Sensor Networks Preliminaries

Dr. Chengzhi Li

Sensor Networks

Wireless sensor networks consists of group of sensor nodes to perform distributed sensing task using wireless medium.

Characteristics

- low-cost, low-power, lightweight
- densely deployed
- prone to failures
- two ways of deployment: randomly, pre-determined or engineered

Objectives

- Monitor activities
- Gather and fuse information
- Communicate with global data processing unit

Sensor Networks vs. Traditional Wireless Networks (Cellular, MANET)

- Higher number of sensor nodes (several orders of magnitude)
- Dense deployment
- Prone to failures
- Limited in power, computation and memory
- May not have global identification (ID) due to high overhead and the total number of sensors
- Optimization on the energy consumption vs. QoS and high bandwidth constraints
- Stationary vs. mobile
- Data flow: unidirectional vs. bi-directional
- Date rates

Applications of Sensor Networks

1. Military:
   - Monitoring equipment and ammunition
   - Battlefield surveillance and damage assessment
   - Nuclear, biological, chemical attack detection and reconnaissance
2. Environmental:
   - Forest fire / flood detection
3. Health:
   - Tracking and monitoring doctors and patients inside a hospital
   - Drug administration in hospitals
4. Home:
   - Home automation
   - Smart environment
5. Other Commercial Applications:
   - Environmental control in office buildings
   - Detecting and monitoring car thefts
   - Managing inventory control
   - Vehicle tracking and detection

Example:

