Mobile and Ubiquitous Computing
Media Access Control Protocols

Niki Trigoni
www.dcs.bbk.ac.uk/~niki
niki@dcs.bbk.ac.uk

Overview

- Intro to Media Access Control (MAC)
- MAC design goals
- Contention-based MAC protocols
  - CSMA, MACA, MACAW, IEEE 802.11 DCF, PAMAS
- TDMA MAC protocols
  - IEEE 802.11 PCF, Bluetooth
- Energy-efficient MAC protocols for sensor networks
  - S-MAC

Intro to Media Access Control

- Wireless medium is shared
- Many nodes may need to access the wireless medium to send or receive messages
- Concurrent message transmissions may interfere with each other => collisions => message drops
- A MAC protocol is needed to allow the efficient sharing of the wireless medium by multiple nodes

MAC design goals

- Design goals of a MAC protocol:
  - ***ensure reliable communication*** across wireless links (not end-to-end reliability, only 1-hop reliability)
  - ***maximize the use of available bandwidth*** (keep control overhead as low as possible)
  - ***ensure fair bandwidth allocation*** to contending nodes
  - ***minimize delay*** of sending/receiving messages
  - ***minimize energy-consumption*** of sending/receiving messages

Contention-based protocols

- Assumptions in contention-based protocols:
  - nodes may try to use the medium at any time (they don't reserve any time slots)
  - they all use the same frequency
- Protocols:
  - CSMA
  - MACA and MACAW
  - IEEE 802.11
  - PAMAS

CSMA - physical sensing

- **Carrier Sense Medium Access (CSMA)**
  - The transmitter first senses the wireless channel in the vicinity
  - The transmitter refrains itself from transmission if the channel is already in use
  - It waits for some time before the next attempt (backoff procedure).
  - Example: ALOHA protocol

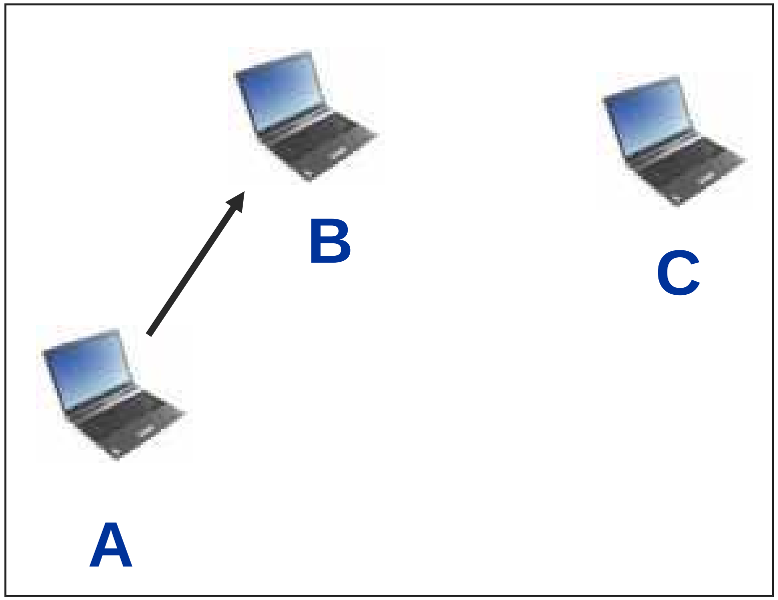
The exposed node problem

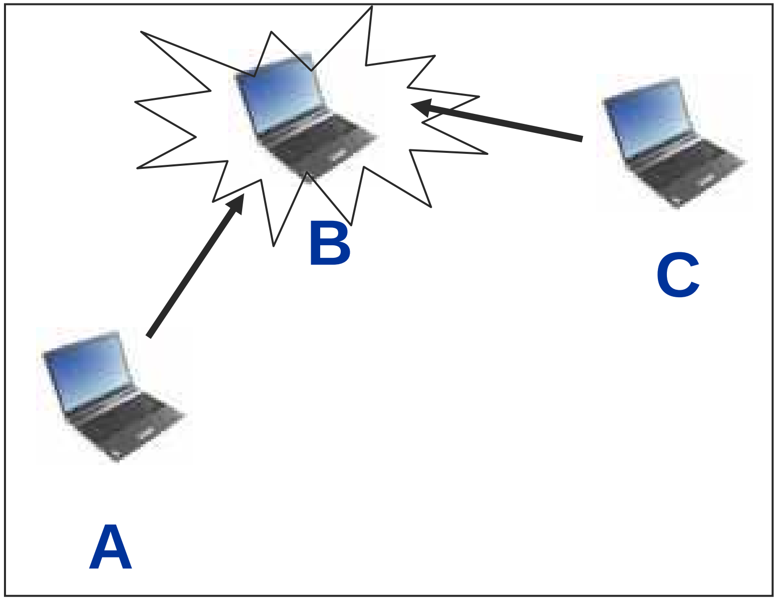
CSMA may cause nodes to unnecessarily refrain from accessing the medium.

