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Introduction to Wireless Local Area Networks MAC Protocol and its Energy Efficiency

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Abstract

- Wireless LAN is getting more and more attentions comparing with other wireless systems. For example, hop-spot application is available at railway stations, airports, harbors, trains, aeroplanes, etc., in many european countries. **Wireless Sensor Networks** (WSN) is promissing for industrial, domestic, and military applications. **Wireless Personal Networks** (WPAN) were also standardized recently. WLAN offers much higher throughput than its cellular counterparts with relatively low cost. However, there are still many pending problems and questions in implementing WLAN systems, especially at MAC layer and network layer. In this presentation a brief introduction to current WLAN access technology is given and some open problems/challenges at MAC layer are discussed for convenience of the interested audiences to start their research. Main concern is on the MAC protocol design for energy efficiency. In special, the features of wireless sensor networks are also discussed.

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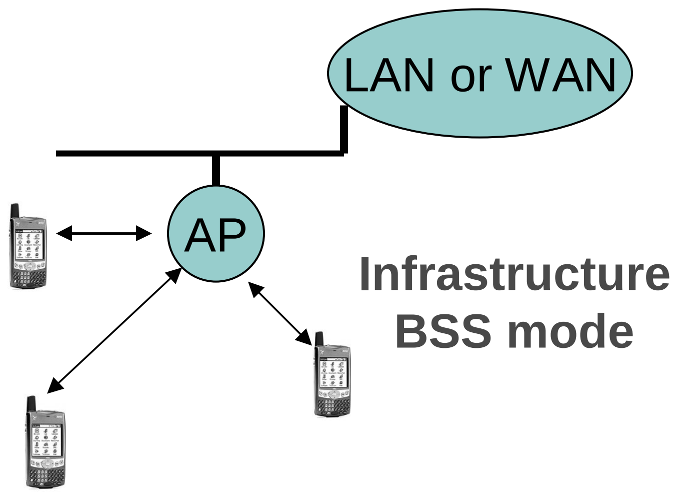
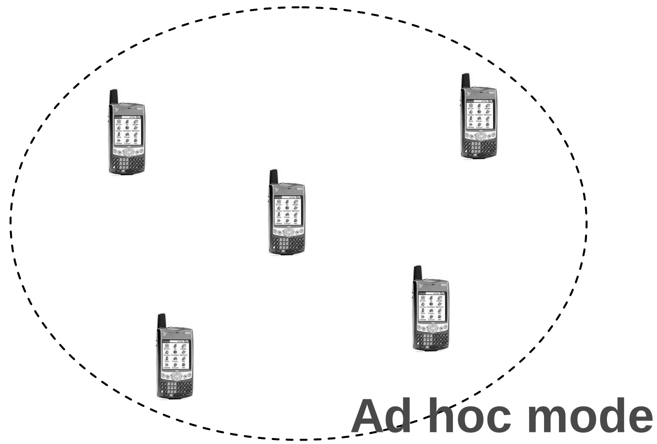
- Type of WLAN
- IEEE 802.11 Standards for WLAN
  - PHY layer
- MAC Layer Problems
- Energy Efficiency
  - Power Control
  - Sleep Mode
- Problems in Sensor Networks

Type of WLAN

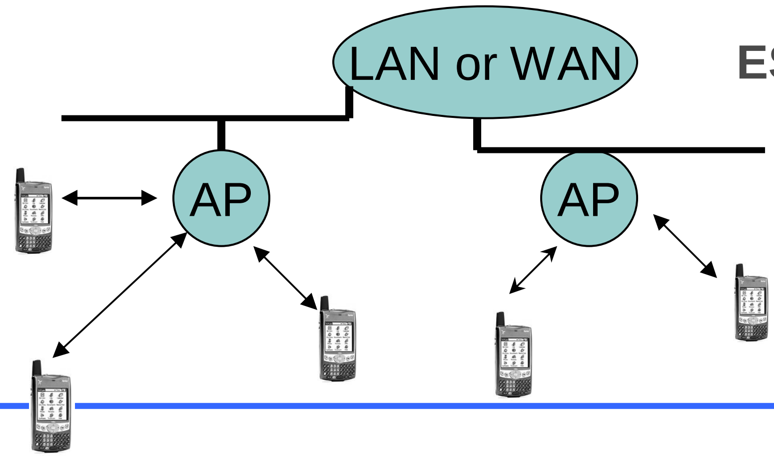
- **WLAN can be categorized into two types: infrastructure and ad hoc.**
- **In an infractucture WLAN, every mobile host is under the control of a Wireless Access Point (WAP).**
- **In an ad hoc WLAN, every mobile host is autonomous and coordinates with other hosts in an independent way.**





WLAN Standards - IEEE 802.11

- **The most popular standard in use.**
- **Apply to infrastructure mode and ad hoc mode.**
- **The infrastructure mode further contains** Basic Service Set **(BSS) and** Extended Service Set **(ESS) modes.**
- **A set of sub-standards:**
  - **802.11 – 2Mbps max rate at 2.4GHz ISM band**
  - **802.11b – 11Mbps max rate at 2.4GHz ISM band**
  - **802.11a – 54Mbps max rate at 5GHz band**
  - **802.11g – 54Mbps max rate at 2.4GHz band**



ESS mode

802.11b/a/g PHY layer: Modulation

- **2.4GHz ISM (Industrial, Scietifical, and Medical) band.**
  - **802.11: FHSS/DSSS (at 1 and 2 Mbps)**
  - **802.11b: DSSS (barker code at 1 and 2Mbps, CCK code at 5.5 and 11Mbps)**
  - **802.11g: OFDM (BPSK or QAM at 6, 9, 12, 18, 24, 36, 48, and 54Mbps)**
- **In europe, totally 13 channels are available in frequency band of 2400-2483.5MHz, with each channel 5MHz. Simultaneously 3 channels are available at one location.**
- **802.11a works at 5.15 to 5.35GHz and 5.725 to 5.825GHz (total 300MHz), with each channel 20MHz.**

