Pricing and Power Control for Joint Network-Centric and User-Centric Radio Resource Management

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OUTLINE

- Background & Motivation
- System Model: Utility, Pricing Mechanism, & Revenue
- Problem description
  - User-centric objective
  - Network-centric objective
- Numerical Results
- Approximate Solution
- Conclusions

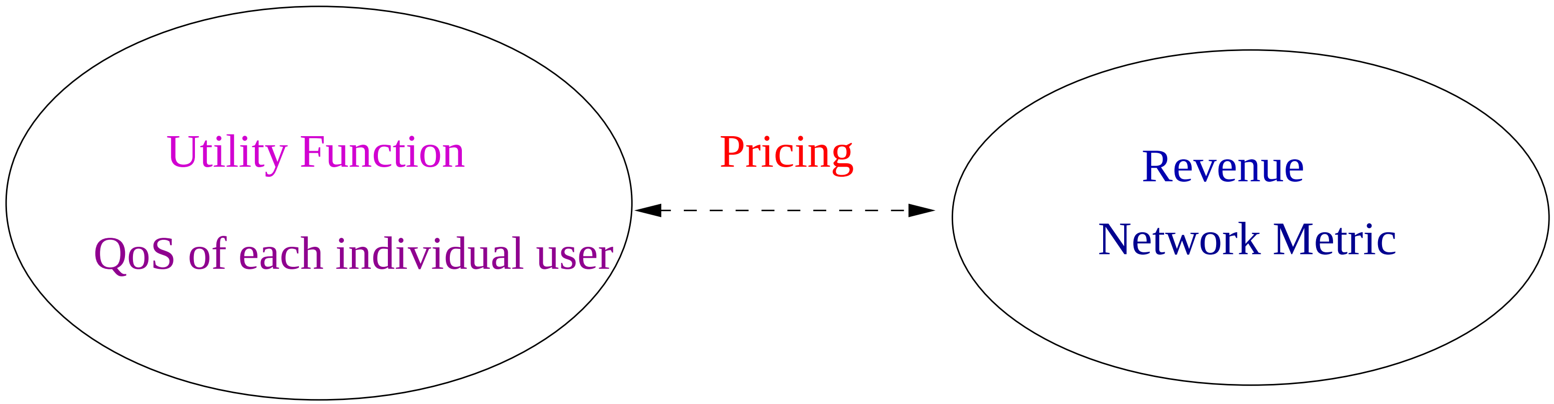
BACKGROUND & MOTIVATION

- Effective radio resource management is essential for the success of wireless communications.
- Radio resource management can be classified into two categories:
  - User-centric: Maximize the interest of each individual user.
    - Distributed power control.
    - Minimization of outage probability.
  - Network-centric: Optimize collective objective for all users.
    - Maximization of sum of rates (information capacity).
    - Maximization of sum of throughputs.

BACKGROUND & MOTIVATION cont'd

- The two categories are motivated by different interests and will generally lead to (sometimes very) different resource allocations.
  - Examples of user interests:
    * Maximize individual througput
    * Minimize individual transmit power while meeting some SIR target
  - Example of network interest:
    * Maximize network revenue
- *What if network-centric and user-centric objectives are allowed to compete/compromise with each other?*

LINKING THE OBJECTIVES



- Pricing mediates between the user-centric and network-centric objectives.
- Pricing does not necessarily imply dollar pricing. It was a policing mechanism in previous power-control work.

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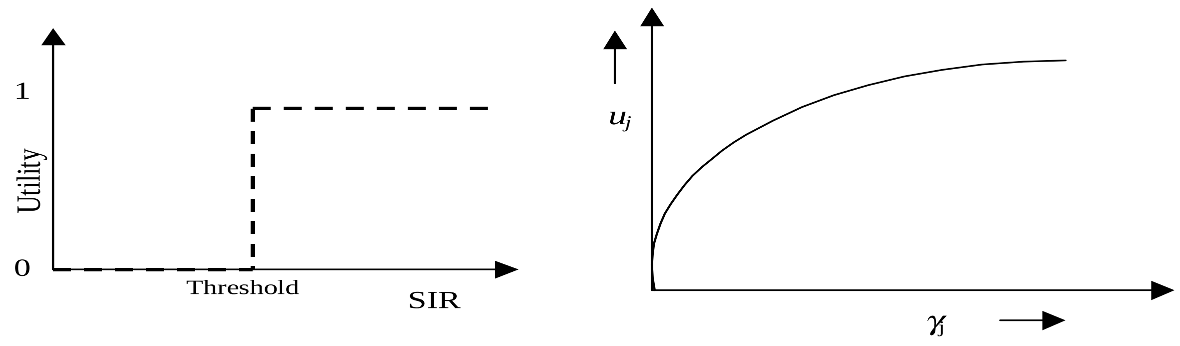
USER-CENTRIC METRIC: UTILITY

Definition 1 *Utility models the level of satisfaction that a user achieves from consuming a good or using a service.*



(a) voice (b) data

- Wireless data user cares about:
  - Throughput; hence transmission rate and frame success rate (FSR).
  - Battery life; hence transmit power.