B transmits to A.
C hears the transmission from B to A.
C ***unnecessarily*** refrains from sending a message to D even though no collision would occur.

The hidden node problem

CSMA does not avoid the hidden node problem.





A transmits to B.
B receives the message.
C does not hear the transmission.

A tries to transmit to B.
C also tries to transmit to B.
Both messages are dropped at B.

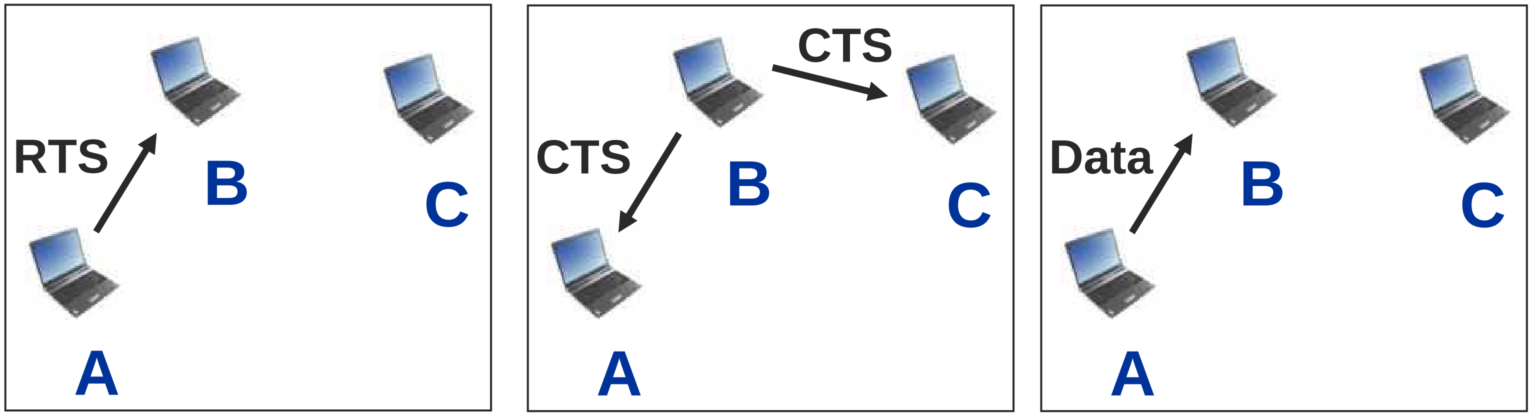
MACA – virtual sensing

- **MACA protocol: Multiple Access with Collision Avoidance** [Karn 1990]

  Nodes reserve the channel using control messages (virtual sensing):

  - The sender first expresses its wish to transmit by sending a Request-To-Send (RTS) message
  - The receiver allows this transmission by sending a Clear-To-Send (CTS) message
  - The sender then sends the Data message

RTS-CTS handshake



A sends RTS to B.
B sends a CTS to A (C overhears it).
A sends Data to B.

Both RTS and CTS carry information about the duration of the Data transmission.

RTS-CTS handshake

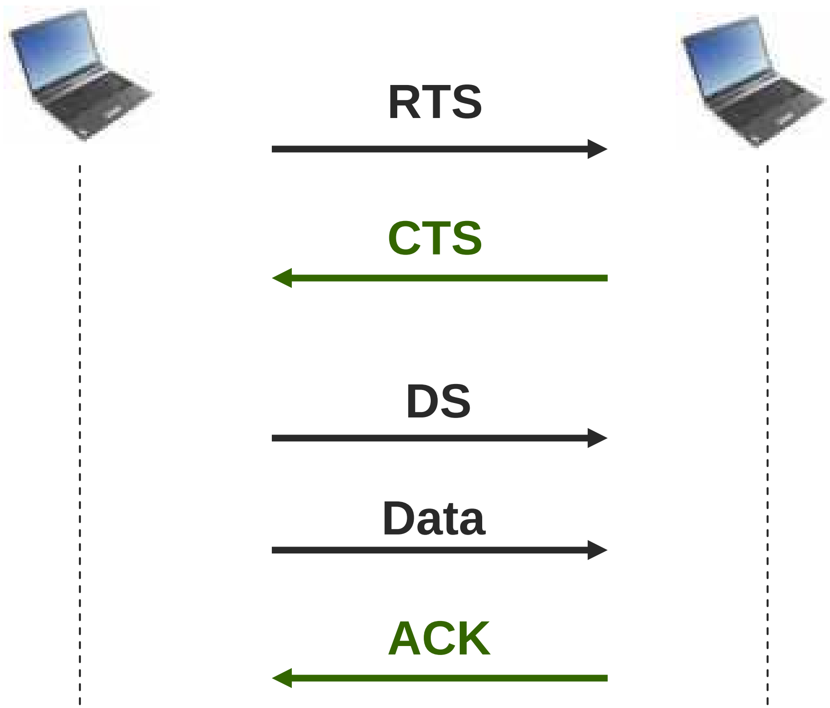
- If control (RTS-CTS) messages collide with each other or with data packets, a backoff procedure is activated (backoff is binary exponential).