MAC Layer - Outline

- IEEE 802.11 MAC layer
- Hidden and Expose Node Problem
- Solution: RTS/CTS handshake
- RTS/CTS flaws
- Other WLAN MAC protocols

IEEE 802.11 MAC layer

- **Carrier Sense Multiple Access with Collision Avoidance** (CSMA/CA) with **Distributed Coordinate Function** (DCF).
- A Src node first senses the channel for DIFS (**DCF Interframe Space**) interval, then the node sends DATA packet.
- The Dest node sends ACK back after a SIFS (**Short Interframe Space**) interval to garuantee the packet delivery phase.
- All other nodes hold one DIFS and start a **random backoff** before sending a new data packet.

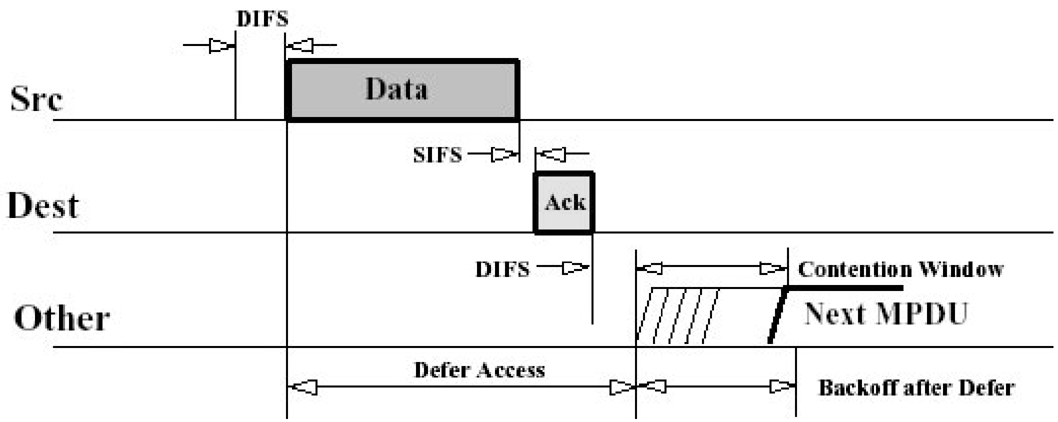
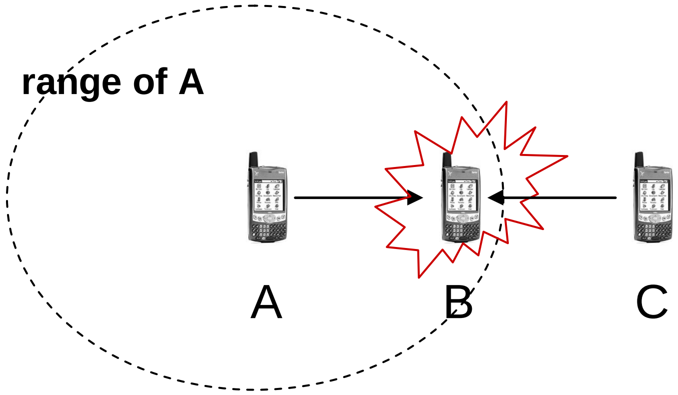


Figure 7 CSMA/CD Back-off Algorithm

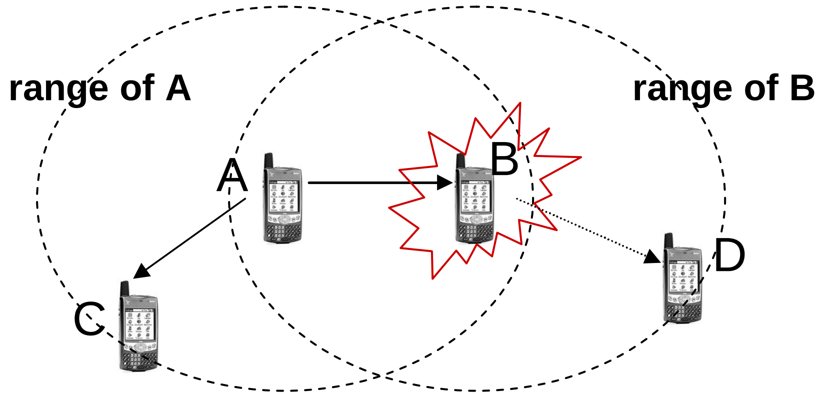
Hidden and Exposed Node Problem

- **When not all the nodes can hear each other, hidden node and expose node problems may occur.**