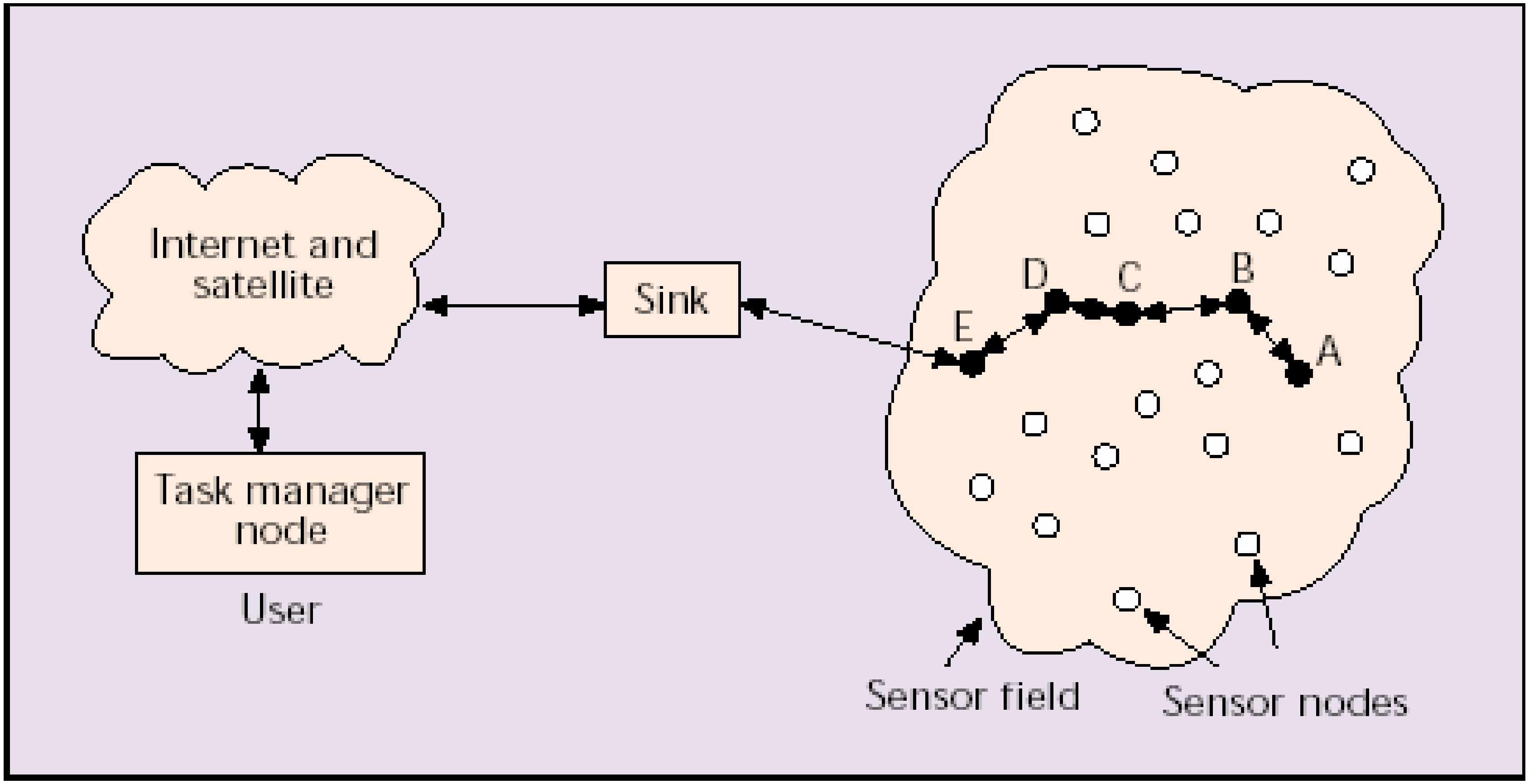


Figure 1. *Sensor nodes scattered in a sensor field.*

Sensor's Hardware

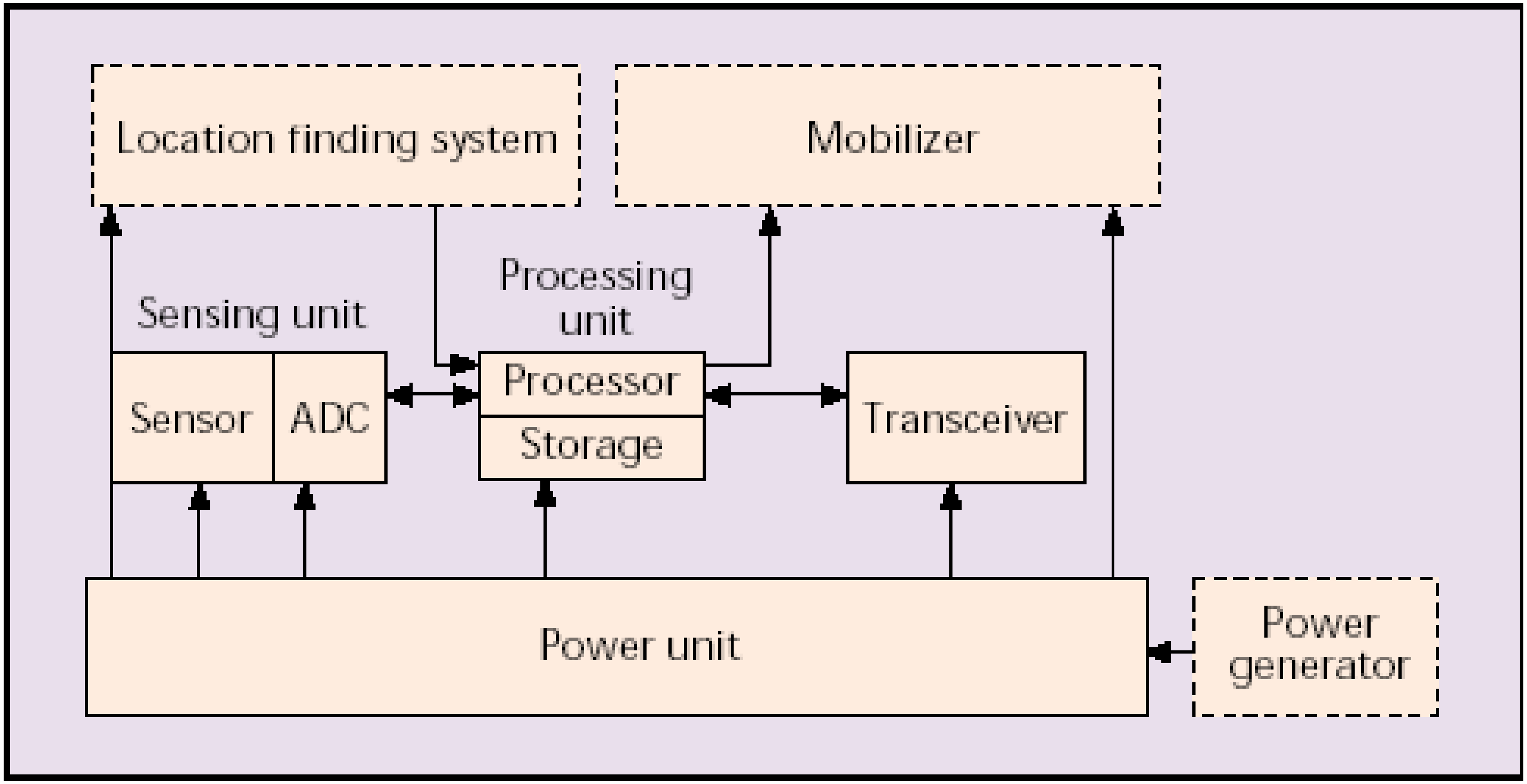


Figure 2. *The components of a sensor node.*

Factors Influencing Sensor Network Design

- Fault tolerance
- Scalability
- Security
- Production costs
- Hardware constraints
- Sensor network topology
- Environment
- Transmission media
- Power consumption

Sources of Power Consumption

- Idle Listening – transceiver goes into receive mode whenever not transmitting

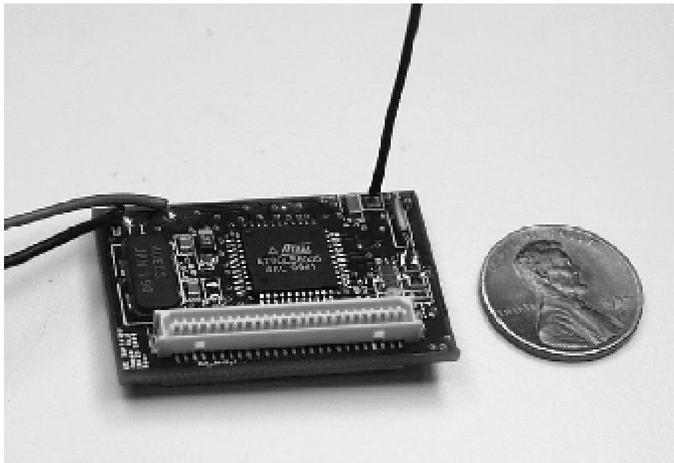
Radio State	Power Consumption (mW)
Transmit	81
Receive	30
Idle Listening	30
Sleep	0.003

Table 1. Characteristics of a sensor radio [7].

- Retransmissions resulting from collision
- Control packet overhead
- Unnecessarily high transmitting power
- Sub-optimal utilization of available resources – e.g., not using routes which utilize the nodes having largest remaining battery life

Fundamental trade-off

Power Saving and Network Connectivity!



- Power cable is infeasible
- Battery recharge is infeasible
- Battery limits the life time of sensor networks

Power Saving Involves Physic Layer, MAC Layer, Network Layer, and Application Layer

Required Reading for Sensor Networks

"**A survey on sensor networks**", *Akyildiz, I.F.; Weilian Su; Sankarasubramaniam, Y.; Cayirci, E.*, Communications Magazine, IEEE , Volume: 40, Issue: 8 , Aug. 2002 Pages:102 - 114

Cross-Layer Scheduling for Power Efficiency in Wireless Sensor Networks

IEEE INFOCOM 2004

Author : Mihail L. Sichitiu

Outline

- Motivation of this paper
- Related works
- Proposed power schedule
- Simulation results
- Comments

