To Layer or Not to Layer

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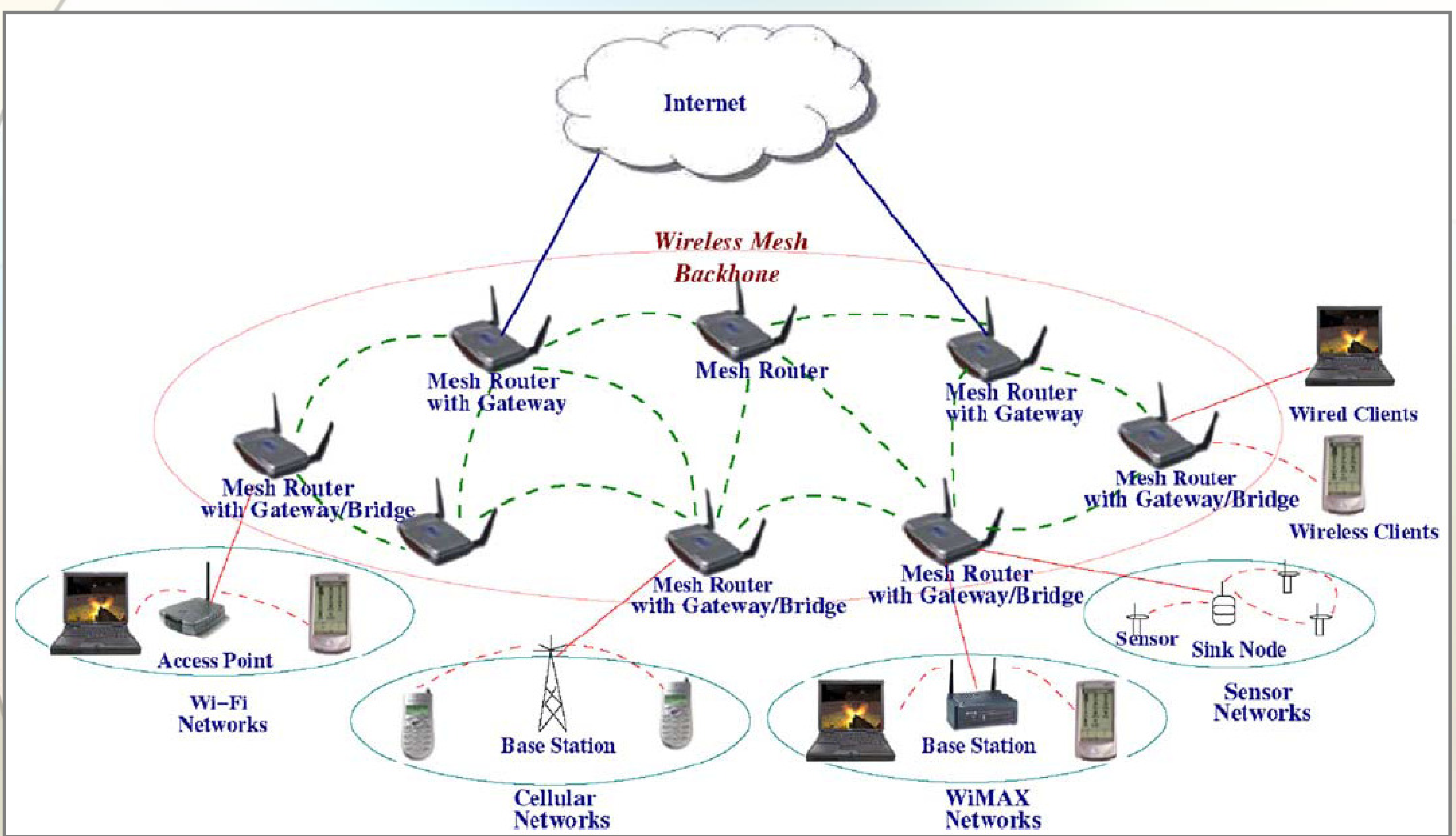
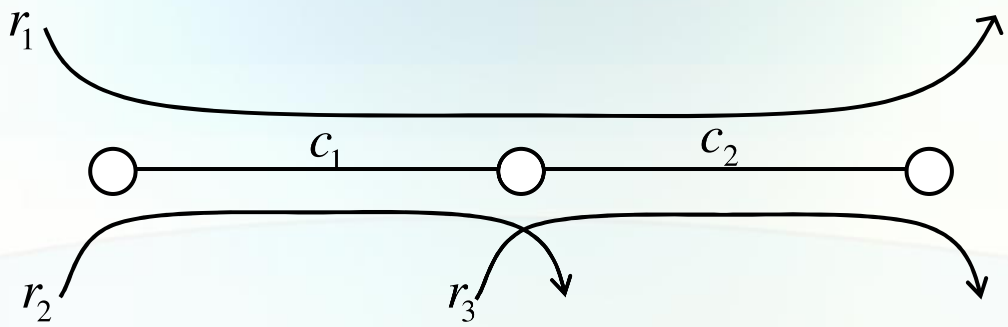
Multihop Wireless Networks