Hidden node

Exposed node



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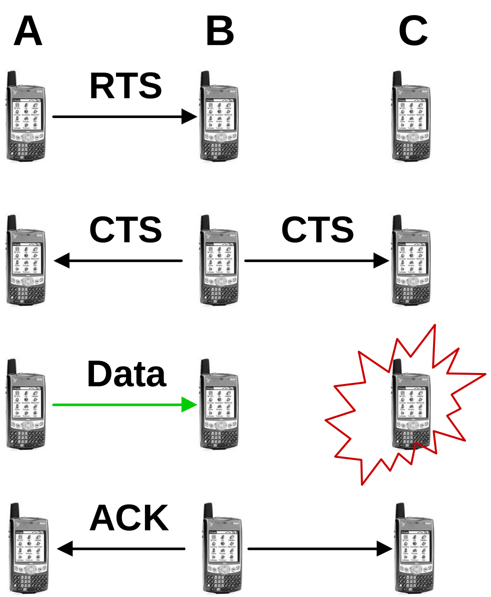
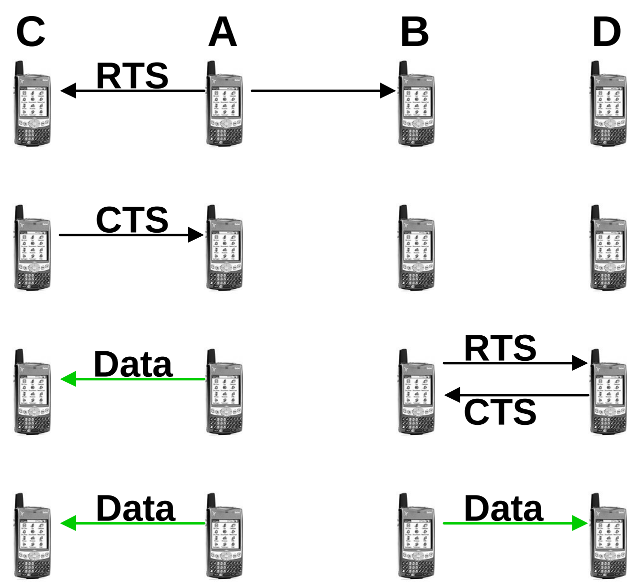
Solution: RTS/CTS

- **Before sending the DATA packet, the Src node sends a RTS (Request to Send).**
- **Upon the reception of RTS, the Dest replys a CTS (Clear to Send).**