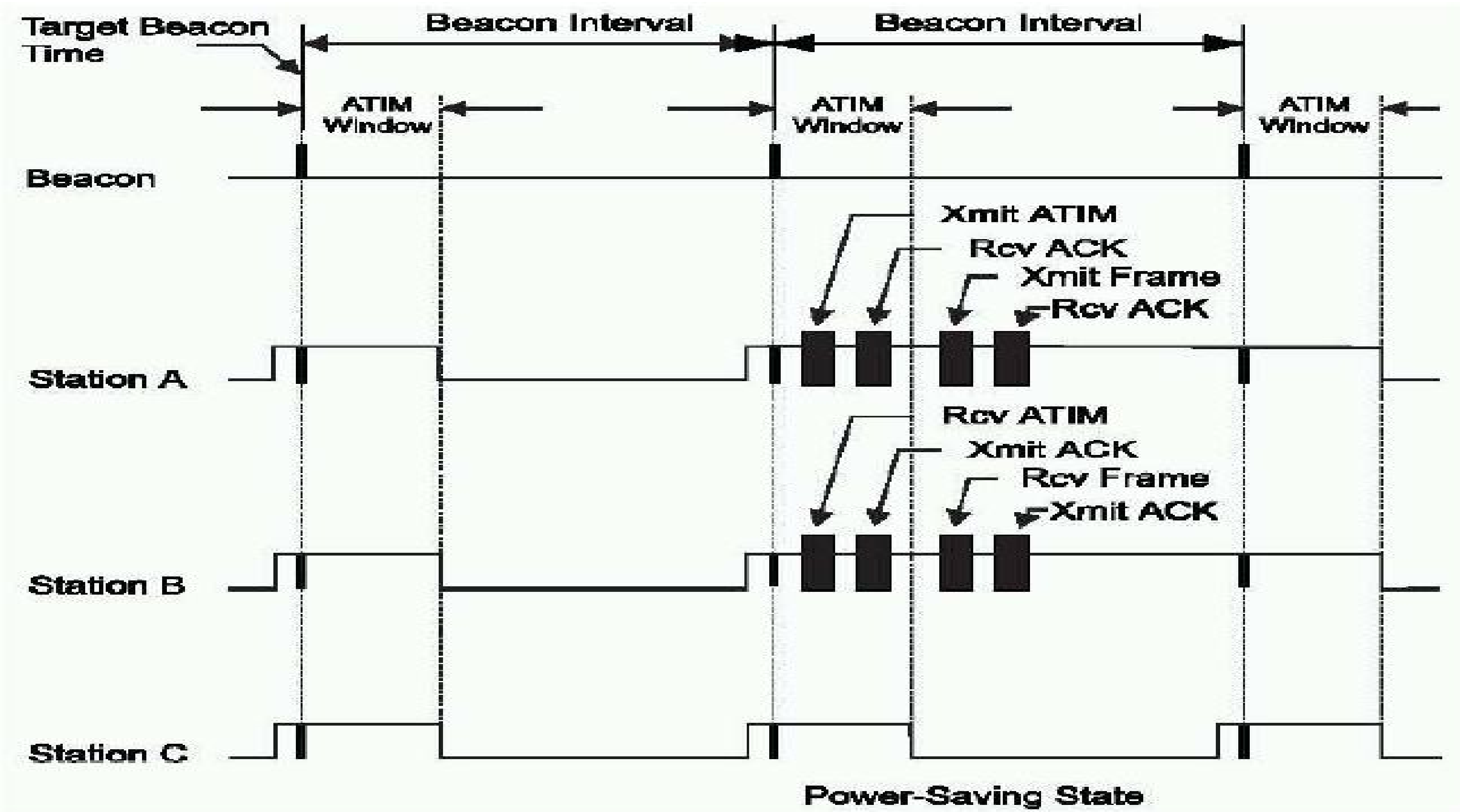
Motivation of This Paper

Saving energy to maximize sensor network life time

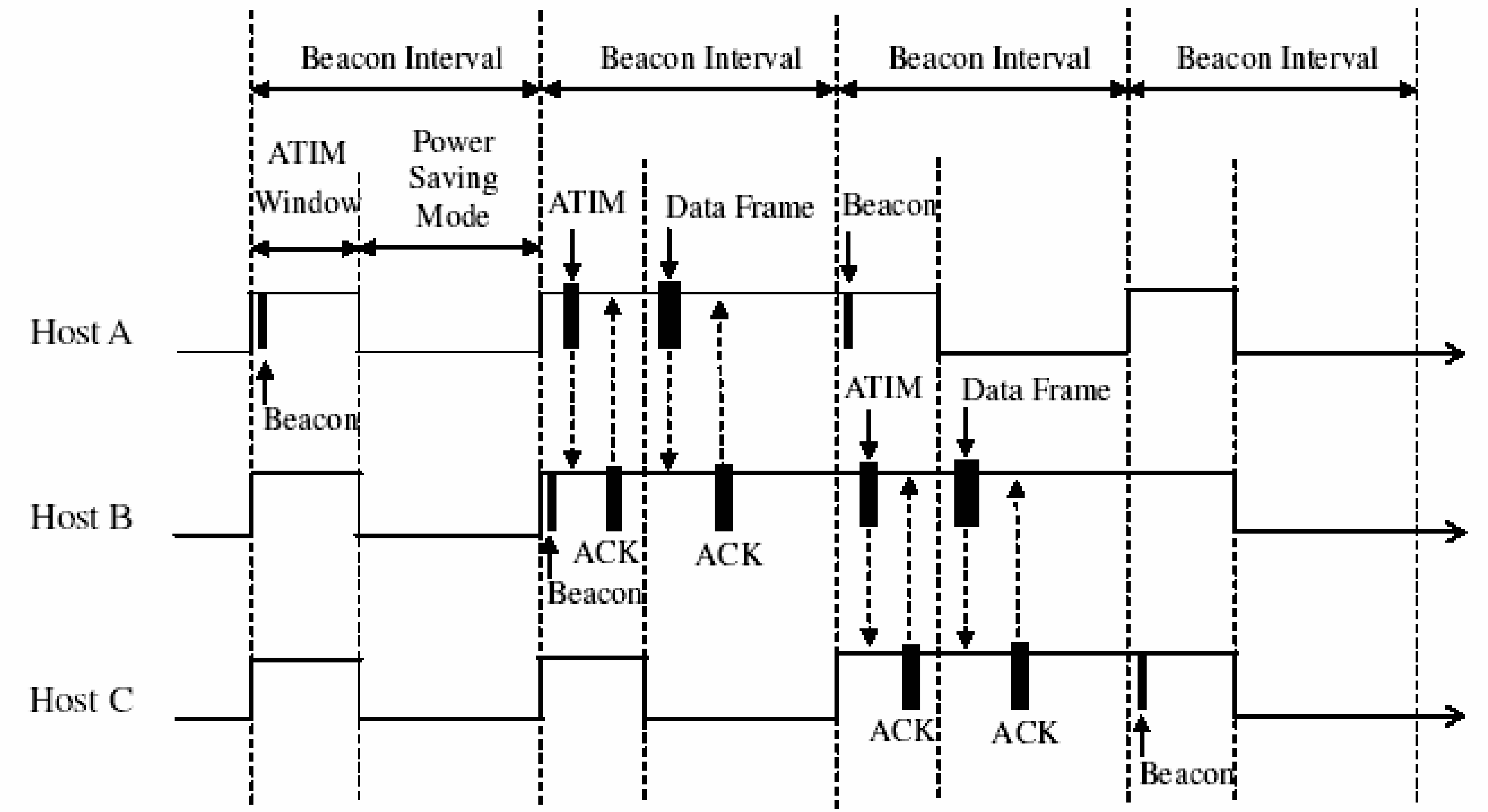
IEEE 802.11 Power Save Mode

- IEEE 802.11 supports two modes
  - Active mode & power save mode (PSM)
- PSM
  - Time is divided into intervals called beacon intervals
  - All nodes are synchronized to wake up periodically to listen to beacon messages
  - Infrastructure network
    - Access point (AP) transmits beacons periodically
    - Beacon frame contains a traffic indication map (TIM) that contains IDs of nodes with packets buffered in AP
    - Those nodes hearing their IDs should awake for the remaining beacon interval
      - DCF: an awake node can issue PS-POLL to AP to retrieve the buffered packets
      - PCF: a awake node will wait for AP to poll it
    - Other nodes in PSM will go to sleep during remaining beacon interval
  - Ad-Hoc networks
    - All nodes will wake up periodically for a short interval called ATIM [Ad-hoc Traffic Indication Message] window
    - In the beginning of each ATIM window
      - Each node will contend to send a beacon frame
      - Successful beacon synchronize time clock among nodes and inhibits other nodes from sending beacons
      - After the beacon, a node with buffered packets will send a ATIM frame to its intended receivers and remains awake for remaining time interval
      - On reception of an ATIM frame, the node should reply an ACK and remains active for the remaining time interval
      - If ATIM frame sender does not receive ACK, it will try in the next ATIM window
      - Nodes that do not receive an ATIM frame during ATIM window will go to sleep.

