Sensor Networks: MAC Protocols

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Outline

- Background and Introduction
- Sensor Networks
- Basics of MAC-protocols
- Three protocols described
- Conclusions

Background

- Presentation based on:
  - C. Siva Ram Murthy and B. S. Manoj. Ad-Hoc Wireless Networks - Architectures and Protocols
  - Alec Woo and David E. Culler. A Transmission Control Scheme for Media Access in Sensor Networks
  - Katayoun Sohrabi, Jay Gao, Vishal Ailawadhi and Gregory J Pottie. Protocols for Self-Organization of a Wireless Sensor Network
  - Eugene Shih, Seong-Hwan Cho, Nathan Ickes, Rex Min, Amit Sinha, Alice Wang and Anantha Chandrakasan. Physical Layer Driven Protocol and Algorithm Design for Energy-Efficient Wireless Sensor Networks

Sensor Networks

- Network of wireless autonomous nodes
- Nodes use some sensors to monitor surrounding conditions
  - Temperature, wind, pressure...
- Network may consist of thousands of nodes
- Nodes are very constrained
- Robust and reliable network
- Nodes transmit their data to some infrastructure
  - Highly correlated traffic: All nearby devices transmit "same" information

Sensor Networks (2)

- Nodes consist of 3 subsystems
  - Sensor subsystem
  - Processing subsystem
  - Communication subsystem
- Communication subsystem is the major consumer of energy
- Randomly deployed networks: no topology
- No infrastructure: Everything must be distributed

MAC-protocols

- Medium Access Control
- Used to establish communication links among the nodes
- Must ensure efficient sharing of resources
  - Goal to maximize overall lifetime of the network
- Specific protocols for sensor networks needed
  - No global synchronization (at least difficult)
  - Topology changes (mobility and link failure)
  - Power efficiency

Basic kind of MAC-protocols

- Fixed-allocation
  - Predetermined assignment
  - Appropriate for networks that generate deterministic data traffic
  - Bounded delay for each node
  - May lead to inefficient use of communication channel
- Demand-based
  - Channel is allocated according to the demand of the node
  - Additional overhead for reservation process
- Contention-based
  - Random-access based contention for the channel
  - Suitable for bursty traffic

The Protocols

- Self-Organizing MAC for Sensor Networks (SMACS)
- Hybrid TDMA/FDMA
- CSMA-Based MAC Protocols