Hidden node

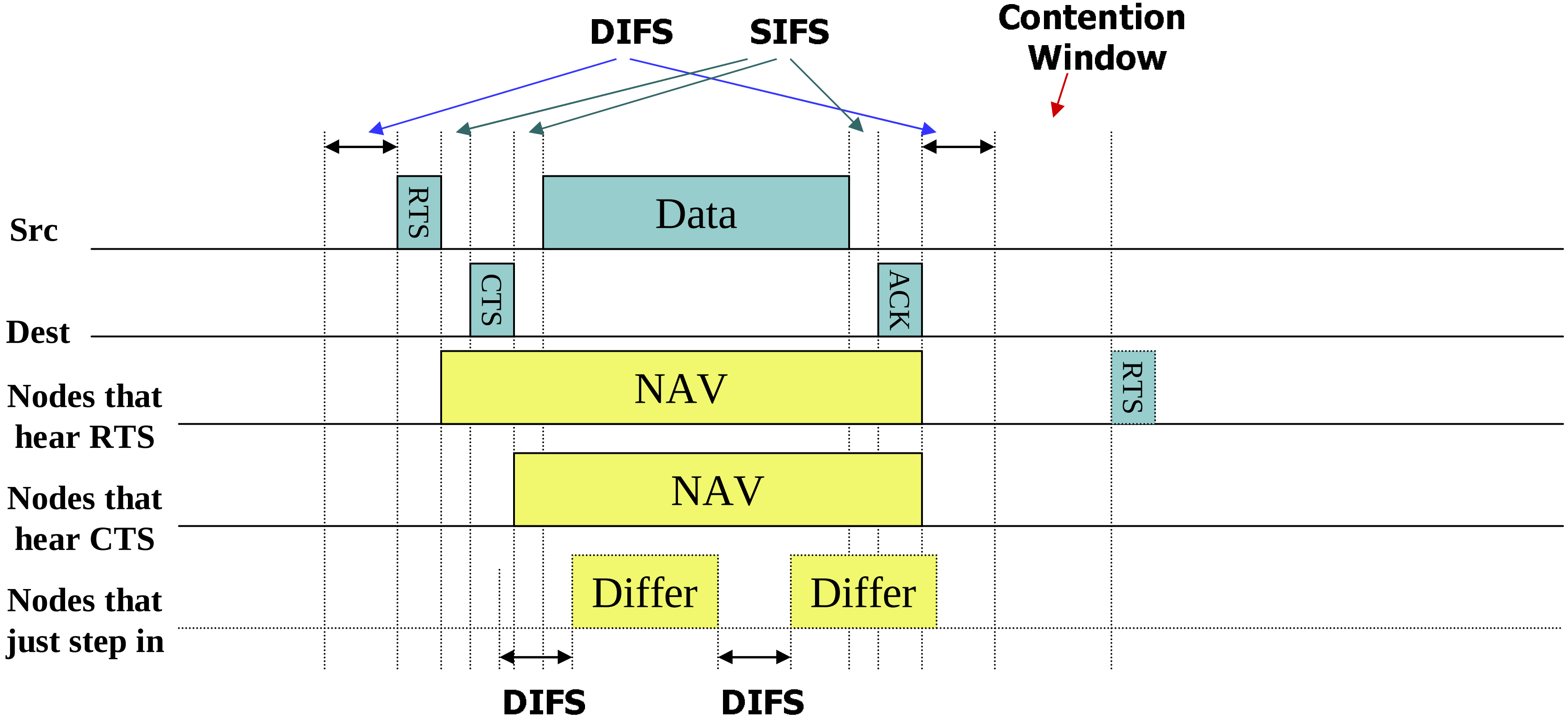


Exposed node



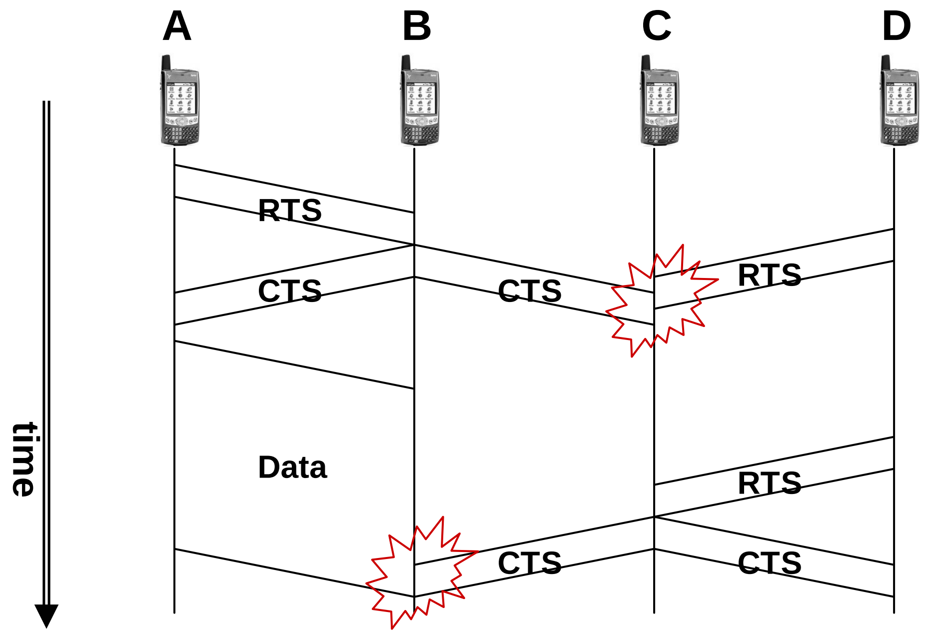
RTS/CTS/DATA/ACK Scenario with NAV

- **NAV: Network Allocation Vector**



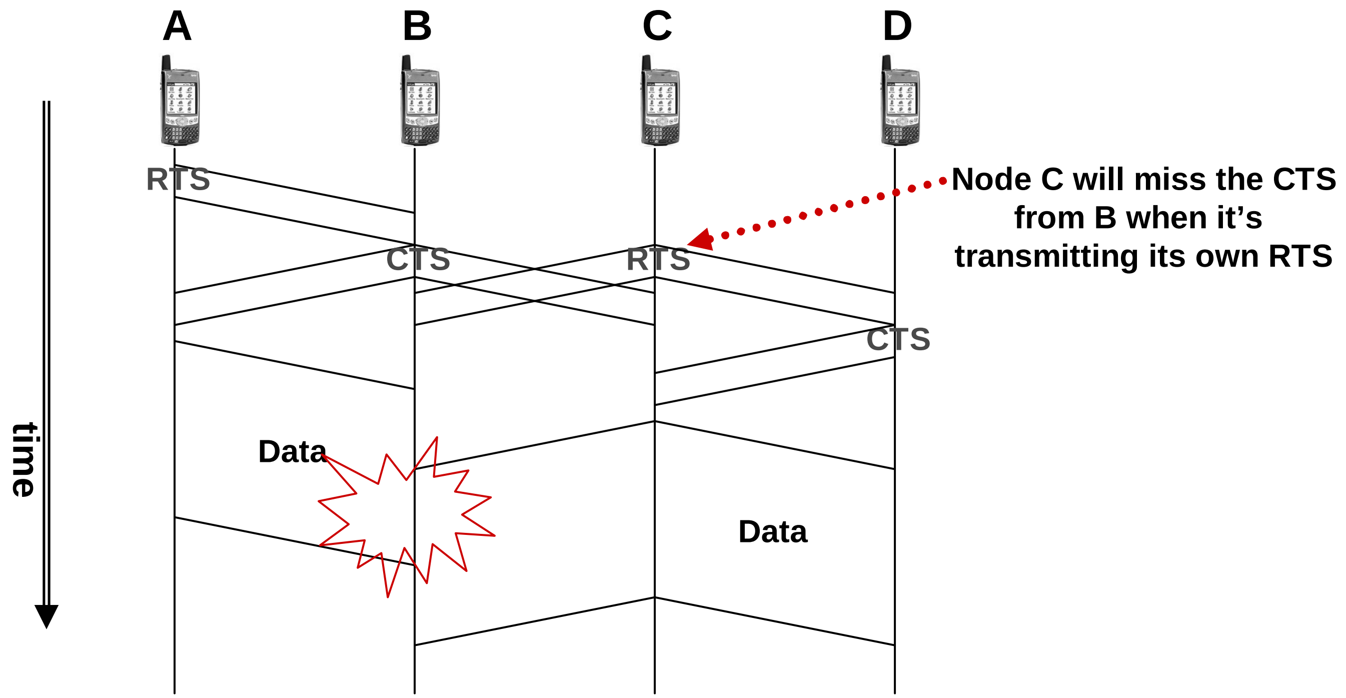
RTS/CTS Flaw (1)

- **Because RTS/CTS themselves are broadcasting packets (i.e., w/o ACK), nodes are not aware of the collision of this kind of packets.**



RTS/CTS Flaw (2)

- **Due to the use single antenna, a node cannot hear anything when transmitting.**



