Transmission Scheduling in Wireless Networks with SINR Constraints

Evelina Klerides and Themistoklis Charalambous

Themistoklis Charalambous

Control Laboratory, Department of Engineering
University of Cambridge

April 22, 2009

Outline

Outline

1. Introduction
   - Motivation
   - Medium Access Control (MAC)
2. System Model
   - Notation
   - The network
   - The channel
3. Main Results
   - Problem Definition
   - Assumptions
   - Formulation - Solution
   - Examples
4. Conclusions
   - Conclusions
   - Future Directions

Motivation

Applications:

- Battlefield communications
- Disaster recovery efforts
- Impromptu communication between people
- Wireless traffic sensor networks
- Ecological habitat monitoring
- Industrial process control

Why transmission scheduling?

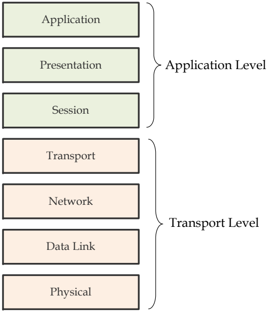
Orchestrate channel access in order to fully exploit spatial reuse:

- Establish feasible networks for successful transmissions
- Minimize the number of time-slots required
- Minimize the power dissipated in the network

Medium Access Control (MAC) - 1/2

MAC: Part of the Data Link Layer (layer 2 of the OSI model)

- Sits directly on top of the Physical Layer (layer 1)
- Purpose: to manage access to the shared wireless medium

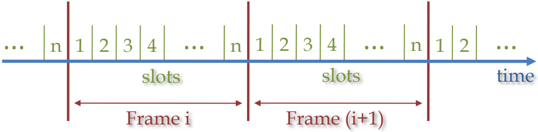


Medium Access Control (MAC) - 2/2

Nodes must decide when to access the channel, **avoiding collisions** and **efficiently utilizing the bandwidth**.

Classification of MAC protocols:

- Random access
  - Nodes contend for the channel
  - Most popular is CSMA/CA, the basis for IEEE 802.11
- Transmission Scheduling
  - Time is divided into frames and frames into time-slots.
  - Simplest example is TDMA (as many slots as nodes, one node per slot).



Outline

1. Introduction
   - Motivation
   - Medium Access Control (MAC)
2. System Model
   - Notation
   - The network
   - The channel
3. Main Results
   - Problem Definition
   - Assumptions
   - Formulation - Solution
   - Examples
4. Conclusions
   - Conclusions
   - Future Directions

Notation

$\mathscr{N}$	The set of all nodes in the network
$\mathscr{L}$	The set of active links in the network
$\mathscr{G} = (\mathscr{N}, \mathscr{L})$	The graph of the network
$\mathscr{T}$	The set of transmitters in the network
$\mathscr{R}$	The set of receivers in the network
g_{ij}	The channel gain on the link between transmitter i and receiver j
ν	The variance of thermal noise at the receiver
I_i	The interference power at the i^{th} receiver
Γ_i	The SINR at the i^{th} receiver
γ_i	The capture ratio set by the i^{th} receiver
P_i^{max}	The maximum power capacity of the i^{th} transmitter
D	The deadline of the network

The network

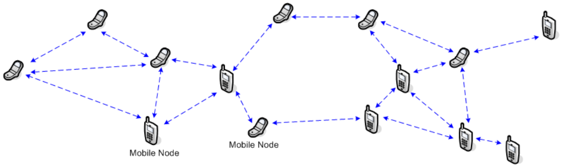


Figure: An example of an ad hoc topology.

- Planar network
- Half-duplex transceivers ⇒ Unidirectional links
- Omnidirectional antennas

Models

The simultaneous operation of wireless links usually is characterized by models that assume fixed interference and communication ranges, such as

1. The *Ideal Model*
2. The *Protocol Model*

On the contrary, the ***Physical Model*** is more realistic, since it considers the cumulative effects of interference due to simultaneous transmissions. This model considers the Signal-to-Interference-and-Noise Ratio (SINR) constraints at the receivers by considering all the secondary transmissions as noise.