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WIRELESS DATA UTILITY

Definition 2 *Utility of a wireless data user is the average amount of data received correctly at the base station per unit of average battery energy expended:*

$$U_i \equiv \frac{T_i}{p_i} = \frac{R_i f(\gamma_i)}{p_i} \frac{\text{Bits}}{\text{Joule}} . \tag{1}$$

p_i : Transmitter power of user i

γ_i : SIR of user i

T_i : Throughput of user i

R_i : Transmission rate of user i

$f(\gamma_i)$: approximate frame-success rate.

- $f(\gamma) \equiv [1 - 2\text{BER}(\gamma)]^M \approx [1 - \text{BER}(\gamma)]^M$.

  M: packet length measured in bits.

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NETWORK-CENTRIC METRIC: REVENUE

- Users are charged according to their throughputs.
- Revenue is defined as the aggregate payment from all the users:

$$\text{Revenue} \equiv \sum_i \rho_i \equiv \sum_i \lambda T_i \ , \tag{2}$$

where,

$$\begin{aligned}
\rho_i &\equiv \lambda T_i = \text{Payment made by user } i \text{ for achieving throughput } T_i \ , \\
\lambda &= \text{Unit price, charging rate, or pricing factor} \\
&\quad \text{(equivalent to dollar per unit throughput),} \\
T_i &= \text{Throughput of user } i \ .
\end{aligned}$$

USER-CENTRIC OPTIMIZATION

- Users' satisfaction are reduced by their payments.
- They engage in a non-cooperative game resulting in distributed power control:

$$\max_{p_i \in S_i} \; U_i^{\text{net}}(\mathbf{p}) \;, \qquad\qquad \forall i \;;$$

$$U_i^{\text{net}} \equiv U_i - \lambda T_i \;\; = \text{net utility}.$$

- This non-cooperative game has a unique Nash Equilibrium, at which no user can improve its net utility by unilaterally changing its power.
- For any λ, a round-robin iterative algorithm converges to the unique Nash eqm. given by $\mathbf{p}^*(\lambda)$.
- User optimization is a machine generating $\mathbf{p}^*(\lambda)$.

NETWORK-CENTRIC OPTIMIZATION

$$\max_{\lambda \geq 0} \sum_i \lambda \, T_i \left(\mathbf{p}^*(\lambda)\right) \qquad \text{[Maximize Revenue (total payment)],}$$

$$\text{Let} \quad \rho(\lambda) \equiv \text{ Revenue } \equiv \sum_i \lambda \, T_i \left(\mathbf{p}^*(\lambda)\right) \; .$$

- Through $\mathbf{p}^*(\lambda)$, the network knows its revenue $\rho(\lambda)$ at each λ.
- Network searches in one-dimension for the λ^* that maximizes $\rho(\lambda)$.