Wired Internet



- Network Utility Maximization

$$\max_{r} \sum_{s} U(r_s)$$

s.t.

$$\sum_{s \in S(l)} r_s \le c_l, \quad \forall l$$

$$r \ge 0$$

  – Link capacity is given and constant
  – Rate allocation problem

Functional Decomposition

- Lagrangian function

$$L(r,\lambda)=\sum_s U(r_s)-\sum_l \lambda_l\left(\sum_{s\in S(l)} r_s - c_l\right)$$

- Dual problem

$$\min_\lambda \max_r L(r,\lambda)$$

- Dual decomposition
  - Flow control at source

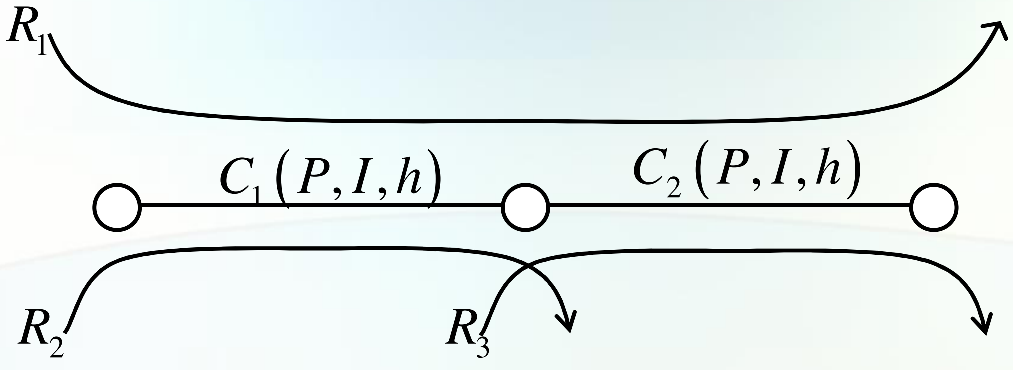
$$\max_r \sum_s\left(U(r_s)-r_s\sum_{l\in L(s)}\lambda_l\right) \quad\Rightarrow\quad r_s = U'^{-1}\left(\sum_{l\in L(s)}\lambda_l\right)$$

  - Congestion price at link

$$\min_\lambda \sum_l \lambda_l\left(\sum_{s\in S(l)} r_s - c_l\right) \quad\Rightarrow\quad \dot{\lambda}_l = \sum_{s\in S(l)} r_s - c_l$$

- TCP is an approximation of this dual decomposition

Wireless Internet



P: power allocation
I: link scheduling
h: channel state

- Long-term Network Utility Maximization

$$\max_{R,P,I} \sum_s U(R_s)$$

s.t.

$$R \in F(P,I)$$

  - Link capacity is time-varying and a function of resource control
  - Joint rate, power allocation and link scheduling