Models

The simultaneous operation of wireless links usually is characterized by models that assume fixed interference and communication ranges, such as

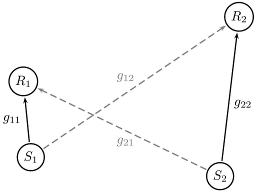
1. The *Ideal Model*
2. The *Protocol Model*

On the contrary, the ***Physical Model*** is more realistic, since it considers the cumulative effects of interference due to simultaneous transmissions. This model considers the Signal-to-Interference-and-Noise Ratio (SINR) constraints at the receivers by considering all the secondary transmissions as noise.

The channel

We consider the *Physical Model* where receivers experience **interference**:

$$I_i = \sum_{j \neq i, j \in \mathscr{T}} g_{ji} p_j + \nu. \tag{1}$$



where

g_{ij} the channel gain on the link between transmitter *i* and receiver *j*.

p_i the power level chosen by transmitter *i*.

ν the variance of thermal noise at the receiver.

The link quality is measured by the *Signal-to-Interference-and-Noise-Ratio* (SINR). A transmission is successful (error free), if the SINR at the receiver (Γ_i) is greater than the *capture ratio*, γ_i. Therefore, we require,

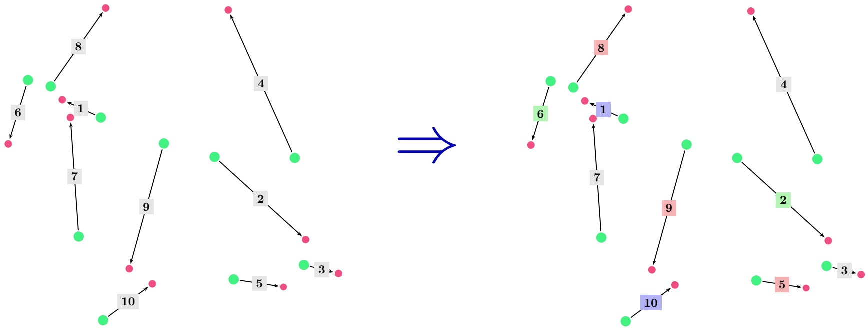
$$\Gamma_i = \frac{g_{ii} p_i}{\sum_{j \neq i, j \in \mathscr{T}} g_{ji} p_j + \nu} \geq \gamma_i \tag{2}$$

Outline

Problem Definition

Problem

Given N communication requests, assign a color (time-slot) to each request. For all requests sharing the same color specify the power levels such that each request can be handled correctly.



Assumptions

- No node mobility or routing is considered.
- Time is slotted and each communication pair needs exactly one slot.
- Nodes maintain global synchronization: They know when slots and frames start.

Problem formulation

Minimize

$$\tau = \max_{i \in \mathscr{T}} \{ \sum_{t=0}^{D} t x_i(t) \} \tag{3}$$

subject to:

$$\sum_{t=0}^{D} x_i(t) \geqslant 1 \qquad \forall i \in \mathscr{T} \tag{4}$$

$$p_i(t) \leqslant x_i(t) P_i^{max} \qquad \forall i \in \mathscr{T}, t \in [0, D] \tag{5}$$

$$p_i(t) g_{ii} \geqslant \gamma_i \left\{ \sum_{j \neq i, j \in \mathscr{T}} g_{ji} p_j(t) + \nu \right\} - (1 - x_i(t)) M_i \qquad \forall i \in \mathscr{T}, t \in [0, D] \tag{6}$$

$$x_i(t) \in \{0, 1\} \qquad \forall i \in \mathscr{T}, t \in [0, D] \tag{7}$$

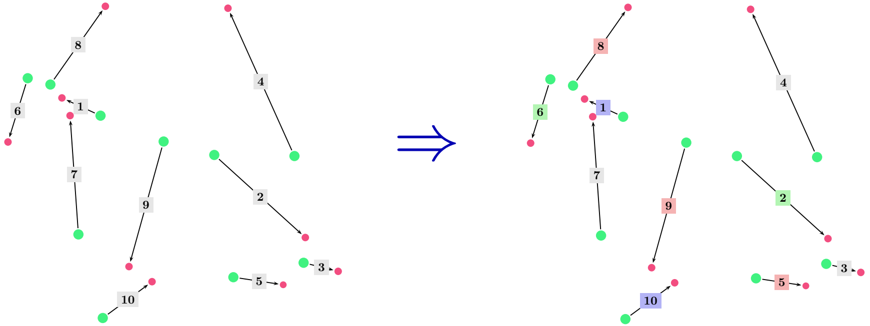
$$p_i(t) \geqslant 0 \qquad \forall i \in \mathscr{T}, t \in [0, D] \tag{8}$$