Other WLAN MAC protocols

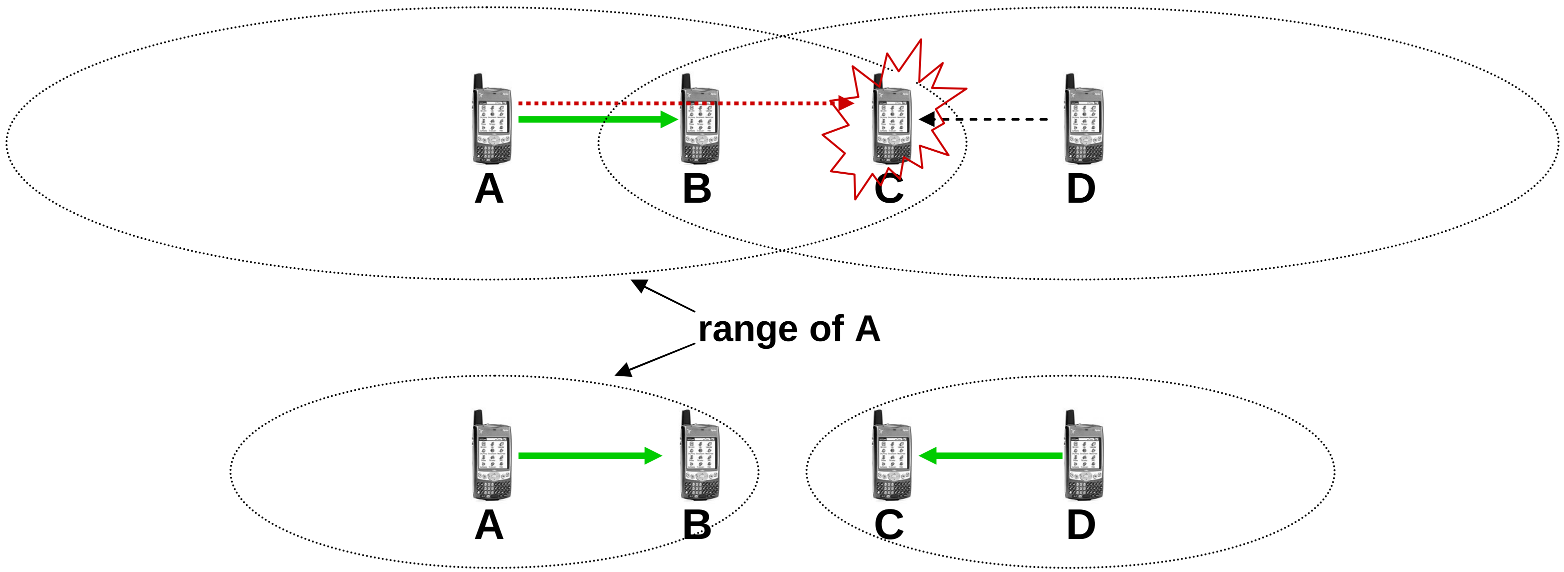
- MACA – Multiple Access with Collision Avoidance
- MACA with Power Control
- MACA-BI – MACA By Invitation
- PAMAS – Power Aware Multi-Access with Signalling
- STDMA – Spacial TDMA
- Slotted ALOHA
- DBTMA – Dual Busy Tone Multiple Access

MAC Energy Efficiency - Outline

- Power Control
  - basic idea
  - drawbacks
  - realization
- Sleep mode
  - in infrastructure mode
  - in ad hoc mode
- Energy efficiency can be also achieved by low power system design of Tx/Rx electronics and embedded systems, which is out of the scope of this talk.

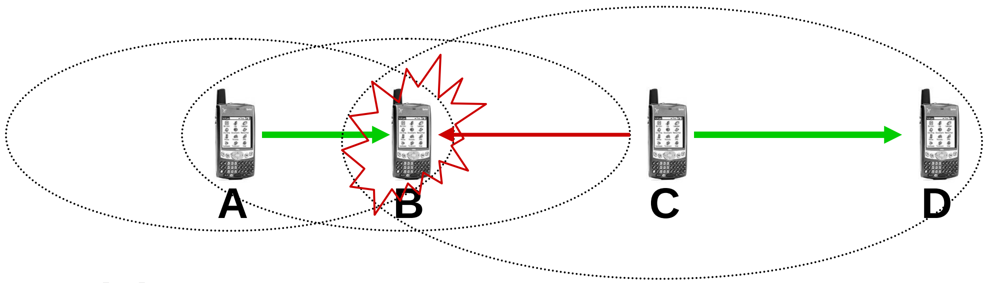
Power Control – Basic Idea

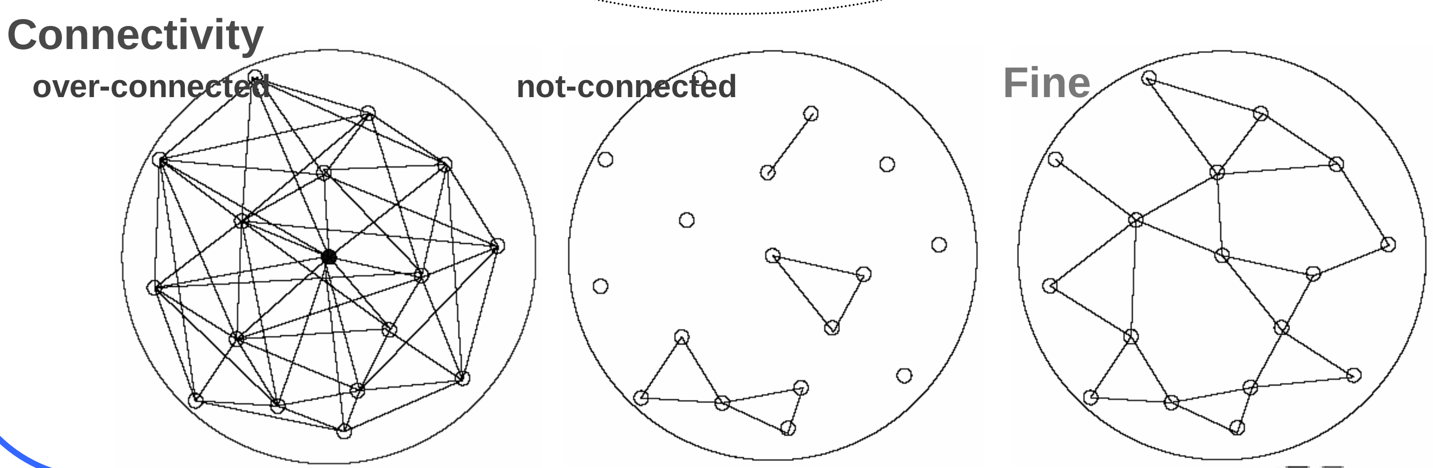
- **Power control is to dynamically adjust the transmit power so that the remote node can be reached by minimum power.**
- **Reduction of Tx power can also improve the network throughput.**