- RTS-CTS helps to avoid some cases of the hidden and exposed node problems, because:
  - All neighbors of the sender hear the RTS.
  - All neighbors of the receiver hear the CTS.

- However, it does not always avoid these problems!

MACAW

- **MACAW** [Bharghavan et al. 1994] extends MACA
  - RTS-CTS-**DS-**Data-**ACK**



MACAW

- **MACAW** extends MACA with
  - DLL acknowledgements
  - an improved backoff mechanism

    => fair allocation of the medium to contending nodes
  - DS (Data Sending) message:
    - Say that a neighbor of the sender overhears an RTS but not a CTS (from the receiver)
    - In this case it can't tell if RTS-CTS was successful or not
    - When it overhears the DS, it realizes that the RTS-CTS was successful, and it defers its own transmission

IEEE 802.11 DCF

- **IEEE 802.11** is the standard MAC and physical protocol for wireless LANs.
- The DCF (Distributed Coordination Function) of the MAC sublayer does ***physical and virtual sensing***:
  - CSMA / CA (Carrier Sense Multiple Access with Collision Avoidance)
  - RTS-CTS-Data-ACK
  - RTS and CTS include the busy channel duration
  - All nodes that overhear either the RTS or CTS set their NAV (Network Allocation Vector) to the busy channel duration indicated in RTS/CTS.
  - A node can access the channel only if no signal is physically detected and its NAV value becomes zero.

PAMAS

- PAMAS [Singh and Raghavendra, 1998]: Power-Aware Multi-Access Protocol with Signaling
- Similar to MACA
- RTS-CTS occur over a ***separate signaling*** channel
- PAMAS conserves energy by:
  - Powering off its data channel, when it has not data to transmit or when its neighbors are using the medium
  - Powering up the data channel, upon being notified by the signaling channel that the node is ready to receive or send data
- Special circuit design is required

TDMA MAC protocols

- TDMA (Time Division Multiple Access) protocols
- Time is divided into timeslots
- Nodes transmit one after the other using their own timeslot
- TDMA requires good time synchronization
  - Scalability issue: hard to achieve time synchronization in large multi-hop networks
- Protocols:
  - IEEE 802.11 PCF
  - Bluetooth

IEEE 802.11 PCF

- IEEE 802.11 PCF (Point Coordination Function)
- One node, called Access Point (AP), coordinates the transmissions of its neighbors
- The AP polls neighbors one after the other, and allows them to transmit in a round robin manner
- PCF is not suitable for large multi-hop networks

Bluetooth

- Piconet: One node, called the master can communicate with up to 7 nodes called the slaves
- Bluetooth uses 79 channels (each 1 MHz wide) and changes channels up to 1600 times
- Each channel is divided into time slots of 625 µsecs
- The master switches from slave to slave in a round-robin fashion
  - Time-Division Duplex (TDD): master (downlink) and slave (uplink) transmissions occur in alternative slots
  - Slaves can talk back to the master immediately after they are polled by the master

Energy-efficient MAC protocols

- Energy savings are important in sensor networks:
  - battery-powered sensor nodes are left unattended in remote areas for large periods
- To increase lifetime of battery-powered nodes
  - Minimize the time that the radio is switched on:
    - Reduce collisions and packet retransmissions
    - Reduce overhearing

      (the receiving cost is comparable to the sending cost)
    - Reduce idle-listening