Solution

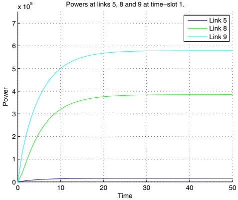
- Coded in Microsoft Visual Studio 2005 $C++$ using CPLEX v11.1
- Intel Core 2 computer (RAM: 3.5GB, Processor: 2.5GHz)
- **ICNS paper:**
    1. Solution approach: a non problem specific Branch and Bound (B&B) algorithm.
- **Improvements:**
    1. Solution approach: Exact cutting plane algorithm with lower and upper bounding techniques.
    2. Optimal schedule such that total power is minimized.

Illustrative example - 1/2

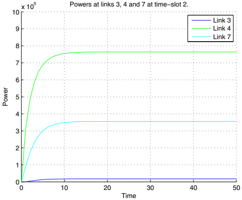
Time Slot	Links in process
1	5 (15820.5), 8 (385019), 9 (579226)
2	3 (17739.8), 4 (763932), 7 (355380)
3	2 (206559), 6 (24638.4)
4	1 (2924.78), 10 (166.464)



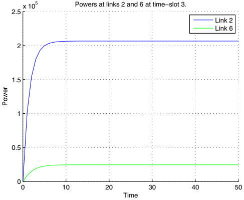
Illustrative example - 2/2



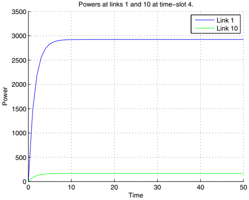
(a) Time-slot 1: Links 5, 8 and 9



(b) Time-slot 2: Links 3, 4 and 7



(c) Time-slot 3: Links 2 and 6



(d) Time-slot 4: Links 1 and 10

Numerical examples

No. of pairs	CPU time (sec)				
10	0.250	0.407	0.422	0.422	0.937
20	8.797	36.829	57.297	121.643	1655.220
30	73.126	178.204	296.160	2444.550	3600
40	75.409	900.033	3600	3600	3600

- Exponential growth of complexity with the number of communication pairs.

Numerical examples

No. of pairs	CPU time (sec)				
10	0.250	0.407	0.422	0.422	0.937
20	8.797	36.829	57.297	121.643	1655.220
30	73.126	178.204	296.160	2444.550	3600
40	75.409	900.033	3600	3600	3600

- Exponential growth of complexity with the number of communication pairs.

Outline

1. Introduction
   - Motivation
   - Medium Access Control (MAC)
2. System Model
   - Notation
   - The network
   - The channel
3. Main Results
   - Problem Definition
   - Assumptions
   - Formulation - Solution
   - Examples
4. Conclusions
   - Conclusions
   - Future Directions

Conclusions

- Solved the general transmission scheduling problem
  - Under SINR constraints.
  - Transmitters are able to adjust their power levels.
- Significance is twofold:
  - Of practical importance when a centralized controller exists.
  - Provides bounds for the evaluation of distributed algorithms.

Future Work

- Improve centralized algorithm:
    - Find a fast and efficient methodology. ✓
    - Make it problem specific. ✓
    - Find the scheduling that minimizes the total power as well. ✓
- Consider the geometrical physical model where:
    - Attenuation coefficients depend only on distance.
    - Information on the topology can be extracted.
- Distributed algorithm:
    - So far, a central entity makes decisions, based on global topology information. Not very useful for large networks since ***complexity*** and ***overhead communication*** increases.
    - ***Scalability***: extremely important, as wireless ad hoc networks are expected to be potentially large.