Wireless Sensor Networks: Applications and Research Issues

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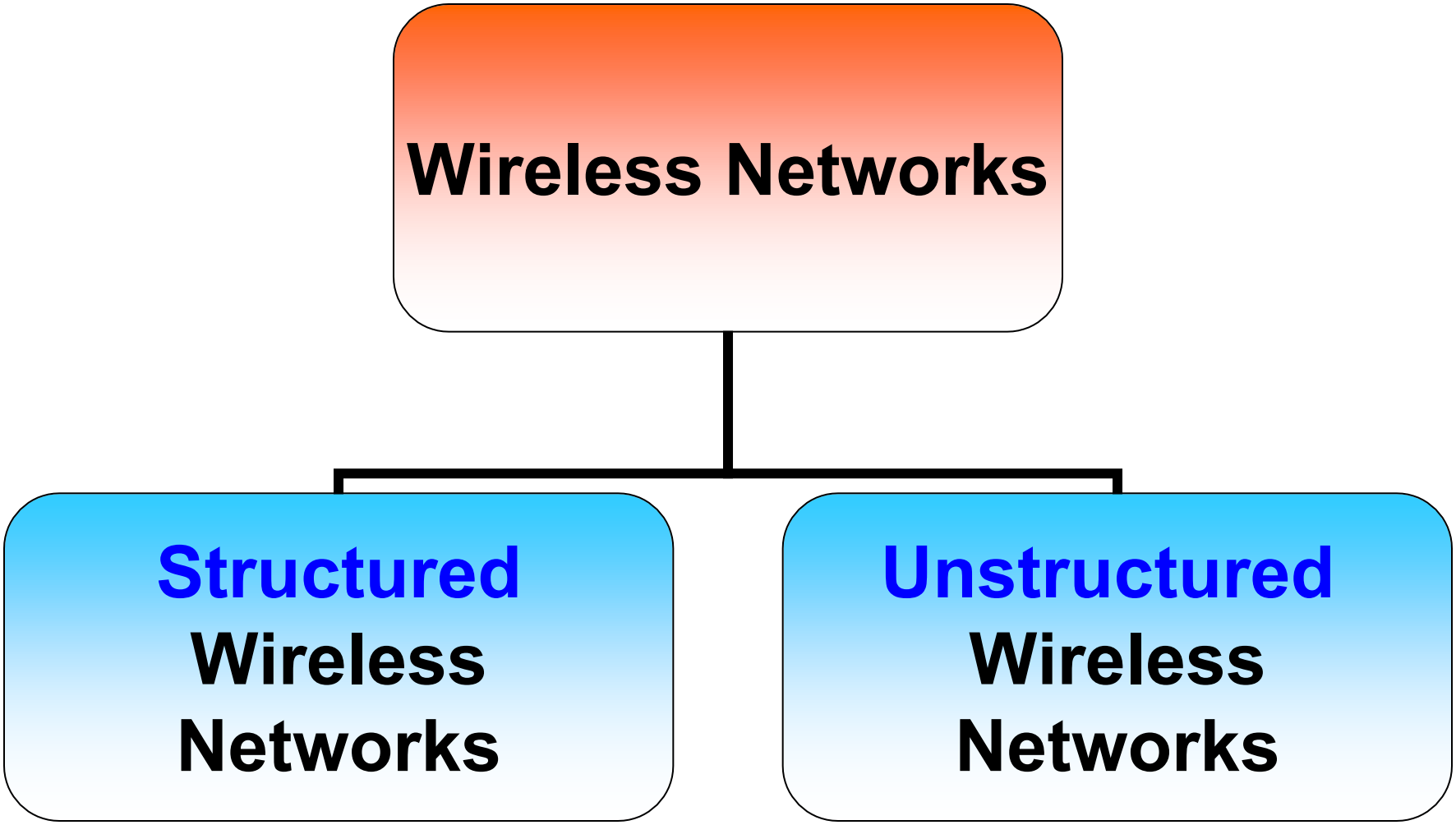
Outline