Drawback of Power Control

- **Unfairness: the communications with higher power have more chance to get the radio channel.**
- **Connectivity: the whole (ad hoc) network must be fully connected, but should not be over-connected.**





Realization of Power Control

- **Use Beacons to notify the neighbours and calculate Tx power.**
- **Use RTS/CTS handshake.**
- **Both apply the formula:** $P_{tx}^{*} = P_{tx} - P_{rx} + P_{min} + M$
- **Where** P_{tx}^{*} : the required power to transmit a packet to the remote node,
  P_{tx} : the transmit power used by the remote node,
  P_{min} : the minimum power required to receive a packet,
  M : safty margin for channel fluctuations.
- **Use GPS (not applicable indoor or geographically complex environments)**

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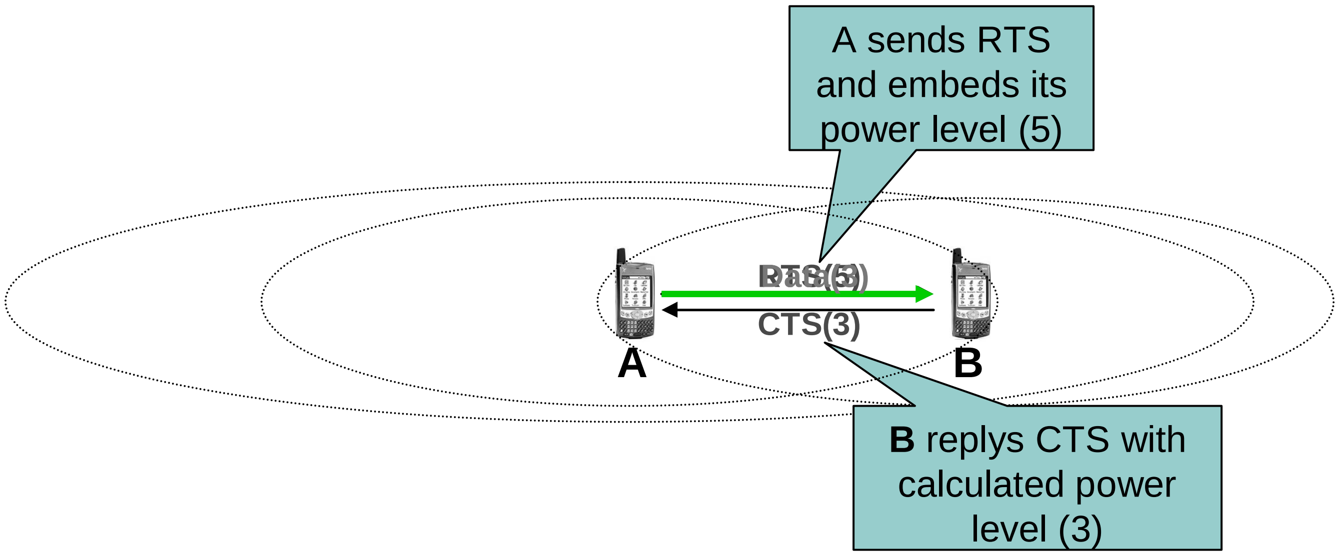
Realization of Power Control