Basic Operation of IEEE 802.11 PSM (Infrastructure Networks)



Basic Operation of IEEE 802.11 PSM (Ad-Hoc Networks)



Assumptions of This Paper

- Continuous monitoring sensor networks
- Traffic is periodic, with the same period throughout the network
- Each node originates only one packet in one period
- The time scale of topology change and that of data forwarding is significantly different
- The network is assumed to be synchronized, allowing margin for error

Main Idea in Proposed Approach

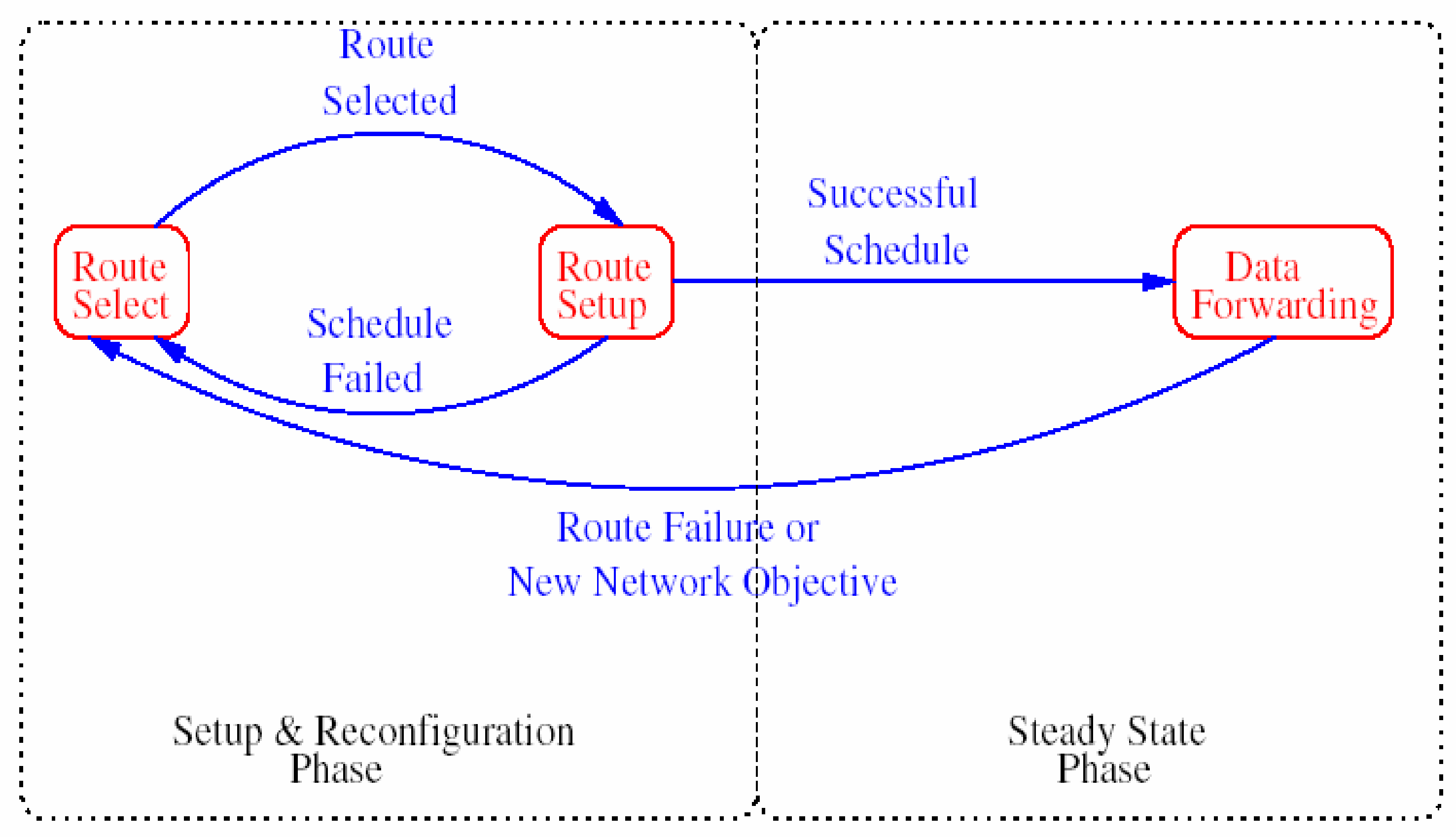
- Creates a distributed, deterministic, schedule based energy conservation scheme

- Sensor nodes will only be awake when needed and be asleep rest of the time

- Derives its power efficiency from eliminating idle listening times and collisions in sensor networks

Proposed Approach

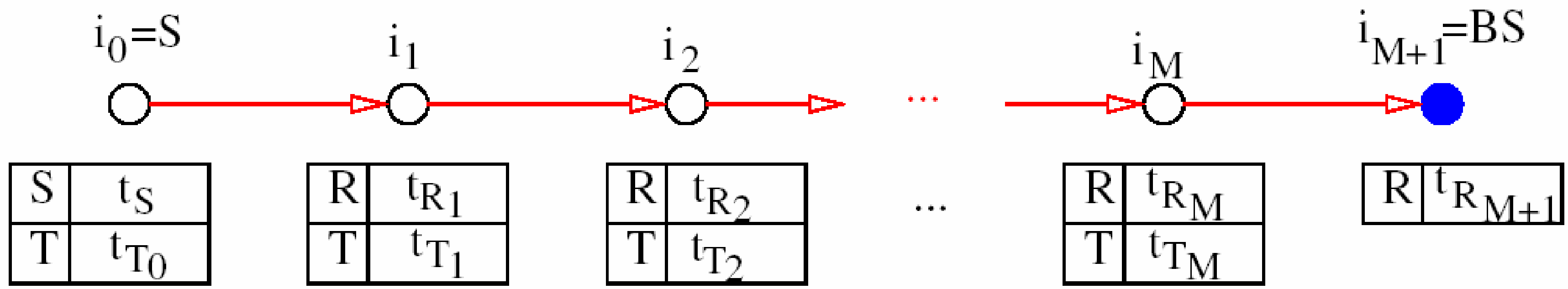
- Two phases
  - Route setup and configuration phase
  - Steady State Phase



Steady State Phase

- Nodes of the path of a flow forward packets based on a schedule table which stores two information fields :
  - First column stores what type of action needs to be performed
  - Second column stores when that action has to be performed
- Three different actions can be taken by a node
  - Sample
  - Transmit
  - Receive

Examples:



S – Obtain a Sample from the Sensor(s)

T – Transmit a Packet

R – Receive a Packet

t_{Ti} – Transmit time of the i^{th} transceiver

t_{Ri} – Receiver time of the i^{th} transceiver

t_S – sample time at source

ΔS – time taken to obtain a sample

ΔR – time taken to receive a packet

ΔT – time taken to transmit a packet

Δ - synchronization error

Thus, we have,

$t_{T0} \geq t_S + \Delta S$

$t_{Tj} \geq t_{Rj} + \Delta R$

$t_{Rj+1} = t_{Tj} - \Delta$

$\Delta R = \Delta T + \Delta$

Examples:

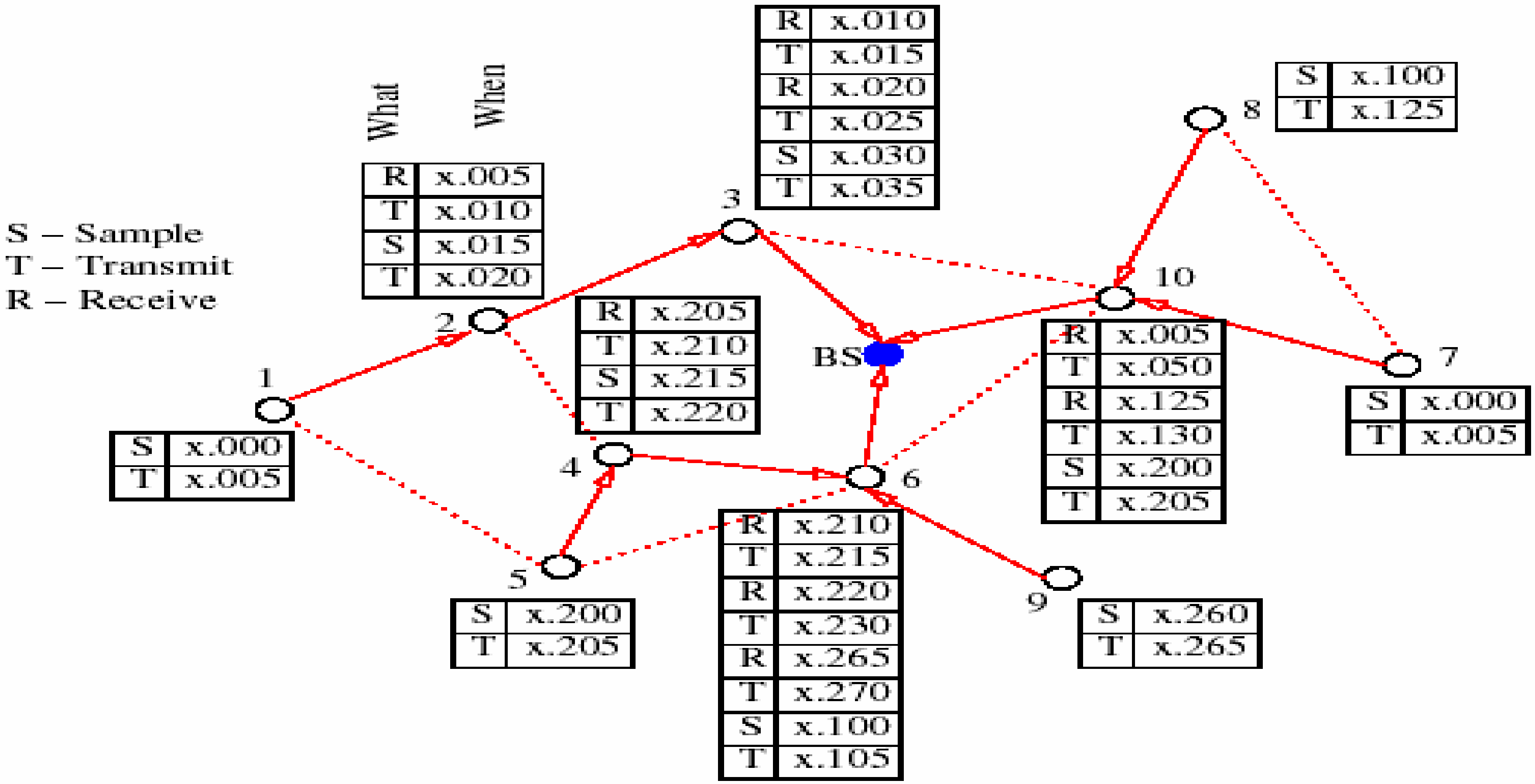


Fig. 3. Example of a 10-node sensor network with a base station BS and a possible distributed schedule.

Discuss

- The nodes closer to the base station will have longer schedules
- Transmission failures have to be handled
- The synchronization precision affects the power saving efficiency of this scheme
- Power schedules which satisfy the non-interference requirement can optimize
  - Schedule Compactness
  - Delay
  - Load Balancing

Route Setup and Reconfiguration Phase

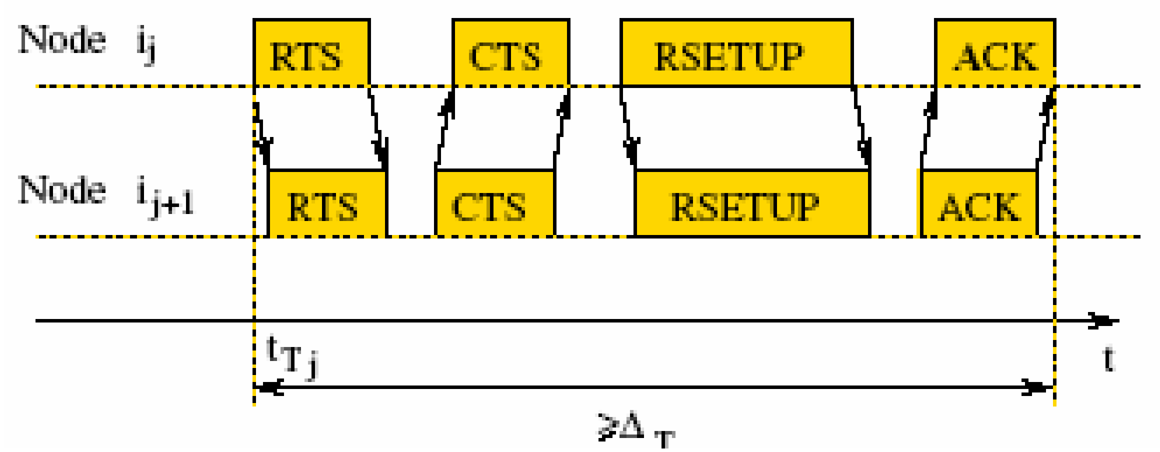
- How is the schedule discovered and maintained ?

- Route Select Phase
  - Based on a routing algorithm – e.g. the base station can advertise routes on a distance vector protocol. Subsequently each node chooses one neighbor with a smaller hop-count than itself as parent

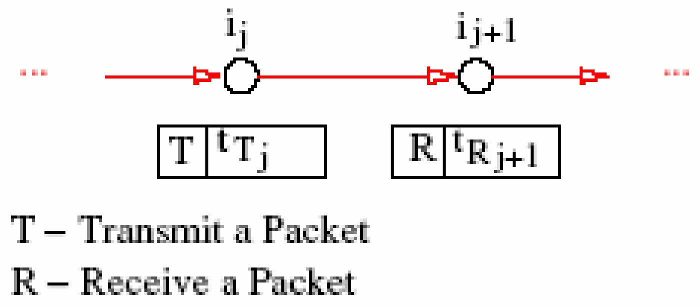
Route Setup and Reconfiguration Phase

- Route Setup Phase
  - A RSETUP packet is sent from the source of the flow to the destination base station.
    - To find a time when a DATA packet can be scheduled without collision
    - To append the appropriate entries in the schedule table of the node
  - The RSETUP packet is sent via an RTS/CTS mechanism at the MAC layer

Route Setup and Reconfiguration Phase



- RTS/CTS exchange of RSETUP packet



- Schedule table update on RSETUP receipt

Route Setup and Reconfiguration Phase

- If RSETUP packet transmission fails, it is postponed to next period at the end of which a RERR control packet is sent to the source