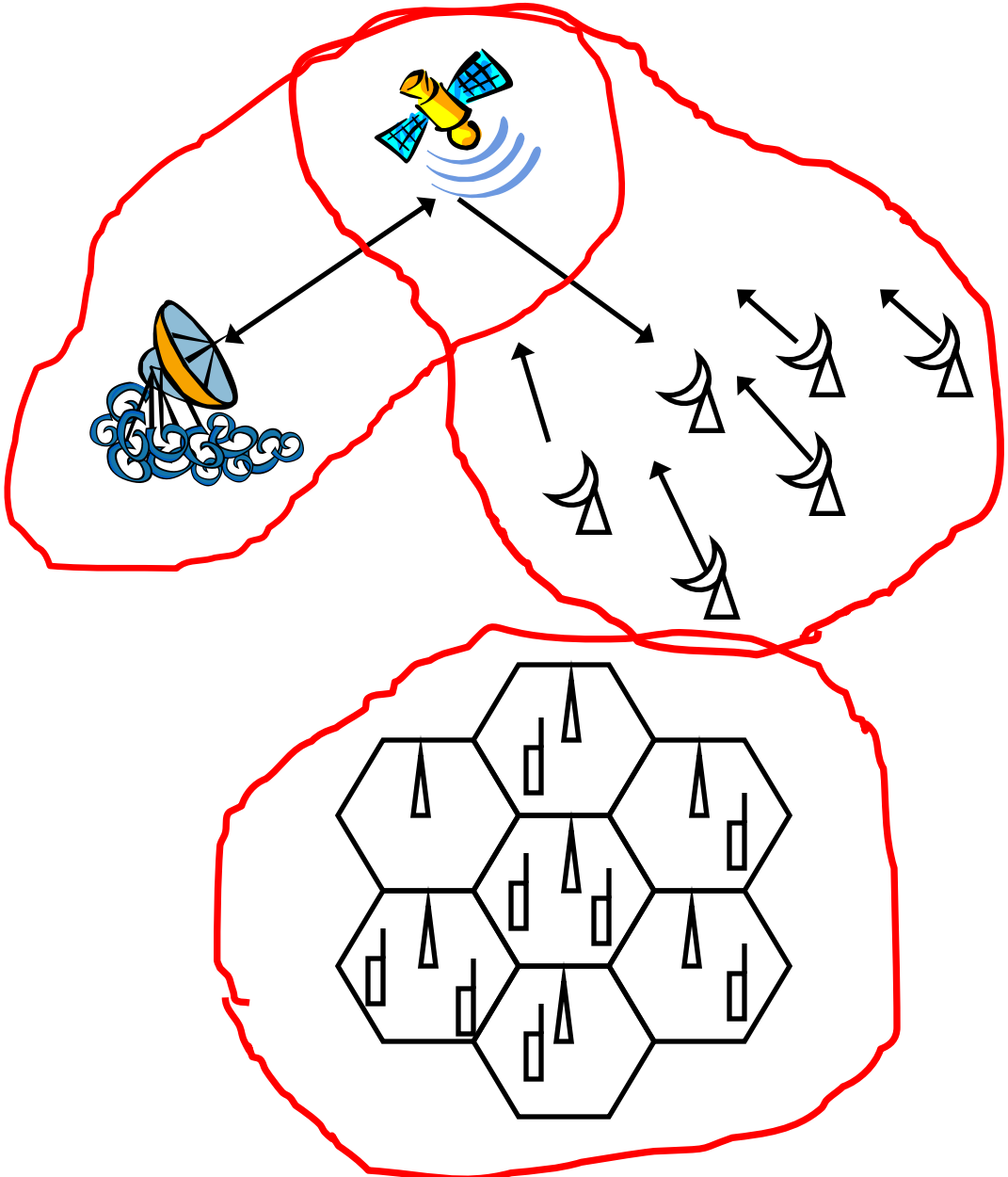
- Introduction
- Applications
- Research Issues
- Conclusions

Introduction



Structured Wireless Network

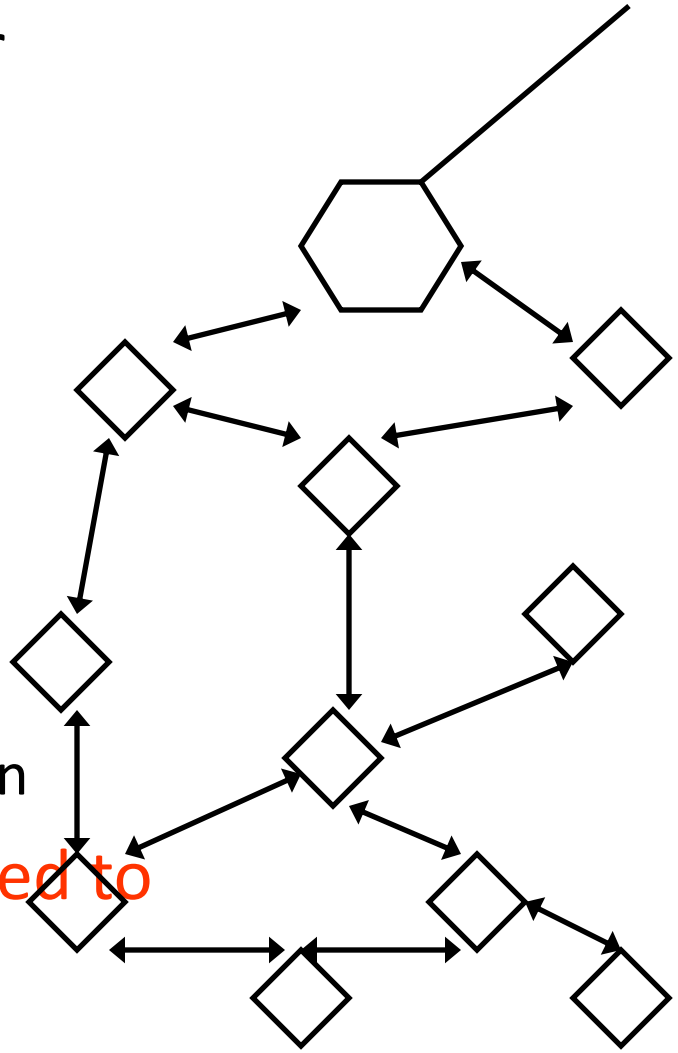
- **Point-to-point links**
  - Terrestrial or satellite
- **Point-to-multipoint networks**
  - Satellite TDM/TDMA
- **Cellular mobile networks**