Functional Decomposition

- For a realization of channels
- Lagrangian function

$$L(r,P,I,\lambda)=\sum_s U(r_s)-\sum_l \lambda_l\left(\sum_{s\in S(l)} r_s - C_l(P,I,h)\right)$$

- Dual problem

$$\min_{\lambda}\max_{r,P,I} L(r,P,I,\lambda)$$

- Dual decomposition
  - Flow control at source

$$\max_r \sum_s\left(U(r_s)-r_s\sum_{l\in L(s)}\lambda_l\right) \Rightarrow r_s = U'^{-1}\left(\sum_{l\in L(s)}\lambda_l\right)$$

  - Scheduling/power control at link

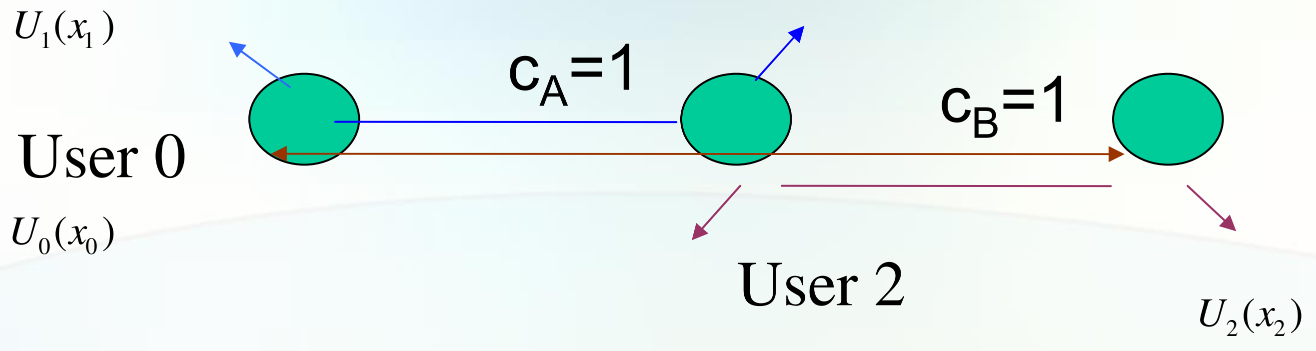
$$\max_{P,I}\sum_l \lambda_l C_l(P,I,h)$$

  - Congestion price at link

$$\min_{\lambda}\sum_l \lambda_l\left(\sum_{s\in S(l)} r_s - C_l(P,I,h)\right) \Rightarrow \dot{\lambda}_l = \sum_{s\in S(l)} r_s - C_l(P,I,h)$$

- Joint MAC and transport problem
- Distributed scheduling/power control is a challenge

Per-link Queueing Case



$$\max_{x_0,x_1,x_2} \sum_i U_i(x_i)$$

subject to

$$\begin{aligned} x_0 + x_1 &\leq \mu_a \\ x_0 + x_2 &\leq \mu_b \\ \mu_a + \mu_b &\leq 1 \\ x, \mu &\geq 0 \end{aligned}$$

μ_a is the fraction of time link A is used

Lagrange Multipliers

$$\max_{x,\mu} \sum_i U_i(x_i) - p_A(x_0 + x_1 - \mu_a)$$
$$-p_B(x_0 + x_2 - \mu_b)$$