- If RSETUP packet reaches a base station, it sends a RACK packet back along the route while the schedule table is updated by the intermediate nodes

- Potential collisions between DATA packets and control packets have to be avoided
  - a two priority schedule system as in IEEE 802.11 is suggested for this purpose

Advantages of This scheme

- Enables power saving by eliminating idle time listening
- Proper schedule avoids collisions
- As collisions are avoided, packets experience small delay and delay jitter
- As packets are immediately processed on schedule, no buffering is required at intermediate nodes

Simulation Results

- Nodes are assumed to be battery powered with power consumption parameters taken from Berkeley motes
- Results of the power schedule approach are compared with the 802.11 PSM and no power saving mode
- No collision is assumed to be taking place
- Time until a certain percentage of nodes can no longer forward packets is taken as the performance metric

Simulation Results

	Network Lifetime	
	Mean	Std. Deviation
No power savings	8.3 days	4 minutes
802.11 PSM	3.2 months	7.5 days
Power scheduling	24.2 months	5 months

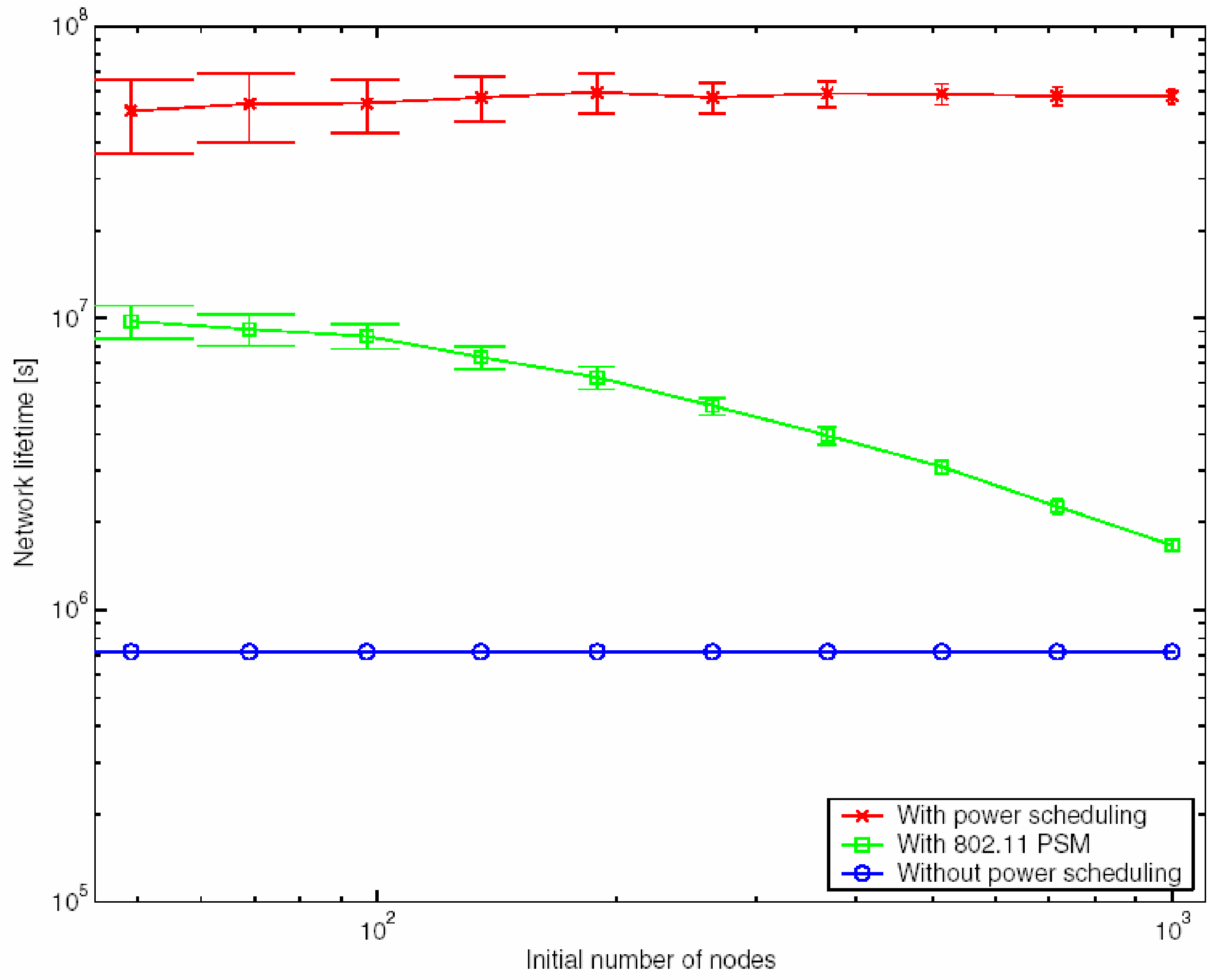


Fig. 6. Dependency of the network lifespans on the number of nodes for a constant deployment area.