Unstructured Wireless Network

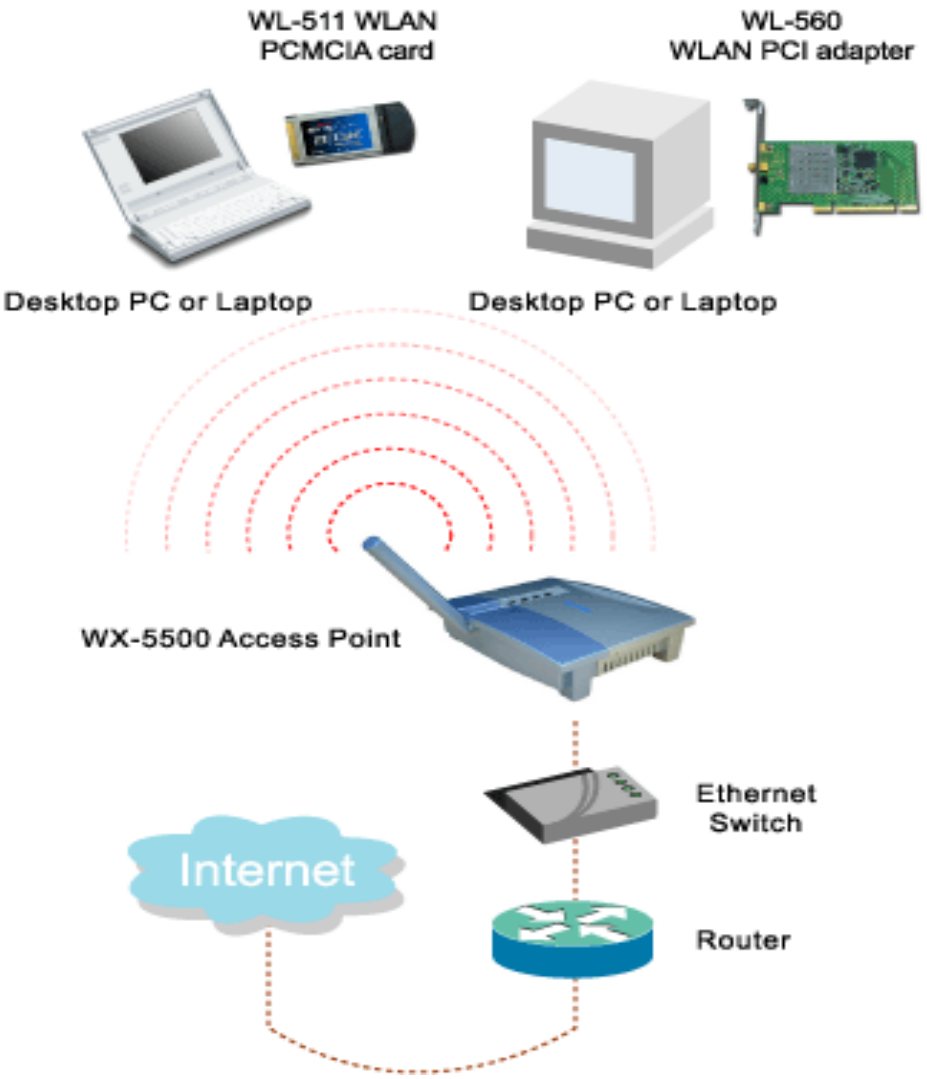
- Each node has a wireless transceiver
- Every node can forward packets
- Nodes associate in an

  Ad Hoc manner to form a network
  - self organize to form a network
  - multiple access wireless communication
- Certain periphery nodes may be linked to the wired network

