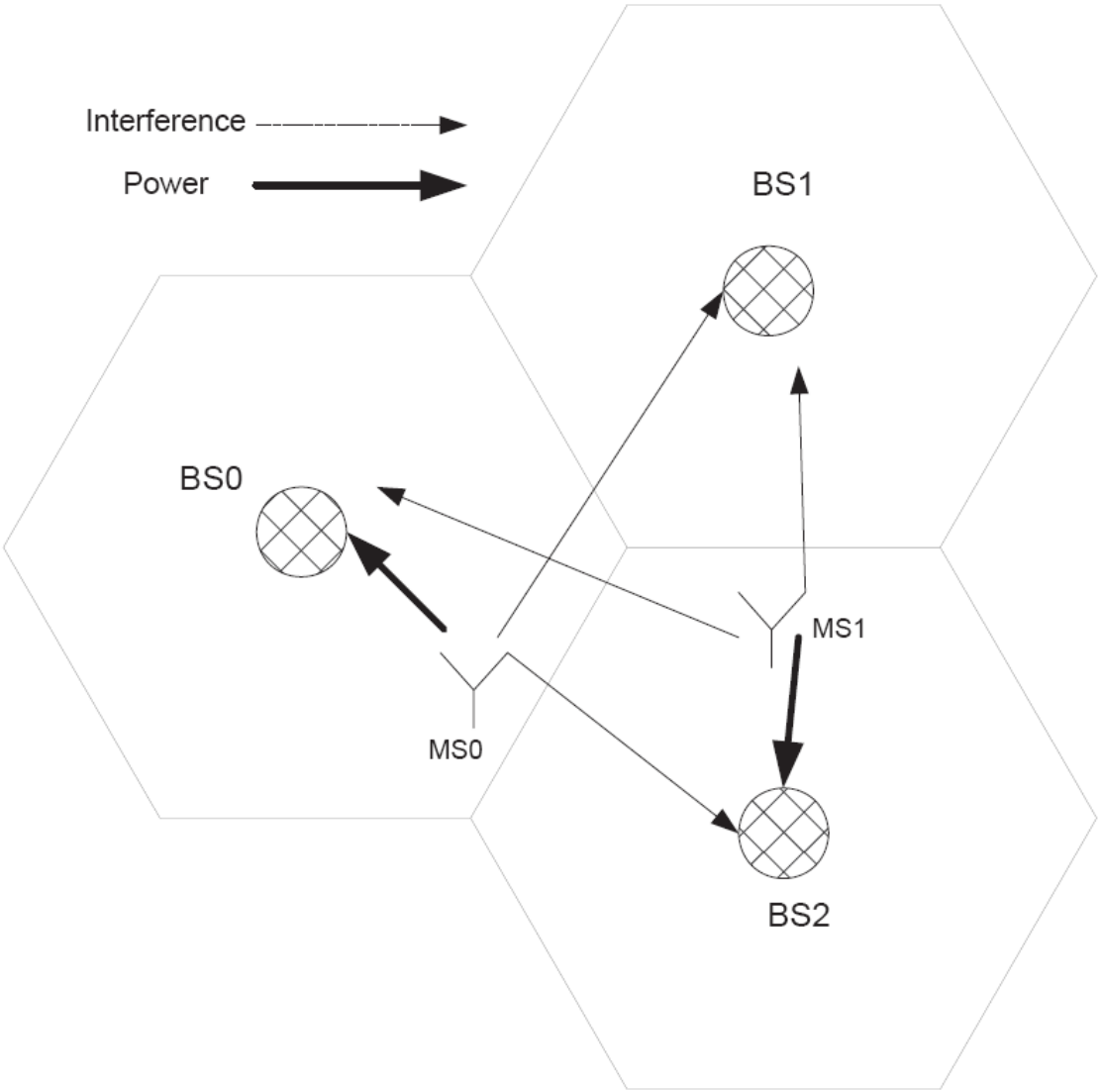


Interference Management in DSL

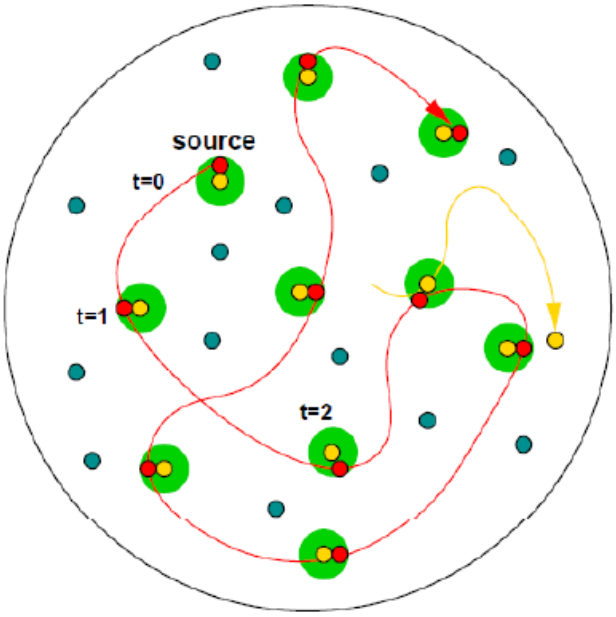


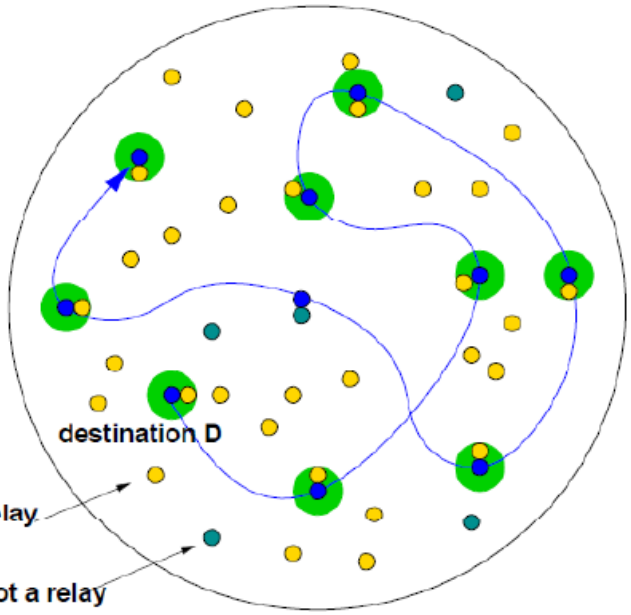
- Electromagnetic coupling causes ***crosstalk***
- Crosstalk leads to ***major decrease in bit rates***

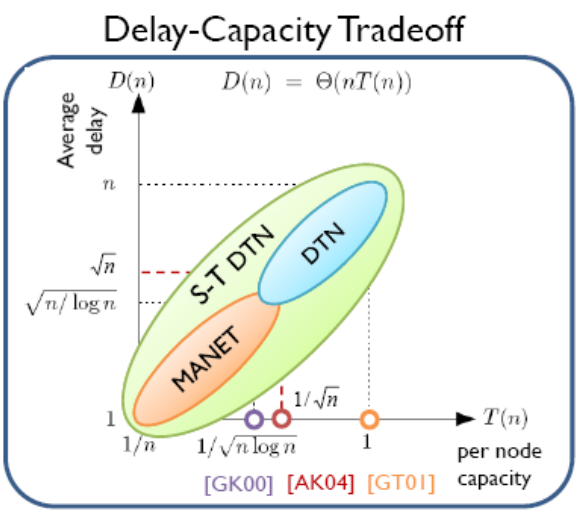
Interference Management in Multi-cell Wireless Networks

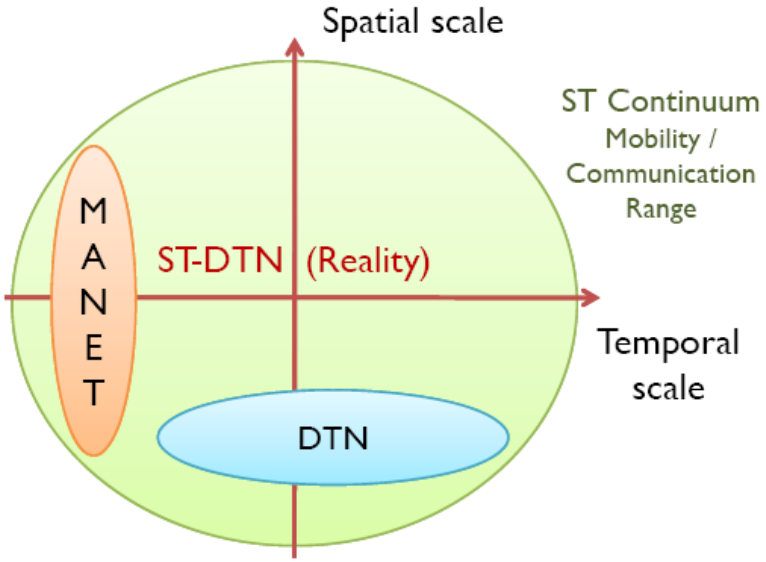


Optimization in DTN (Delay Toleration Networks)









Advice from the Instructor

- Write equations and math with your hand!
- "Print out the handout, and write something small in the blank space of the handout": a short-cut to obtain just the minimum gain from this course!
- Try to understand the big pictures, principles, and fundamentals, and then go to the details
- Read the papers and books related to this course (I will let you know).
- Use the office hours actively.
- This course focuses more on layer 2 and higher. However, it will give PHY guys a lot of nice chances to look at larger context.
- To Do

  Have fun, and study actively. Search and read papers. Ask many questions to me. Discuss many things with your colleagues

- Not To Do

Worry about grades, i.e., grade-oriented activity. Be lazy. Sleep or be silent in the class.

Course Project

- You may need to read about 5-10 papers
- Make about one and a half hour presentation slides
- Make presentation at the final workshop day

  Tutorial Workshop on Optimization in Communication Networks

- What to do

  Read papers, and understand very well

  Make self-contained, easy-to-understand lecture slides

  Make nice presentation

- Will invite other professors or senior PhD students or post-docs (if available) for grading
- Will advertise the workshop to EE
- Start early!