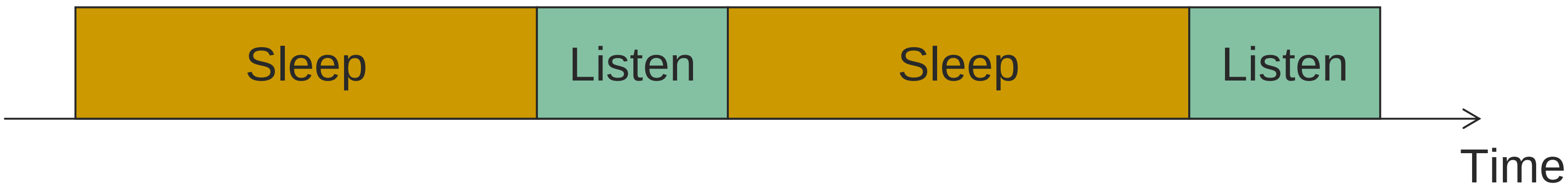
      (the listening cost is comparable to the receiving cost)
- Protocol: S-MAC (others are B-MAC, Z-MAC etc.)

S-MAC

- Main features of S-MAC [Yet et al. 2004]:
  - Nodes follow periodic sleep-listen schedules
  - Nodes avoid overhearing neighbor transmissions
  - Long messages are fragmented and sent together in a burst
  - Nodes on the same sleep-listen schedule contend for the medium using RTS-CTS-Data-ACK
- S-MAC ***reduces energy consumption*** but:
  - ***At the expense of delay***
  - ***At the expense of per-hop fairness***

S-MAC

- Nodes follow periodic sleep-listen schedules
  - Low duty cycle (say 10%) => increased delay



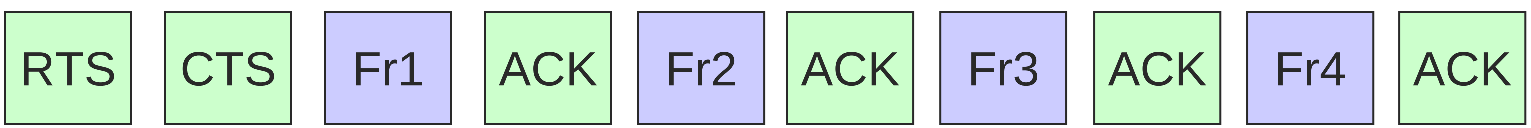
- A node tries to adopt the schedule of its neighbors
- If two neighbors have different schedules then the node may decide to:
  - either adopt both (=> spend more energy listening)
  - or adopt only one. In this case, if a node wants to send a message to a neighbor with a different schedule, it must wake up during the listen interval of that schedule.

S-MAC

- Nodes on the same schedule use RTS-CTS to contend for the medium
- On overhearing an RTS or CTS for a message that does not concern them, they turn off the radio for the duration allocated to the message's transmission
- Nodes save energy because they avoid overhearing Data-ACK packets not destined to them.

S-MAC

- Long messages are fragmented and sent in bursts
  - Only one RTS-CTS pair is sent
  - An ACK is sent for each fragment



- In this way, a node may reserve the medium for the period needed to send all fragments. The neighbors of the sender and receiver go to sleep.
- ***Fairness issue:*** The other nodes don’t get the chance to access the medium until the last fragment is transmitted

Summary

- The most important design goal of a MAC protocol is to enable ***shared access to the common wireless medium***
- ***Contention-based*** vs. ***TDMA-based*** MAC protocols
  - Contention-based protocols try to sense whether the medium is busy before accessing it (through physical or virtual sensing)
  - TDMA-based protocols share the medium by accessing it at different times
- In ***energy-constrained*** environments (e.g. sensor networks), MAC protocols aim to reduce radio usage (retransmissions, overhearing and idle listening)

Related Reading

- Vaduvur Bharghavan, Alan Demers, Scott Shenker, and Lixia Zhang. *MACAW: A media access protocol for wireless LAN's*. In Proceedings of the SIGCOMM '94 Conference on Communications Architectures, Protocols and Applications, pages 212--225, August 1994. **http://citeseer.ifi.unizh.ch/bharghavan94macaw.html**
- Wei Ye, John Heidemann and Deborah Estrin. *An Energy-Efficient MAC Protocol for Wireless Sensor Networks.* In Proceedings of the 21st International Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM 2002), New York, NY, USA, June, 2002. **http://www.isi.edu/~weiye/pub/smac_infocom.pdf**

Paper to prepare for discussion

- Wei Ye and John Heidemann. Medium Access Control in Wireless Sensor Networks. Technical Report, USC/Information Sciences Institute, ISI-TR-580, 2003. **http://www.isi.edu/~weiye/pub/isi-tr-580.pdf**