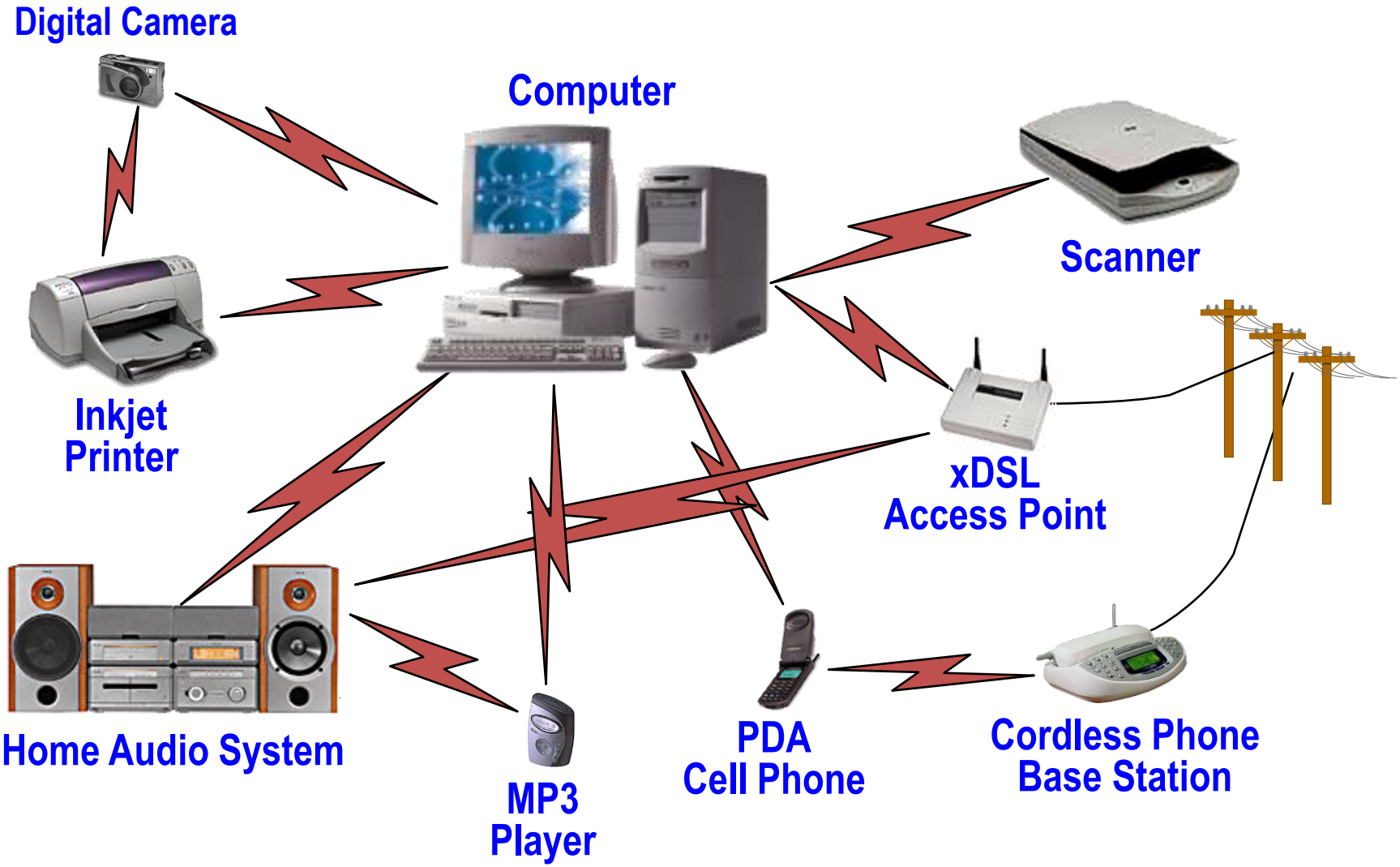


Wireless LAN

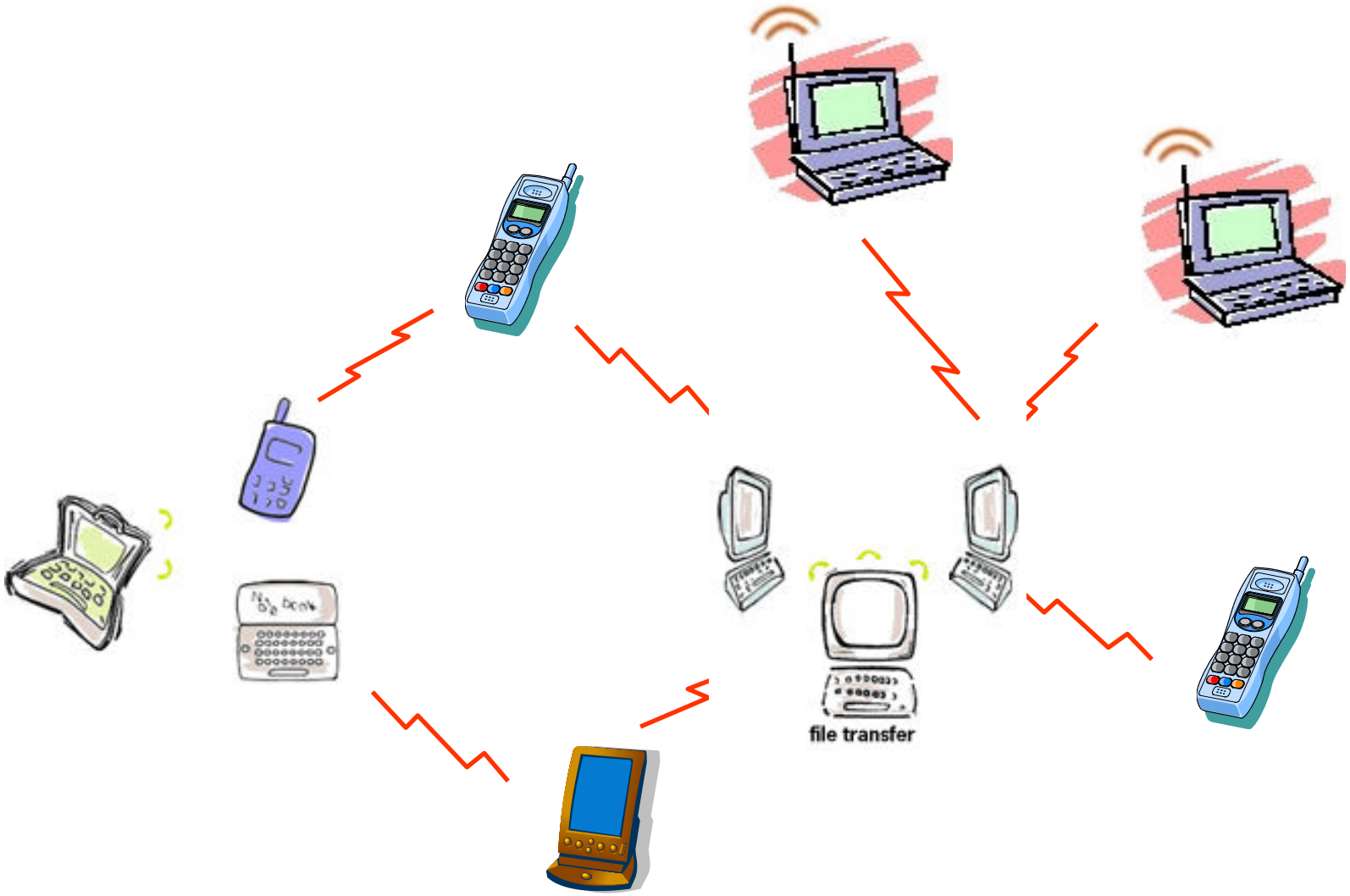
- Usually extensions to an Ethernet LAN
- **IEEE 802.11 MAC**
- Several PHYs defined
  - 2.4GHz ISM Band
  - 5GHz Band
- TCP/IP protocol stack
- Expected functionality is same as from a LAN



Bluetooth Technology (WPAN)



Ad-Hoc Network



Wireless Sensor Network

- **What is a Wireless Sensor?**
- Multifunction device
- Sensing
  - temperature, chemicals, light, body pulse rate
- Processing
  - e.g., 8 bit, 4Mhz, 8KB flash, 512 B RAM
- Communicating
  - Digital Radio
- Battery operated