- **Example (MACA with power control)**



Sleep Mode in Infrastructure

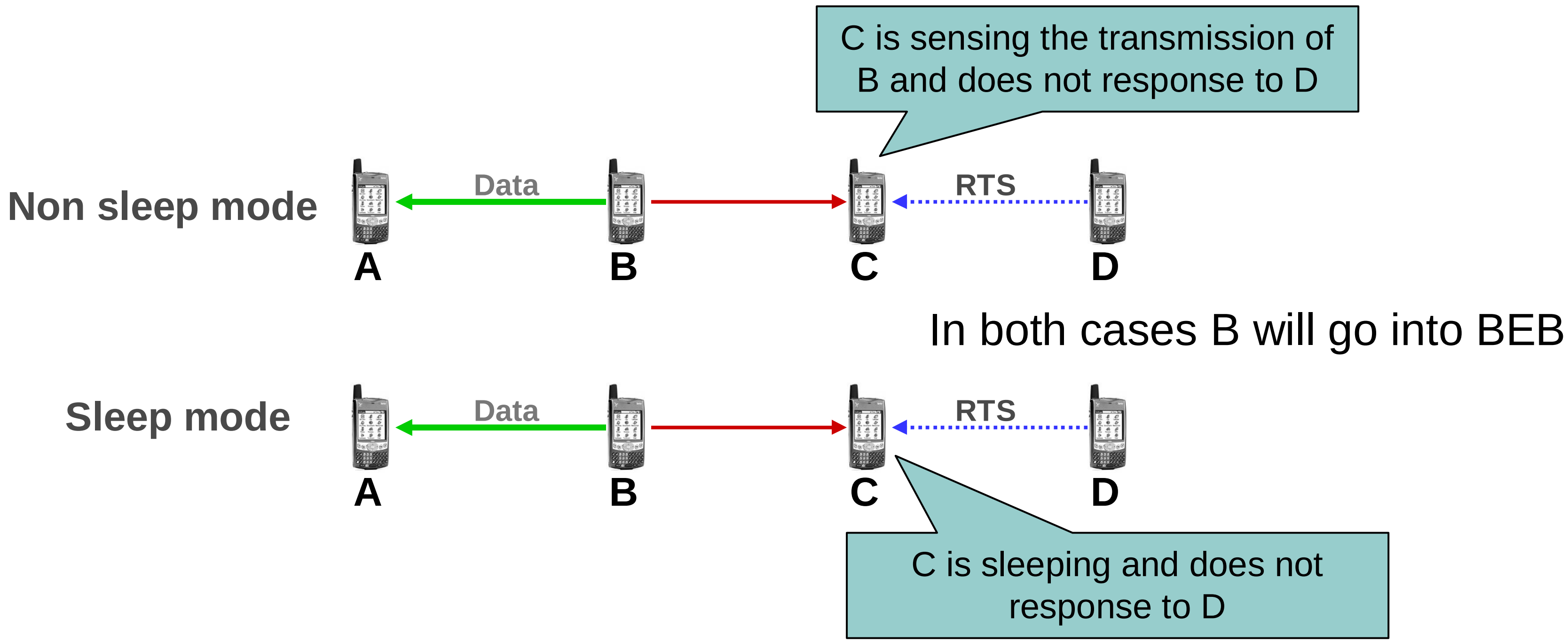
- A node consumes much less energy in sleep mode.
- Example: Cisco Aironet 350 802.11b PC card
  - Transmit: 450mA
  - Receive: 270mA, Idle mode is similar to it
  - Sleep: 15mA
- In an infrastructure WLAN, sleep mode is coordinated by the WAP(s).
  - When a node is sleeping, the WAP buffers all the incoming packets for it.
  - The node periodically wakes up and listens to Beacons from the WAP.
- The drawback of sleep mode is the increment of delay.

Sleep Mode in Ad-hoc: PAMAS

- **In an ad hoc WLAN, sleep mode is a distributed function at MAC or Network Layer.**
- **PAMAS – Power-Aware Multi-Access protocol with Signalling for ad hoc networks**
  - **Separate Signalling Channel: RTS/CTS and busy tones use a separate channel.**
  - **6 different states: Idle, Transmit, Receive, Await Packet, Await CTS, and BEB (Binary Exponential Backoff).**
- **PAMAS Sleep Mode:**
  - **If a node has no packet to send, if should power off itself if a neighbour begins transmitting.**
  - **If at least one neighbour is transmitting and another is receiving, it powers off itself (even has packets to send).**

PAMAS Example

- **Sleep mode does not degrade the performance significantly.**



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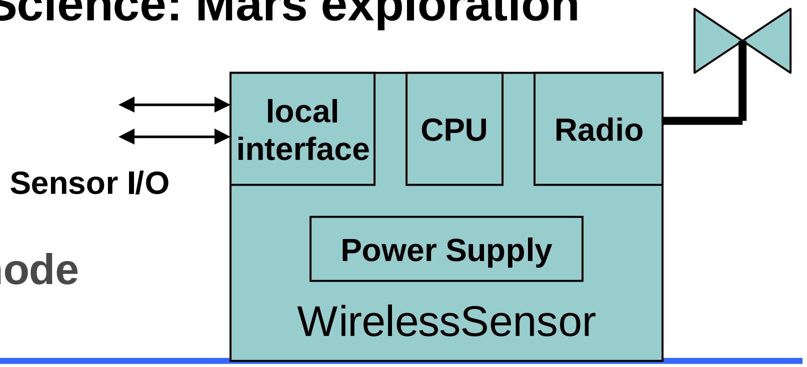
Sensor Networks

- **A Sensor Network is usually a huge number of wireless embedded devices binded together for environmental sensing & actuating.**
- **Applications:**
  - **Military: Battle field**
  - **Industry Automation: wireless auto-control**
  - **Forest fire alarming**
  - **Geographical surveying: ecosystems, earth resources**
  - **Environmental surveying: air, pollution, water quality, etc.**
  - **Space Science: Mars exploration**
  - **etc.**