NETWORK-CENTRIC OPTIMIZATION cont'd

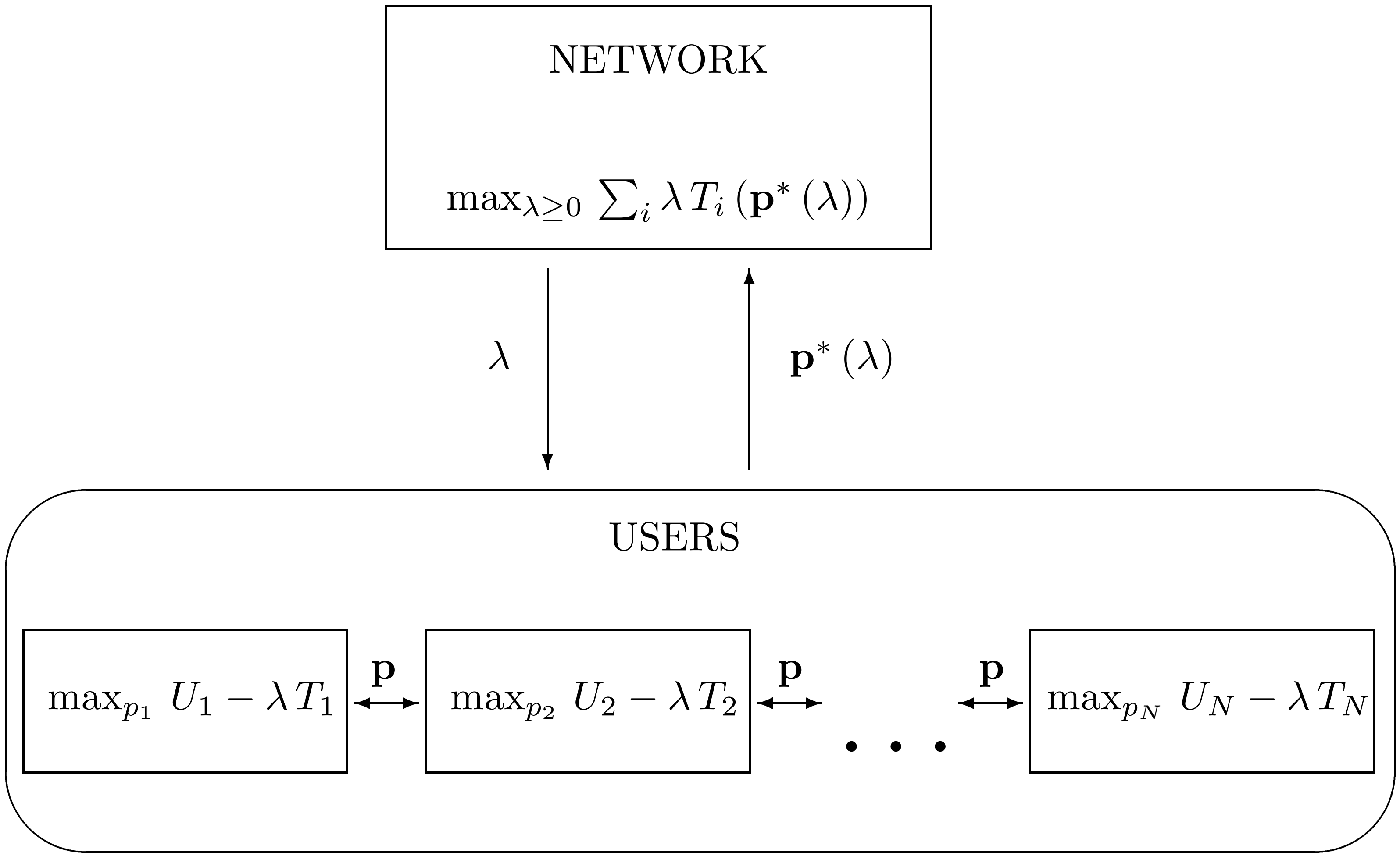
$$\rho(\lambda) \equiv \text{Revenue} \equiv \sum_i \lambda T_i(\mathbf{p}^*(\lambda)).$$

- Sensibility of our formulation:

  1. $\rho(\lambda) \geq 0$, because throughput $T_i \geq 0$.
  2. $\rho(\lambda) = 0$ when $\lambda = 0$.
  3. $\rho(\lambda) \to 0$ when $\lambda \to \infty$:
     - Users cannot afford to transmit when price is too high.
     - Network cannot derive arbitrarily high revenue by greedily increasing λ.

Lemma 1 *The revenue $\rho(\lambda)$ has at least one maximum at some finite positive pricing factor λ^*.*

JOINT OPTIMIZATION



NUMERICAL EXPERIMENT

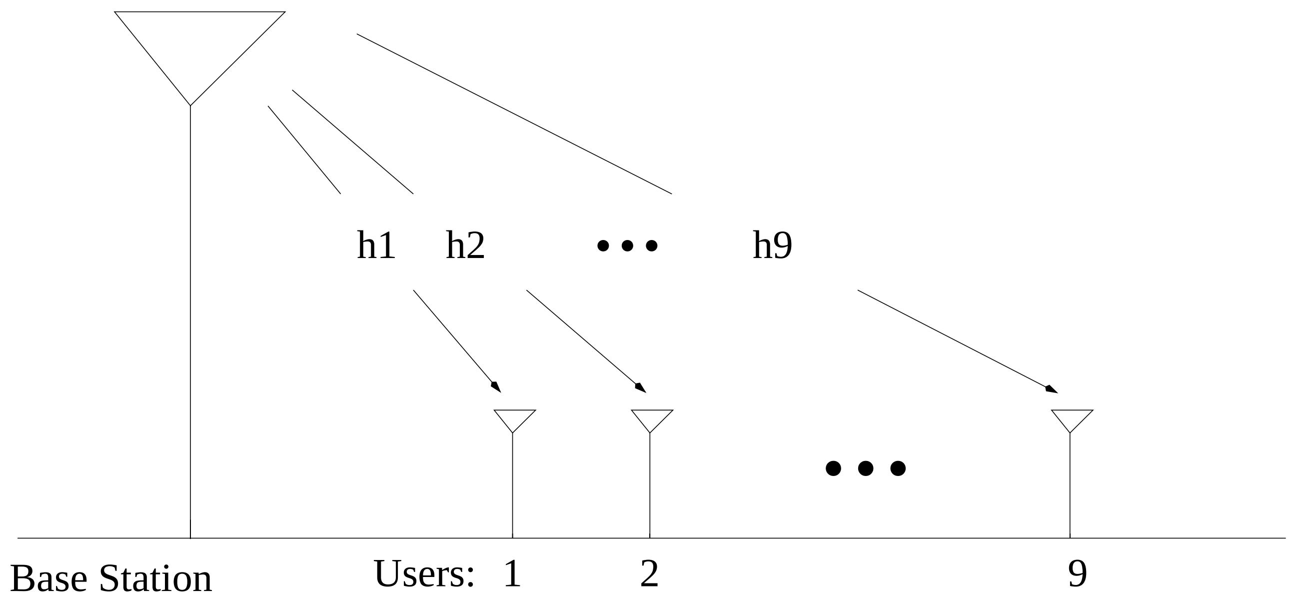
Table 1: Main System Parameters Used in Numerical Simulations