The Berkeley Mote with a light & temperature sensor

Conventional Sensors

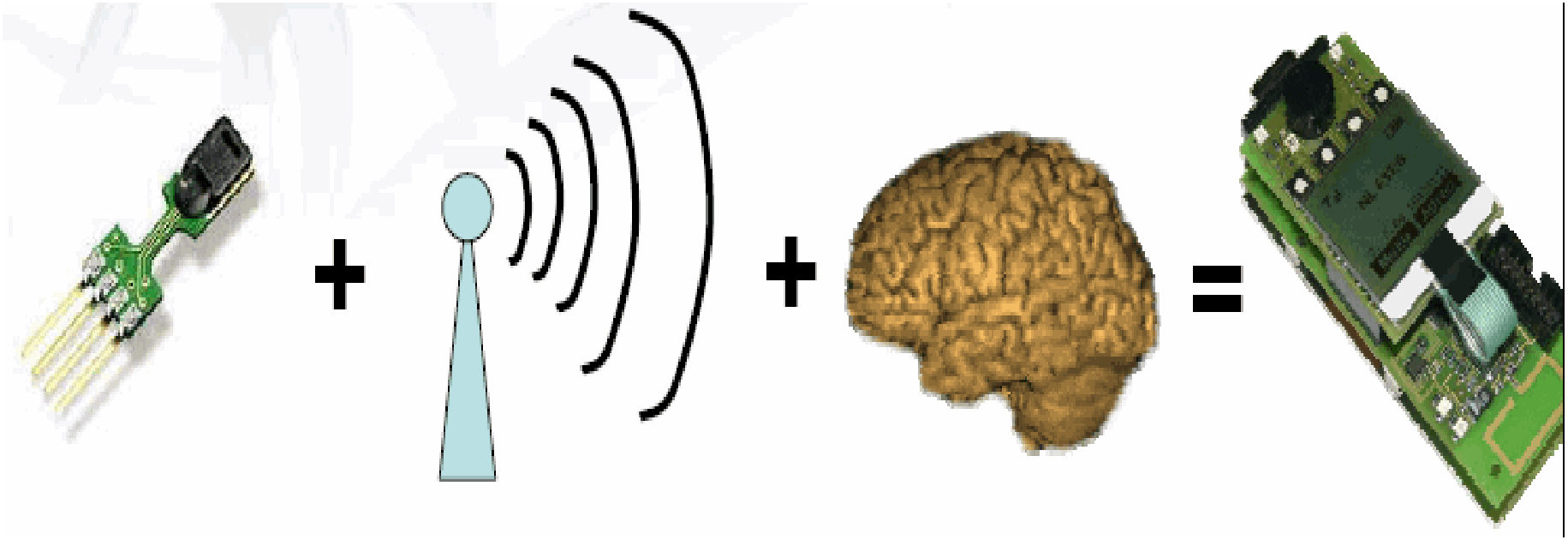
Mini Alert Sensor Alarm

Industrial Alert Sensor Alarm

Metal Detector

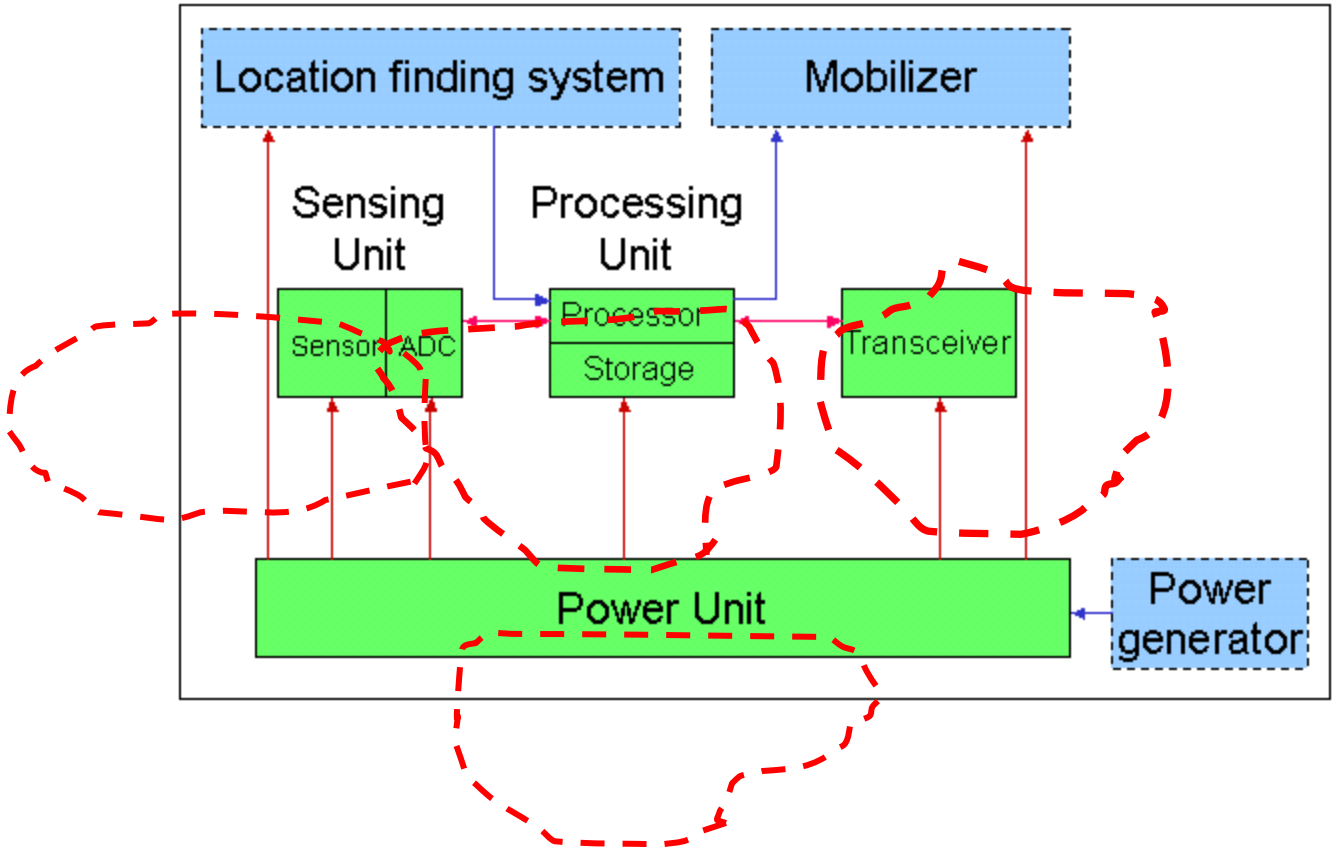
Wireless Sensors

- **What's the difference between Wireless Sensors and conventional sensors?**