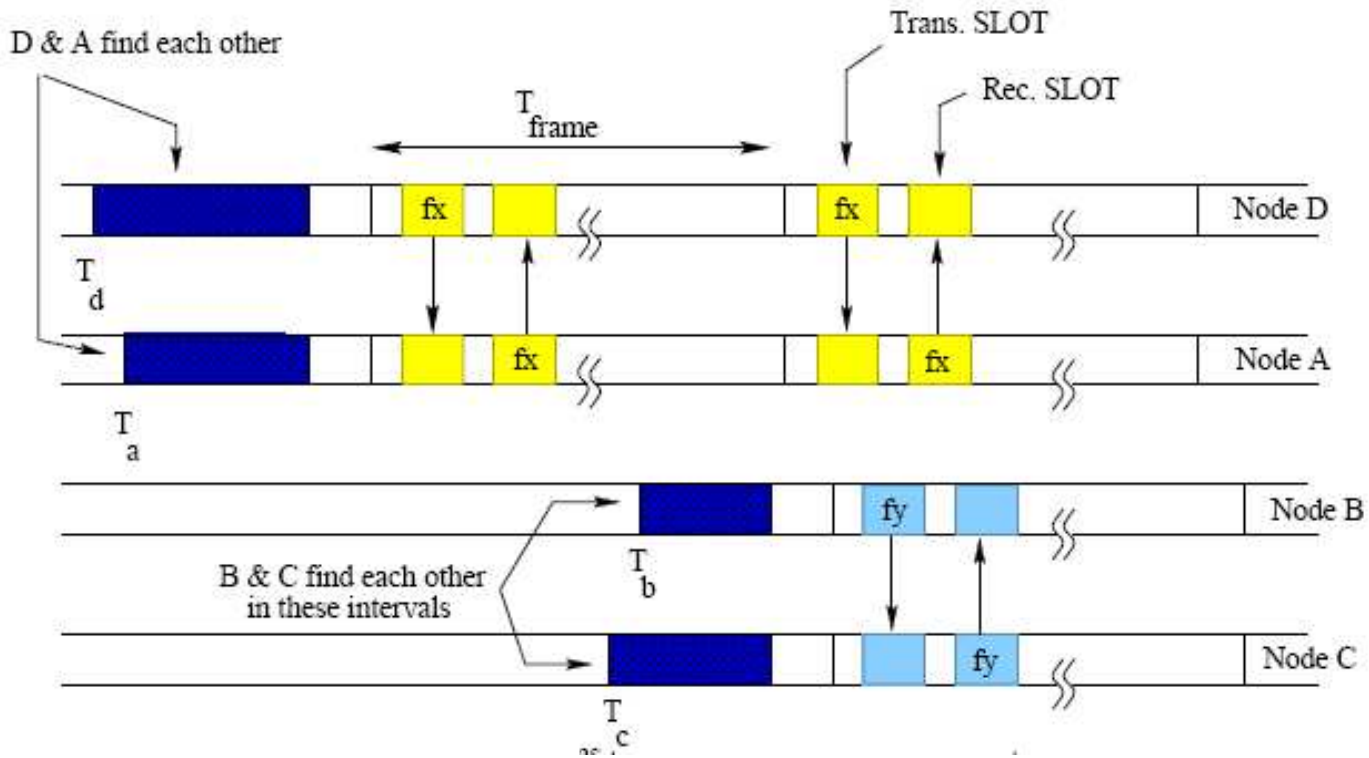
SMACS

- Protocol to build infrastructure
- Uses fixed allocation
- Assumptions
  - Nodes are able to turn radios on and off
  - Able to use different bands
- A pair of time slots defines a channel
- Synchronization needed only between a pair of devices
- Each link operates on different frequency
  - Frequency chosen from a large pool when the link is formed

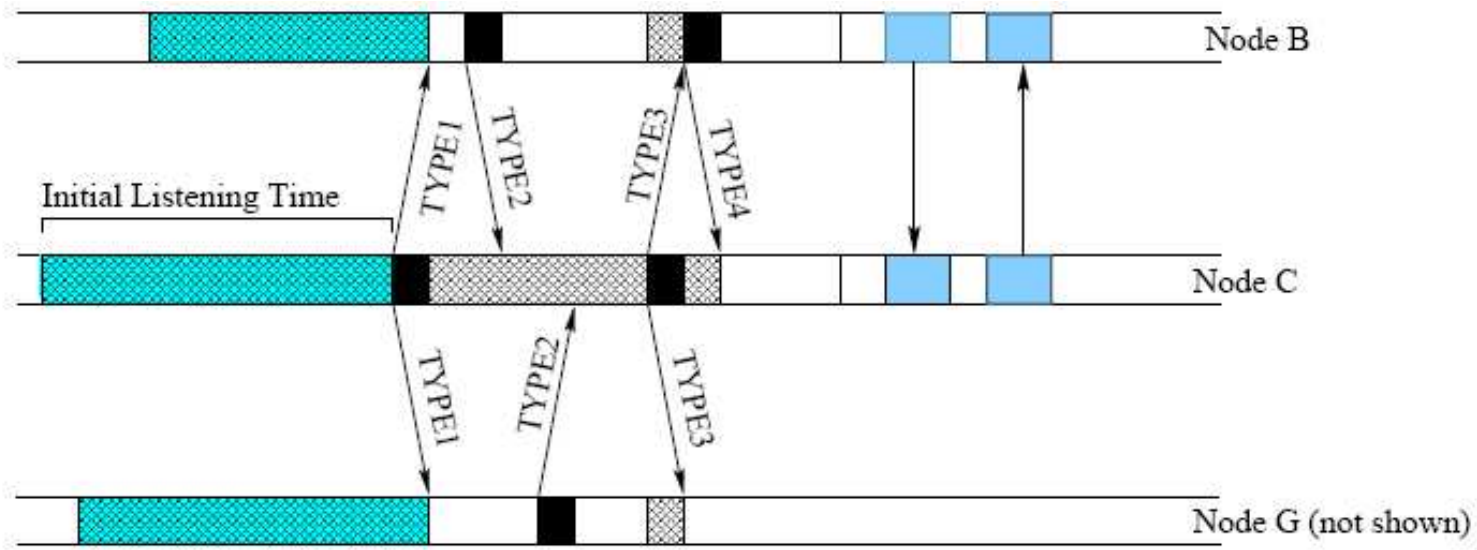
SMACS procedure

- Nodes wake up at some random time
- The nodes discover each other
- After discovery, nodes agree on a pair of fixed time slots
- The transmission pattern is repeated every T_{frame}
  - T_{frame} is a parameter of the system, fixed for each device

SMACS Communication Schedule



SMACS Node Discovery



(c) Details of node discovery phase

Hybrid TDMA/FDMA

- TDMA: Time division multiple access
- FDMA: Frequency division multiple access
- A centrally controlled scheme: All devices communicate directly with a base station
- TDMA minimizes the time a node needs to be kept on, the nodes can transmit at the highest data rate, but transmit on-time is minimized
- FDMA allots the minimum required bandwidth, and transmit on-time is maximized

Hybrid TDMA/FDMA (2)

- The used scheme is chosen based on energy consumption
- If transmitter consumes more power, TDMA is used
  - The transmitter can be switched off during idle slots
- If receiver consumes more power, FDMA is used
  - No need to expend power for time synchronization

