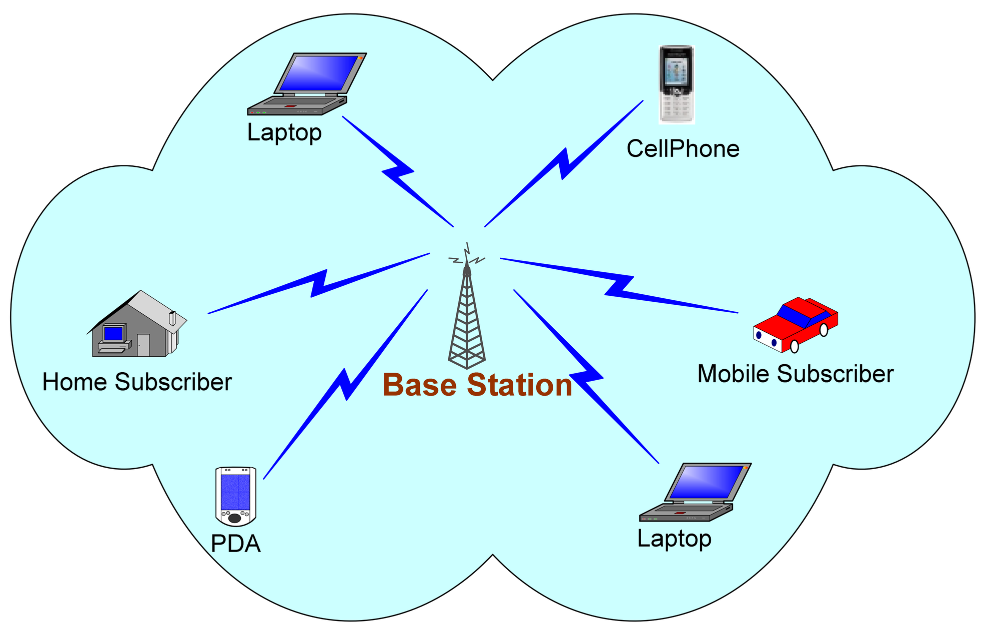
Opportunistic Scheduling for Wireless Networks

Zhi Zhang and Edwin K. P. Chong

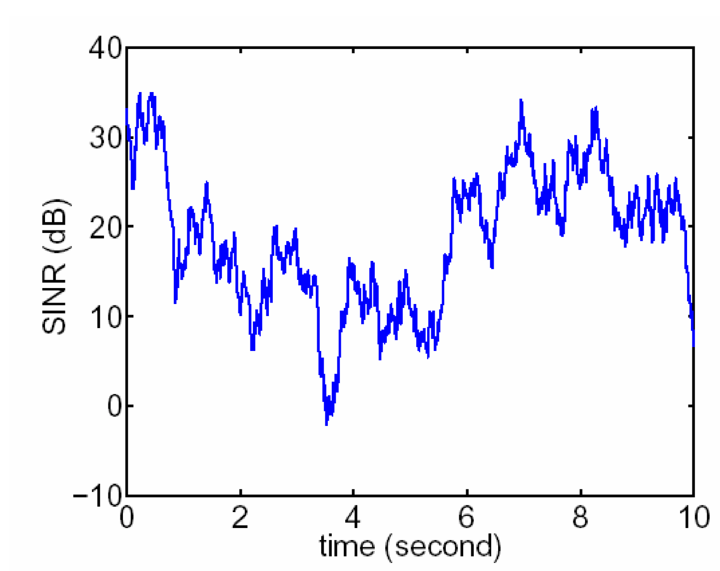
Electrical & Computer Engineering, Colorado State University

Wireless Multimedia Networks



Cut the Wires, Go Wireless!

Time-varying Wireless Channel



- **Wireless resource (bandwidth, energy): scarce, expensive.**
- **Wireless channel (communication link):**
  fading, interference, Doppler effects, energy limitation, etc.

➡ **Radio Resource Management: scheduling, power control, etc.**

Opportunistic Scheduling : An example

- One base-station and four active users in a cell.
- At each time, scheduler in the base-station picks up only one user to transmit in a given channel.
- Scheduling decision is based on channel condition feedback & QoS constraints.