- It is Not just sensors, but sensors with tiny brains!

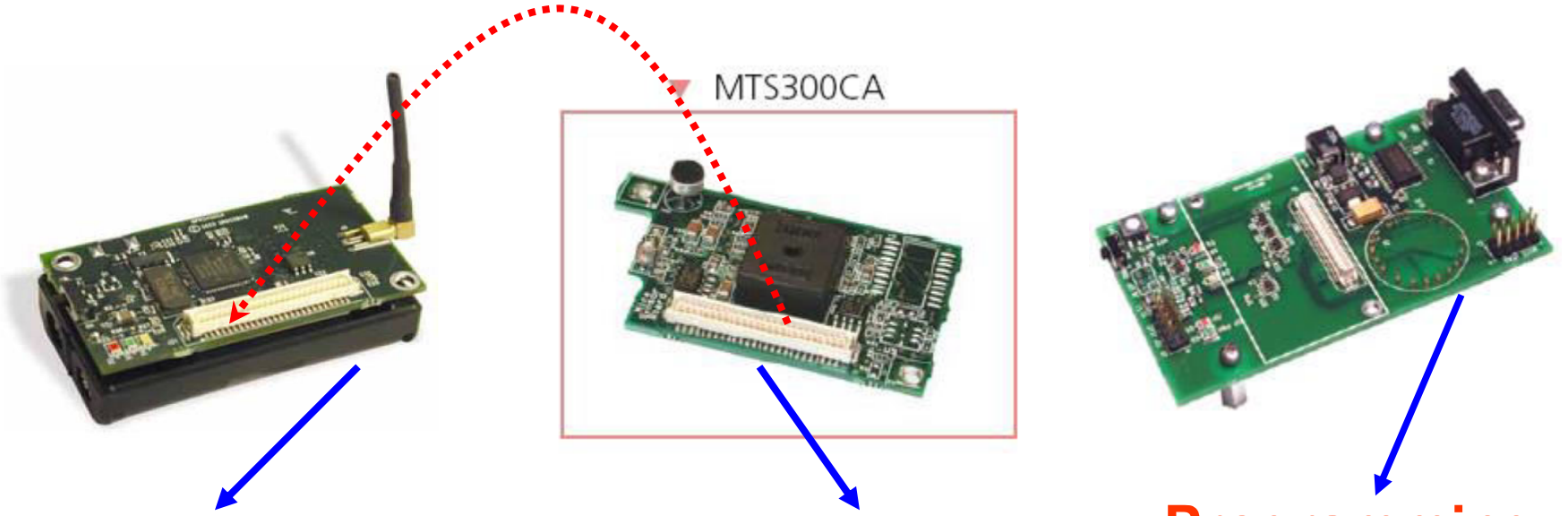


Wireless Sensor

Components of a wireless Sensor



Various Parts of a Wireless Sensor



Processing Unit
+ Power unit
+ Transceiver

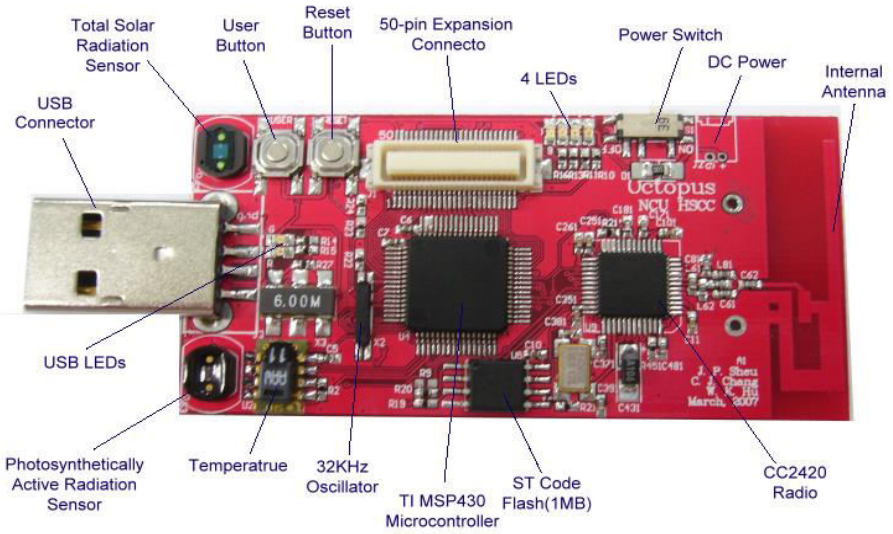
Sensing Unit

Programming Board (Interface to PC)