CSMA-based

- Carrier sense multiple access
- Contention-based MAC-protocol
- The basic idea: Listen to channel and transmit if it is free
  - If the channel is not free, backoff
  - Effective if all nodes can hear each other
  - Listening comes with cost: The radio must be on
  - Shorten the listening period
- Backoff
  - Should be applied as a phase shift to the application's periodicity
  - To break the synchronization of periodic streams

RTC/CTS control scheme

- Request to send/Clear to send
- More suitable for computer networks with bigger packet sizes
- In sensor networks, a RTS-CTS-DATA-ACK chain constitutes up to 40% overhead
- A node wishing to transmit sends a RTS to its parent and waits for reply
- If no CTS packet received or CTS not destined to it, backoff with a binary exponential increasing backoff window
- If a node hears a CTS before it wishes to transmit, it delays its transmission to avoid corrupting the traffic

Rate Control Mechanism

- A node attempts to send a packet
- If the recipient forwards the packet (or acknowledges), transmission was successful
- If the packet is not acknowledged, backoff
- If transmission succeeds, the sending node can increase its transmission speed

Rate Control Mechanism (2)

- S is the maximum transmission rate of application
- $p * S$ is the actual transmission rate in the beginning ($p \in [0, 1]$)
- If transmission succeeds, increase p with constant α
- If transmission fails, decrease p: $p := \beta * p$, $0 < \beta < 1$
- For intermediate (routing) nodes, the penalty is smaller to achieve fairness

Simulation vs. Empirical results

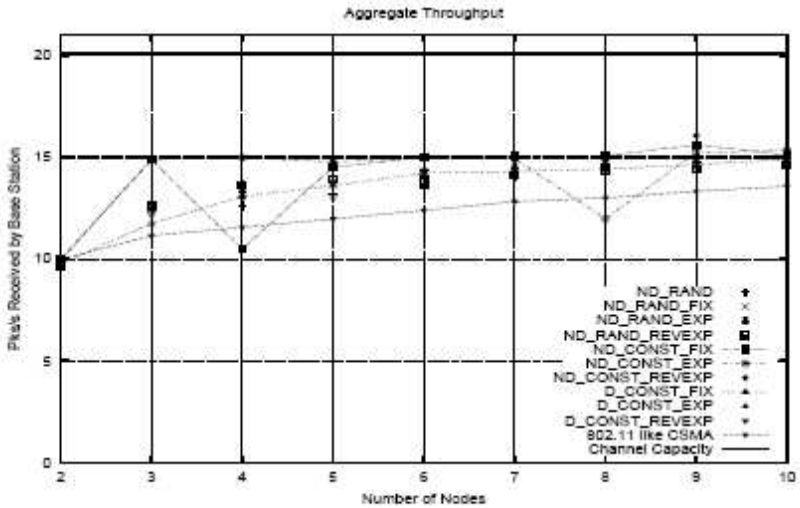


Figure 4: Aggregate delivered bandwidth for CSMA schemes with typical start conditions and offered load of 5 packets per second per node.

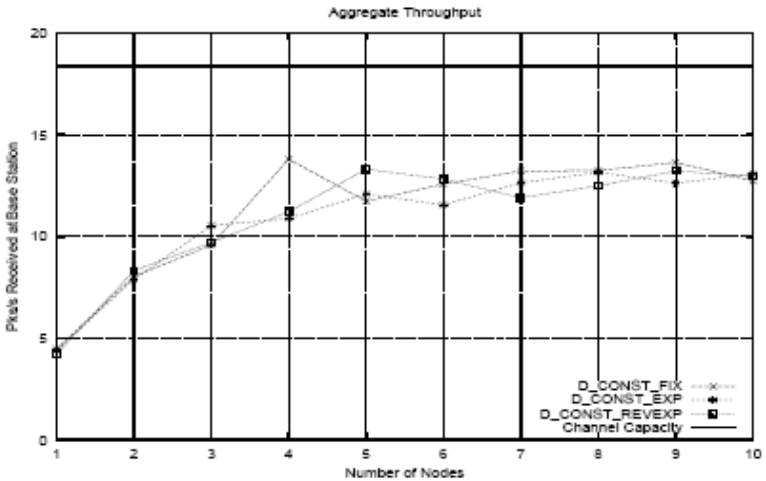


Figure 11: Actual aggregate bandwidth obtained over our network sensor prototypes for the different CSMA schemes. (Empirical)

Conclusions

- The properties of sensor networks should be taken into account while designing MAC protocol
- Battery consumption can be thought as a main goal for each application
- Different kinds of protocols with different applications
  - TDMA-based when traffic is evenly distributed between the nodes
  - CSMA-based protocols are designed mainly to increase energy efficiency and maintain fairness

Thank You!

Questions?