Lecture 7: Centralized MAC protocols

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CS 653 Spring 2014
Jan 27, Monday
Centralized MAC protocols

- Previous lecture – contention based MAC protocols, users decide who transmits when in a decentralized manner
- Today’s lecture – a central entity allocates resources to users sharing a medium
  - TDMA – Time Division Multiple Access
  - CDMA – Code Division Multiple Access
  - Other concepts – SDMA, FDMA / OFDMA
- Mainly used in cellular networks, as voice requires high QoS.
TDMA

- Assign different time slots to different users
- Fixed TDMA – Each user gets a fixed time slot irrespective of whether he has data to send or not
  - Wastes slots when users have bursty data
- Dynamic TDMA – the decision of which user sends when is decided on a per-slot basis
  - Users signal their intention to send data
  - Slots allocated to users who have data to send
  - Scheduling algorithm decides which user is scheduled to transmit in which slot
Scheduling algorithms

- Dynamic TDMA relies on scheduling algorithms. Tradeoff between efficiency and fairness.
- Common scheduling algorithms used in cellular networks
  - Round robin – schedule all users in a certain order. Guarantees fairness.
  - Max rate – schedule the user that has best channel conditions, i.e., can send at highest rate. This guarantees that the network gets high throughput. But may starve some users at cell edge.
  - Proportionally fair – schedule users according to a priority computed as $p = \frac{\text{current_rate}}{\text{average_rate}}$. The current rate is computed based on current channel conditions. So biased towards users with good channel and high rate. Also avoids starving of some users, because if average_rate becomes low enough, the user priority will increase and he will get scheduled.
- Proportionally fair scheduler (or its variants) is the most common design used in today’s networks.
CDMA

- Basic idea: transmit each user’s data using a unique code.
- Take each bit, exor with a longer bit sequence called code, and transmit the resulting new bit stream.
  - For example, suppose a user’s code is 010011. Then, for bit 1 the user sends the code “010011”. For bit 0, the user sends the complement “101100”.
- At the receiver, correlate with the code to recover data.
  - If correlation with 010011 is high, then it is 1. If correlation with complement is high, then it is 0.
- Different users are assigned different “orthogonal” codes, that is, codes which have low correlation with each other.
- Even if the signals of multiple users are combined, the receiver can extract its own transmission by correlating with its own code.
- Can be synchronous (code boundaries are aligned) or asynchronous. Codes are generated in different ways for both schemes.
Example, user A uses code 010011 and user B uses code 110101 (example from Schiller’s textbook)

Suppose A wants to send bit 1 and B wants to send bit 0. Let’s assume we send -1 for code bit 0.

A sends (-1,1,-1,-1,1,1) and B sends (-1,-1,1,-1,1,-1)

In a simplistic model where both signals combine, we get (-2,0,0,-2,2,0)

Correlate received signal with A’s code gives +6 → bit 1

Correlate with B’s code word gives -6 → bit 0

If B’s transmit power is much higher than A’s, that is, B’s bit sequence is scaled up, then harder to decode A’s bit.

Power control is very important in CDMA, as other transmissions appear as noise and reduce SNR
Frequency Domain View of CDMA

- Multiplying a bit with a code is equivalent to spreading the spectrum in the frequency domain (recall: faster pulses -> wider bandwidth)
- That is, each user uses a larger bandwidth than the original signal
- However, CDMA is not inefficient because many users are multiplexed over the same wider band
- This idea can be used for a single user too – spread spectrum modulation scheme
  - Achieves low rates, but useful with frequency selective fading and resilience to jamming by enemies
  - Direct Sequence Spread Spectrum (DSSS) is used for the 1 and 2 Mbps rates in 802.11b. A special 11 bit code is used to spread each bit.
Other ways of multiplexing

- Space Division Multiple Access (SDMA) – the idea behind having "cells" in cellular networks. Frequencies used in one cell can be reused in another cell that is some distance away.
- Frequency Division Multiple Access (FDMA) – assign multiple narrow channels to different users.
- Orthogonal Frequency Division Multiple Access (OFDMA) – Similar to OFDM, but different sub carriers can be allocated to different transmitters.
Challenges in centralized MACs

- TDMA requires tight time synchronization
- CDMA requires fine-grained power control (and possibly time sync)
- FDMA requires very precise channel filters to restrict users to specific frequencies
Multiple Access in Cellular Networks

- All cellular networks use SDMA to partition frequencies to cells.
- 2G networks mainly used plain TDMA (in GSM networks) or CDMA within a cell.
- 3G networks use a combination of TDMA and CDMA in a cell:
  - Voice mainly uses CDMA.
  - Special high-speed data channels exist in some 3G technologies. These use a combination of TDMA and CDMA. In every slot, a single user or multiple users can be scheduled. If multiple users, they are multiplexed using different codes.
- 4G / LTE uses TDMA + OFDMA on the downlink. That is, in each slot, a single user can be scheduled, or multiple users can be scheduled over multiple subcarriers in OFDM.