Commercial Products

Micaz

Octopus II Super node

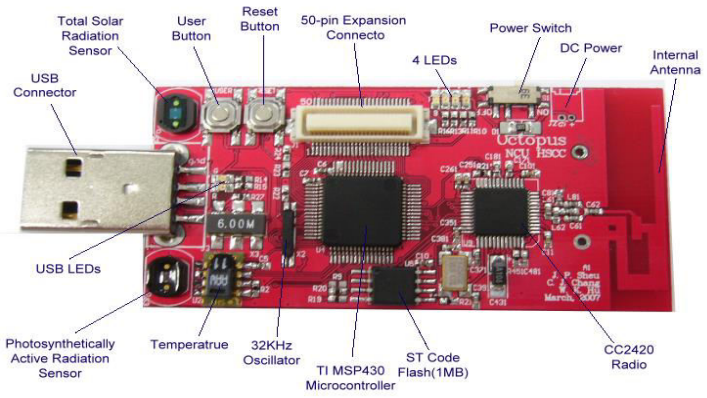


Features of MICAz (Zigbee)

- Atmel ATmega128L micro-controller
- 128KB Program Flash Memory
- **4 KB SRAM**
- **IEEE 802.15.4 MAC**
- **Data rate:** 250 Kbps
- Hardware security (AES-128)
- 2400MHz to 2483.5 MHz band radio transceiver
- **2XAA batteries**

Features of Octopus II

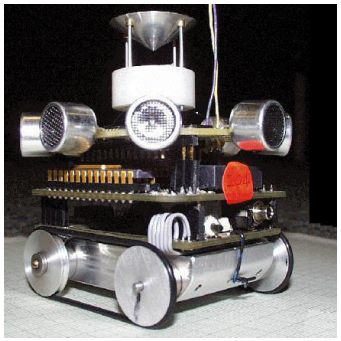
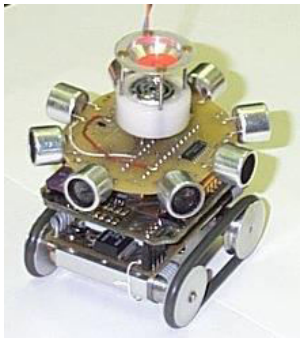
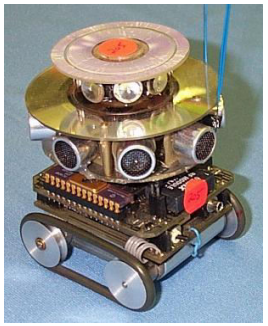
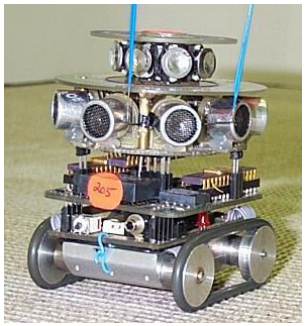
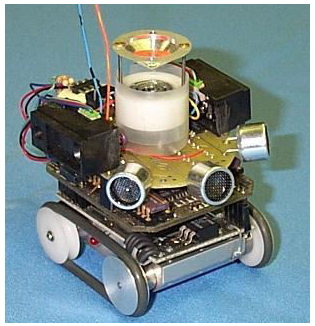
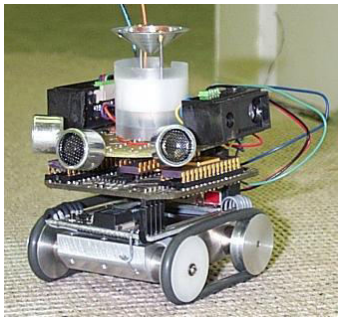
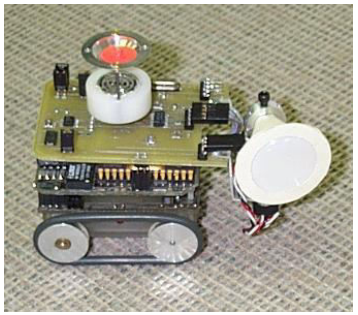
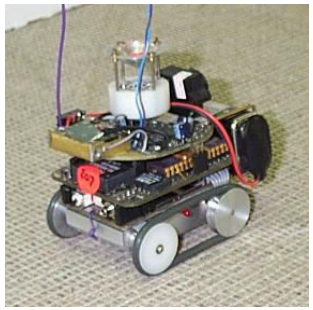
- **MCU (MSP430F1611)**
  - Flash Memory: 48KB
  - RAM: 10KB
  - External Flash: 1MB
  - Humidity, Temperature, Light sensors
  - **2.4GHz IEEE 802.15.4 MAC**
  - **Data rate: 250Kbps**

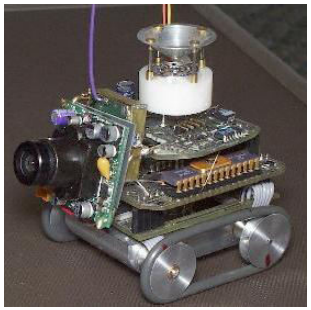


Comparison of WSN with other wireless technologies

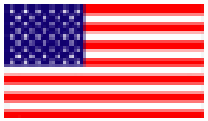
	WLAN (802.11)	Bluetooth-based WPAN (802.15.1)	Low-rate WPAN (802.15.4)
Range	~100 m	~10 - 100 m	~10 m
Data throughput	~2 - 11Mbs	~1 Mbs	~0.25 Mbs
Power consumption	Medium	Low	Ultra low
Size	Larger	Smaller	Smallest
Cost/complexity	>6	1	0.2

Mobile Sensors



Some National WSN initiatives



National Science Foundation WSN first year investment of $43M in 2003

- Industry/Academic network: http://www.bu.edu/systems/industry/consortium/index.html