Wireless Sensor node

Sensor Networks General Challenges

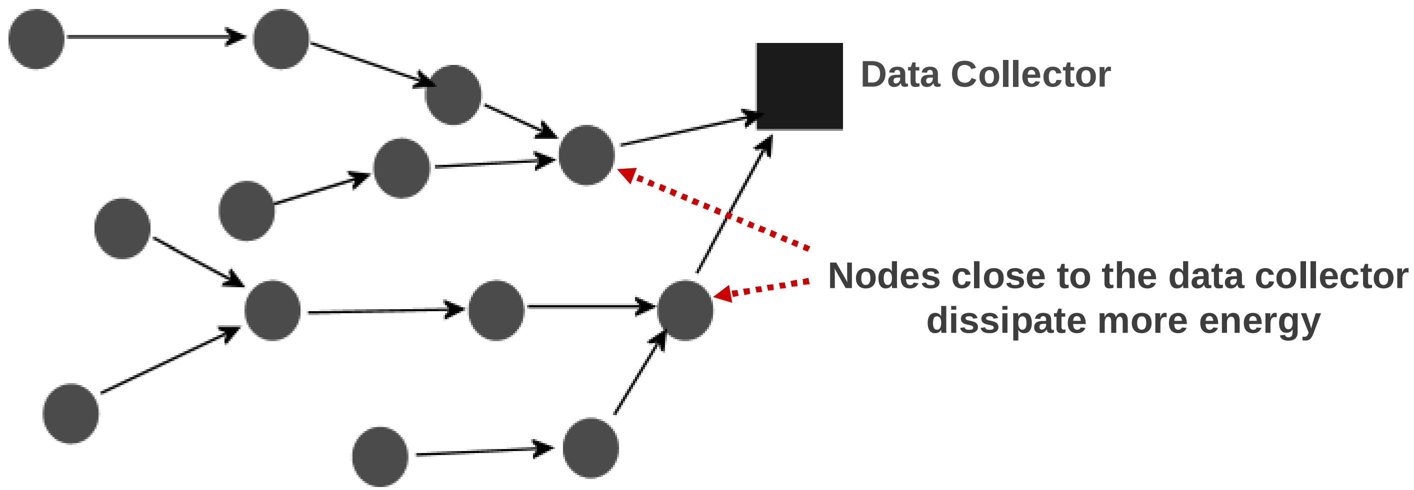
- Real-time analysis for rapid response
- Massive amount of data requires smart, efficient, innovative data management and analysis tools. (E.g., coverage problem, object-tracing, sensor node location, etc)
- Size, energy consumption oriented design
- Energy resource (battery, solar, energy-scavenging)
- Large-size topology organization
- And many more…

Energy Efficiency in MAC

- Collisions
- Control overhead
- Overhearing

} Common to all wireless networks

- Long idle time when no sensing event happens
- Energy unfairness due to the aggregation of information



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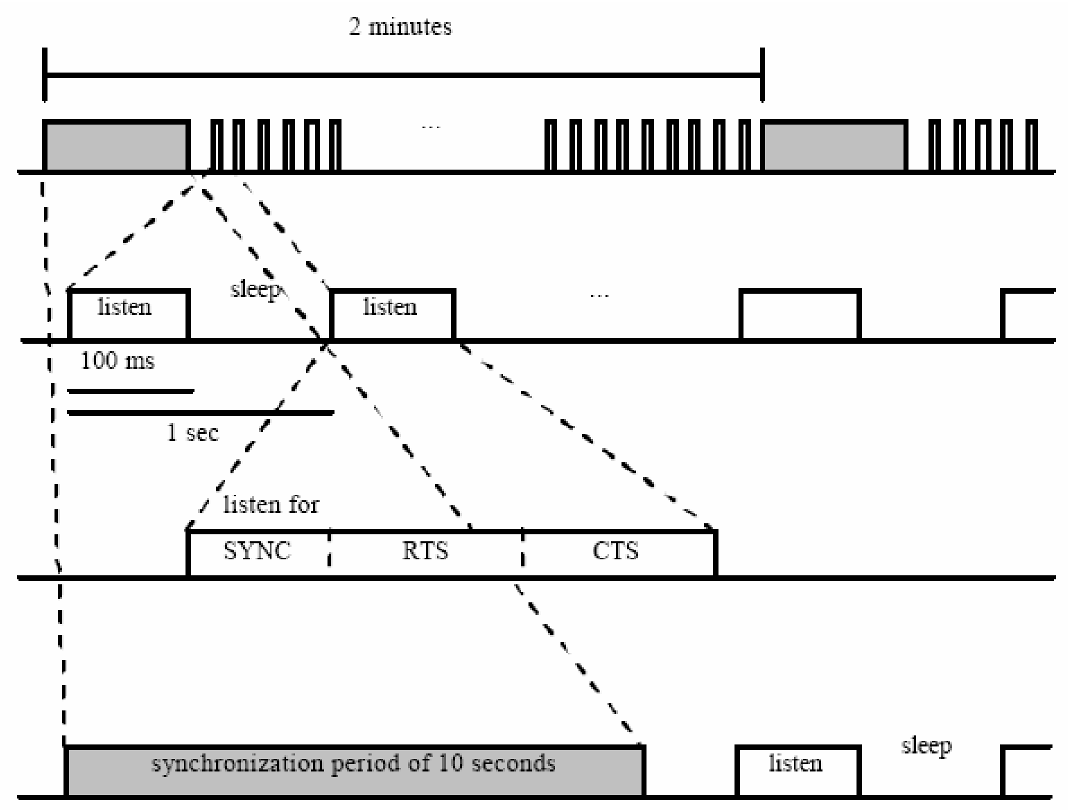
Sensor-MAC (SMAC)

- Designed to save energy in a multihop sensor network
- Based on 802.11 CSMA/CA
- Main components:
  - Periodic listen and sleep
  - Collision avoidance
  - Overhearing avoidance
  - Message passing

SMAC: Virtual Clustering & Synchronization

- **Virtual Clustering** makes a group of nodes close to each other to be synchronized to wake-up/sleep.
- The first node turned on will act as cluster header to synchronize other nodes.
- Nodes that can hear from two or more cluster headers will use multiple schedules to exchange data between clusters.

SMAC



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SMAC Problems

- Inter-Cluster nodes suffer more energy drain
- Long synchronization period makes the protocol not suitable for high mobility networks.
- Data aggregation problem is still existing.

Thank You!

Conclusion & Discussion

1. In wireless environment MAC protocol design is a hard job.
2. It is impossible to find a perfect way to cover all the problems.
3. Protocol complexity must be considered as well, especially in light-weight device design such as sensor nodes.
4. MAC protocol performance is also cross-layer related.
5. Energy-efficiency should not degrade the network performance.
6. ...

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