Motivation

- **Wireless planet : *A wonderland or not ?***
  - **Skyrocketing demand for Wireless Services**
  - **"Whenever, Wherever, Whoever" communication**
  - **3G, Wireless LAN (802.11 a/b, Bluetooth), Ad-hoc networks**
- **Characteristics of wireless systems**
  - **Time-varying and location-dependent channel conditions**
  - **Limited radio frequency spectrum, capacity**
  - **Quality of Service (QoS) support**
- **Cross layer design**
  - **Mixed types of traffic and diverse QoS guarantees**
  - **PHY layer knowledge is shared with MAC or higher layers.**

Opportunistic Scheduling

- **Goal : *Increase the system performance under certain QoS requirements of users*.**
- **Fairness and QoS requirements**
  - **Scheduler must allocate resources fairly among users under specific fairness/QoS constraints.**
  - **Examples of (long-term) constraints:**
    - **Temporal fairness: User i is scheduled at least r_i of the time.**
    - **Utilitarian fairness: User i receives at least a_i of the overall system utility.**
    - **Minimum-performance guarantee: User i receives at least a utility of C_i .**
    - **Proportional fairness.**
- **An opportunist's idea**
  - **Exploit time-varying nature of channel conditions.**
  - **Opportunistic: *Choose a user to transmit when its channel condition is relatively good*.**
  - **However, because of fairness requirements, opportunism should not be too myopic.**
- **Scheduling decision depends on tradeoff between**
  - **Instantaneous channel conditions;**
  - **Specific fairness or QoS requirements.**
- **Scheduling policy**
  - **Policy: *A rule that specifies which user is scheduled at each time*.**
  - **At time t, policy π selects user i, and receives the corresponding "reward" U_i^t .**
  - **Example policies:**
    - **Round-robin: schedules users in a predetermined order.**
      ➡ **simple and fair, but non-opportunistic.**
    - **Greedy: always selects the user with the best channel conditions.**
      ➡ **opportunistic, but violates fairness requirements.**

Problem Formulation

Use temporal fairness scheduling as an example:

- **Define:** average performance of user i up to time T :

$$U_i^T(\pi) = \frac{1}{T}\sum_{t=1}^{T} U_i^t \mathbf{1}\{\pi(U^t) = i\}, \quad i = 1, \ldots, N,$$

  average time scheduled to user i up to time T :

$$R_i^T(\pi) = \frac{1}{T}\sum_{t=1}^{T} \mathbf{1}\{\pi(U^t) = i\}, \quad i = 1, \ldots, N.$$

- **Goal: *Find a policy that maximizes the system performance, while maintaining certain QoS constraints*.**

Temporal Scheduling Problem:

$$\underset{\pi}{\text{maximize}} \quad \limsup_{T\to\infty} \sum_{i=1}^{N} U_i^T(\pi)$$

$$\text{subject to} \quad \limsup_{T\to\infty} R_i^T(\pi) \geq r_i, \quad i = 1, \ldots, N.$$

Temporal fairness requirement: each user i requires at least r_i of the time, where $r_i \geq 0$ and $\sum_{i=1}^{N} r_i \leq 1$.

Optimal Opportunistic Policy

Optimal temporally fair policy π^*:

$$\pi^*(U^t) = \arg\max_i \left\{ \sum_{i=1}^{N} \left(U_i^t + v_i^*\right) \mathbf{1}\{\pi^t = i\} \right\}$$

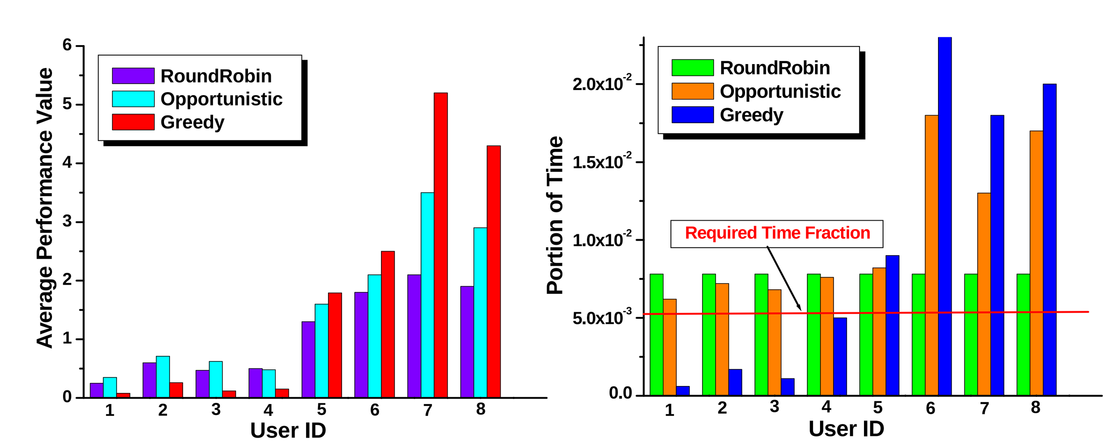
where, for all i , v_i^* satisfies:

1. $v_i^* \geq 0$
2. $R_i(\pi^*) \geq r_i$
3. $\left(R_i(\pi^*) - r_i\right) v_i^* = 0$

Remarks:

- **Similar results apply for other fairness/QoS criteria.**
- **The parameter v_i^* satisfies a set of equations and inequalities (complementary slackness).**
- **v_i^* can be estimated online in practice (e.g., via a stochastic approximation algorithm).**

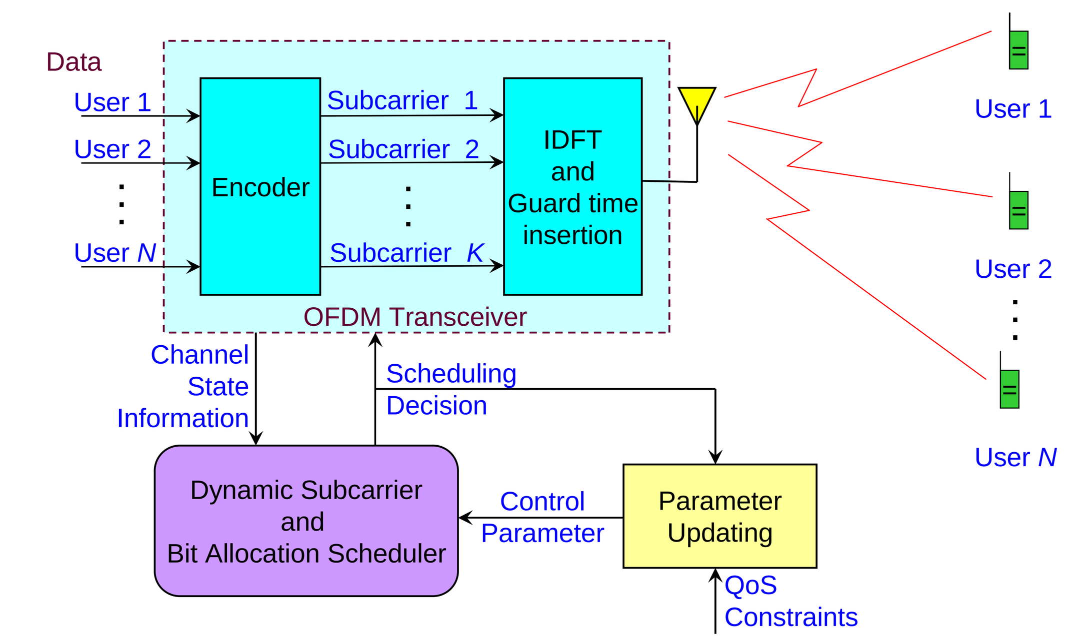
Numerical Results



Performance | **Temporal Fairness**

Interaction with OFDM

- **Integrate opportunistic scheduling into downlink of multi-user OFDM systems.**
- **Basic idea: *Opportunistically schedule users to available subcarriers, while maintaining fairness/QoS constraints*.**
- **Optimal policies can be obtained via the similar methodology as the above single-channel case.**
- **Advantages:**
  - **Opportunistic scheduling exploits temporal diversity in channel conditions.**
  - **OFDM provides efficient frequency utilization by exploiting frequency diversity.**
  - **Opportunistic OFDM system exploits both frequency and temporal diversity opportunistically.**
- **Computation Methods:**
  - **Brute-force approach: exhaustively search**
  - **Hungarian algorithm: an optimal solution with $O(N^4)$ computation.**
  - **Max-Max: a suboptimal algorithm with lower complexity.**



References

- Z. Zhang, Y. He, and E. K. P. Chong, "Opportunistic downlink scheduling for Multiuser OFDM systems," in *Proceedings of the 2005 IEEE Wireless Communications and Networking Conference (WCNC'05)*, New Orleans, LA, March 13--17, 2005.
- X. Liu, E. K. P. Chong, and N. B. Shroff, "A framework for opportunistic scheduling in wireless networks," *Computer Networks*, vol. 41, no. 4, pp. 451--474, March 2003.
- X. Liu, N. B. Shroff, and E. K. P. Chong, "Opportunistic scheduling: An illustration of cross-layer design," *Telecommunications Review*, vol. 14, no. 6, pp. 947--959, December 2004.