Parameter	Value
Channel Bandwidth W	1MHz
Transmission Rate R	10 kbps
Total Bits per packet M	96 bits/frame
Information Bits per packet L	80 bits/frame
AWGN Power at receiver σ^2	5×10^{-15}Watts

SIMULATION SCENARIO

Path gains: h1 > h2 > h3 > ... > h9

$h = \text{const.} / d^4$



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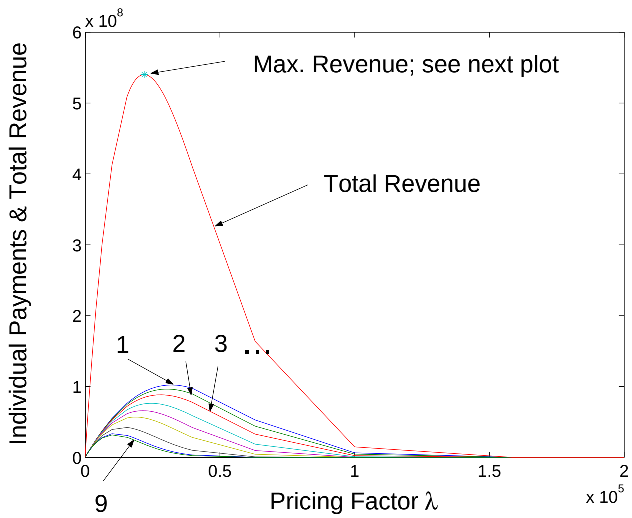
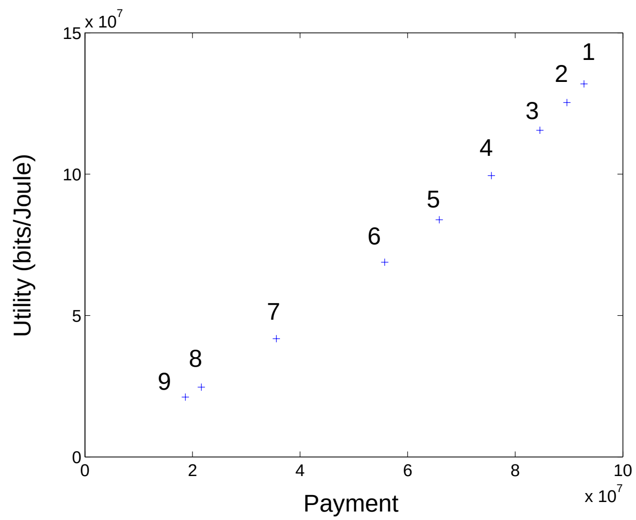
SENSIBILITY OF SOLUTION



(c) Individual payments and total revenue as functions of λ



(d) Allocation at max. revenue

Users with better channels are served better (higher throughputs and more utilities) as usual (e.g., as in water filling), but they pay proportionally more.

CONCLUSIONS

- User-centric and network-centric objectives are mediated via pricing.
- User-centric optimization:
  - Distributed power-control formulated as a non-cooperative game
  - Each user maximizes its net utility $(U_i - \lambda T_i)$
- Network-centric optimization:
  - One-dimensional search for the revenue $(\sum_i \lambda T_i)$ maximizing unit price λ^*
- Numerically shown that revenue has a unique maximum.
- We develop a computationally simple and accurate approximation to λ^* (ask me off line if interested).
- Main Result: Users with better channels receive better services as usual (like in water filling), but they pay proportionally more.

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