Simulation Result

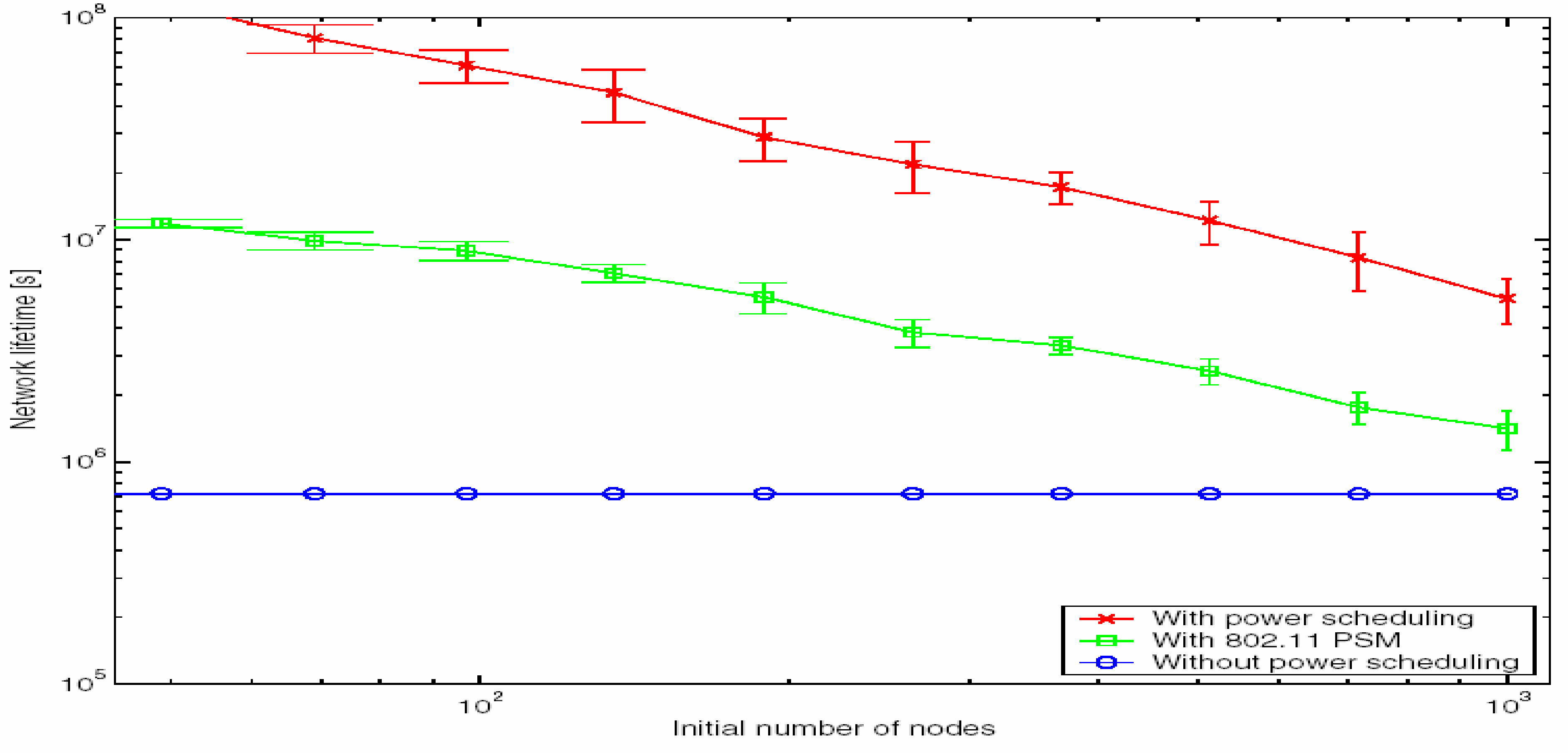


Fig. 7. Dependency of the network lifespans on the number of nodes for a constant density.

Simulation Result

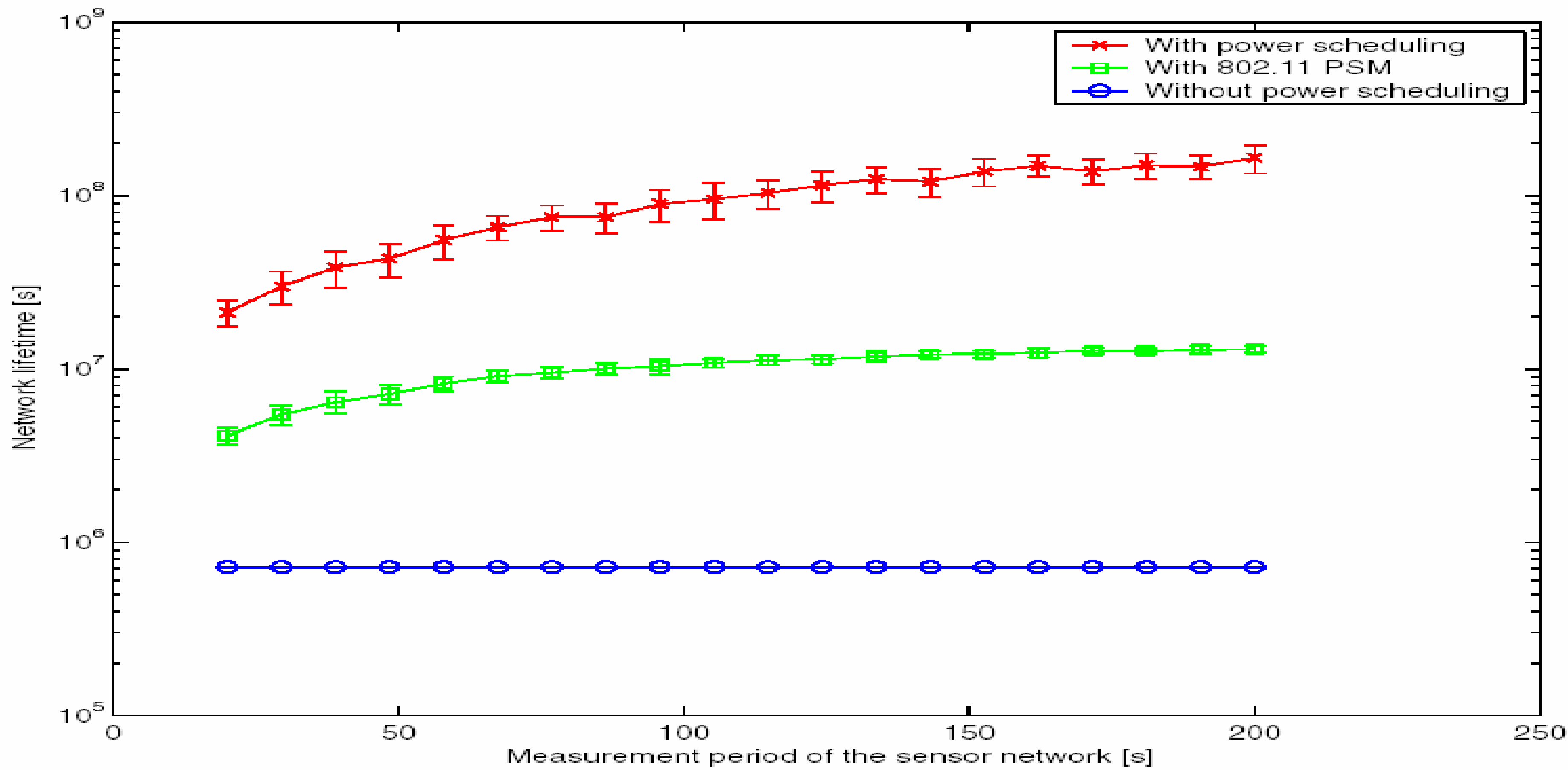


Fig. 8. Dependency of the network lifespans on the measurement period of the network.