$$\mu_a + \mu_b \leq 1$$
$$x, \mu \geq 0$$

Functional Decomposition

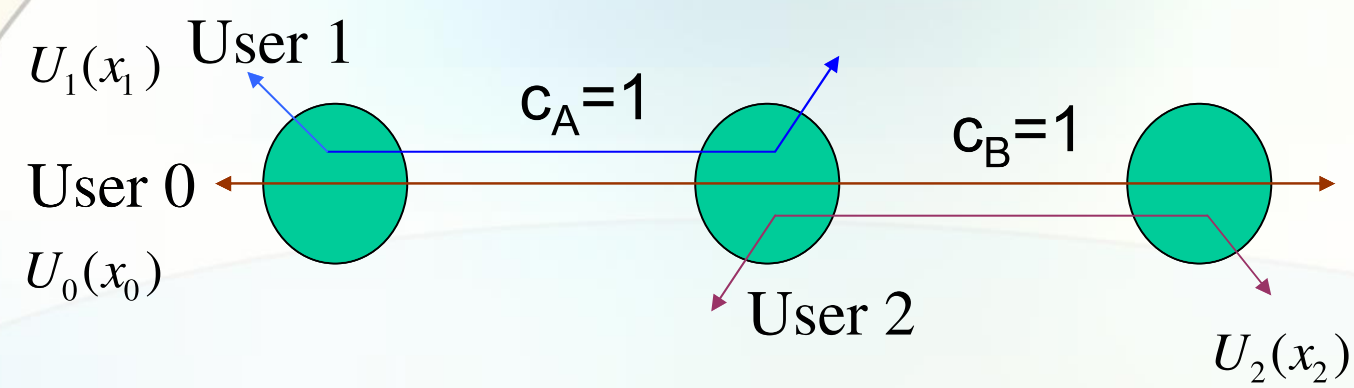
- Congestion control (sources and nodes)

$$\max_{x \geq 0} \sum_i U_i(x_i) - p_A(x_0 + x_1)$$
$$- p_B(x_0 + x_1)$$

- MAC or scheduling (network)

$$\max_{\mu_A + \mu_B \leq 1} p_A \mu_A + p_B \mu_B$$

Per-flow Queueing Case



$$\max_{x,\mu \geq 0} \sum_i U_i(x_i)$$

subject to

$$\begin{aligned} x_0 &\leq \mu_{a0} \\ x_1 &\leq \mu_{a1} \\ \mu_{a0} &\leq \mu_{b0} \\ x_2 &\leq \mu_{b2} \\ \sum_j \mu_j &\leq 1 \end{aligned}$$

μ_{a0} is the fraction of time link A is used for user 0

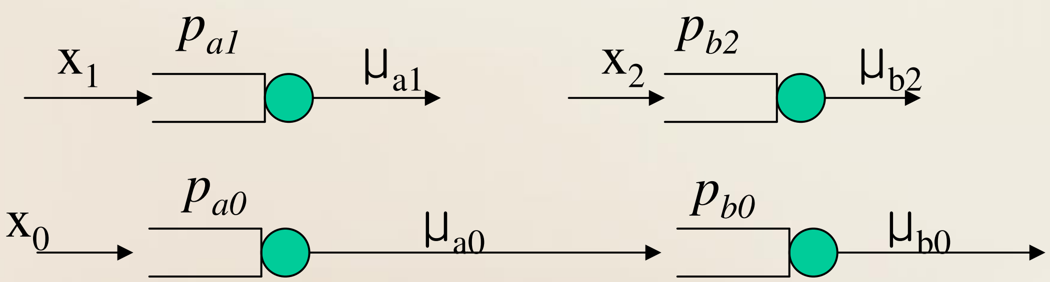
Functional Decomposition

- Congestion control (sources)

$$\max_{x\geq 0} \sum_i U_i(x_i) - p_{a0}x_0 - p_{a1}x_1 - p_{b2}x_2$$

- MAC or scheduling (network)

$$\max_{\sum \mu_i \leq 1} \mu_{a0}(p_{a0} - p_{b0}) + \mu_{b0}p_{b0} + \mu_{a1}p_{a1} + \mu_{b2}p_{b2}$$



Other Challenges

- Routing
  - Single path, multiple path, opportunistic, geographic etc.
- Frequency diversity
  - Channel switching
  - OFDMA
- Power control vs scheduling
  - CDMA mesh vs TDMA/OFDMA mesh
- Energy efficiency
  - Lifetime
- Access Link
  - Separate or shared radio