Simulation Result

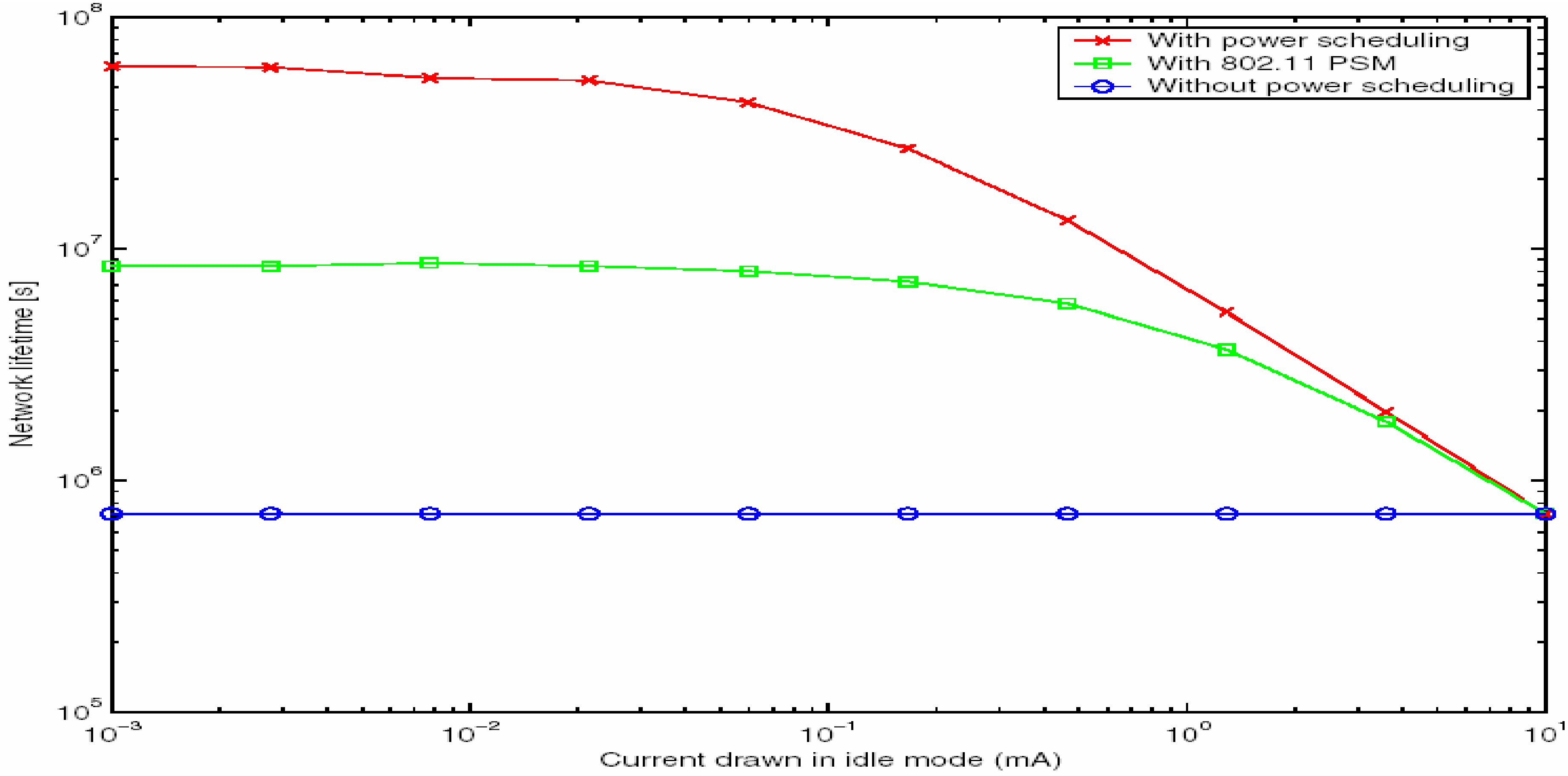


Fig. 9. Dependency of the network lifespans on the power consumption in idle mode.

Simulation Result

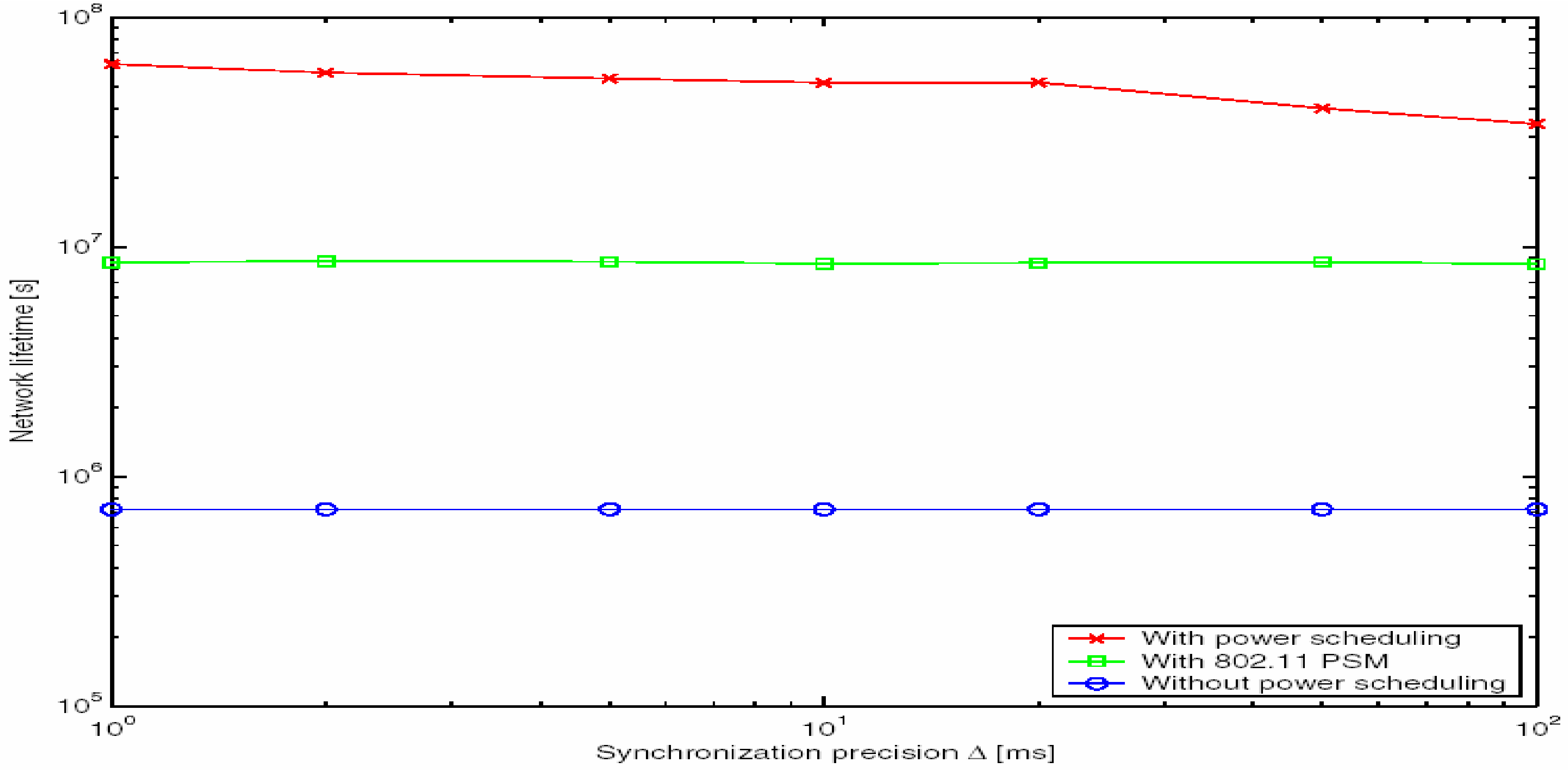
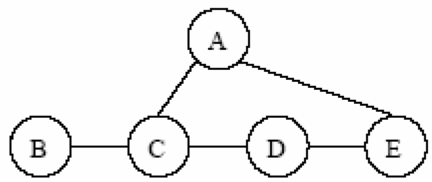


Fig. 10. Dependency of the network lifespans on Δ, the precision of the synchronization algorithm.

Summary

- Limitation
  - How the scheduling scheme works in case of collision and transmission failures
  - As RSETUP packets can potentially collide with data packets, this scheme can fail under certain scenarios as shown in the figure



- Contribution
  - A distributed, deterministic schedule based on MAC layer and Network layer coordinating to saving energy by eliminating idling listening times and minimizing data packet collisions