Major research program to exploit opportunity for Australian companies

- http://www.sensornetworks.net.au/

DTI invest £6M in sensors and control systems research in 2004

Feedback from DTI WSN mission to US on Feb 16

- http://sensors.globalwatchonline.com/epicentric_portal/site

Research has yielded tools to allow "large-scale and real-world deployments of sensor networks"

- http://www.nccr-mics.ch/index.php

IMEC developing ultra low power radios for medical body area networks

IMEC and TNO initiate new research center, the Holst Centre, to develop wireless microsystems and system-in-foil technologies

- http://www.imec.be/human/

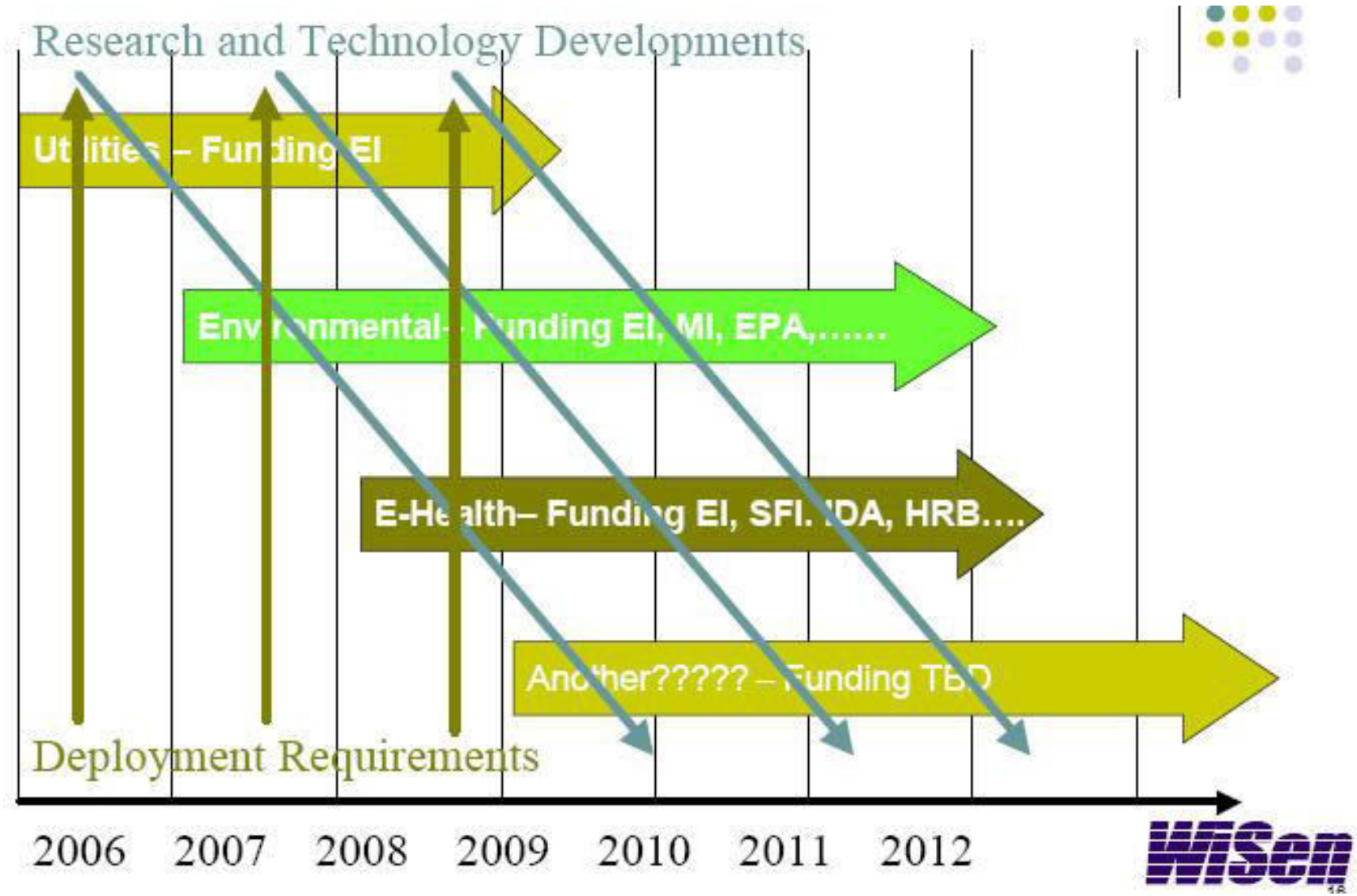
Nine EU funded IST Research Programs in WSN

- EYES, BISON, The Disappearing Computer, Embedded WiSeNts, MobilMAN, PEPITO, Swarm Bots, COBIS, Promise

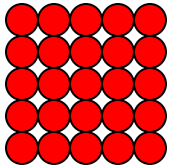
Industry WSN activities

- MEGA CORPS
  - Science Applications International Corp
    - US IT contractor www.saic.com – Homeland Security
  - BP
    - Refinery Monitoring applications - $10K per measurement node saving using Wisen
  - GE
    - Container Tracking
  - Intel
    - Intel motes
  - HP
    - product tracking
  - Microsoft
    - Networked Embedded Computing
  - SUN
    - Security in WISEN
  - SAP - http://accelerating.org/ac2004/downloads/GetSmartSAP.pdf
  - IBM
    - Sensors and actuators business group, $250M investment over 5 years
- Startups
  - Dust Networks www.dust-inc.com
  - Ember Corp www.ember.com
  - Crossbow Technologies www.xbow.com

Target Application Domains

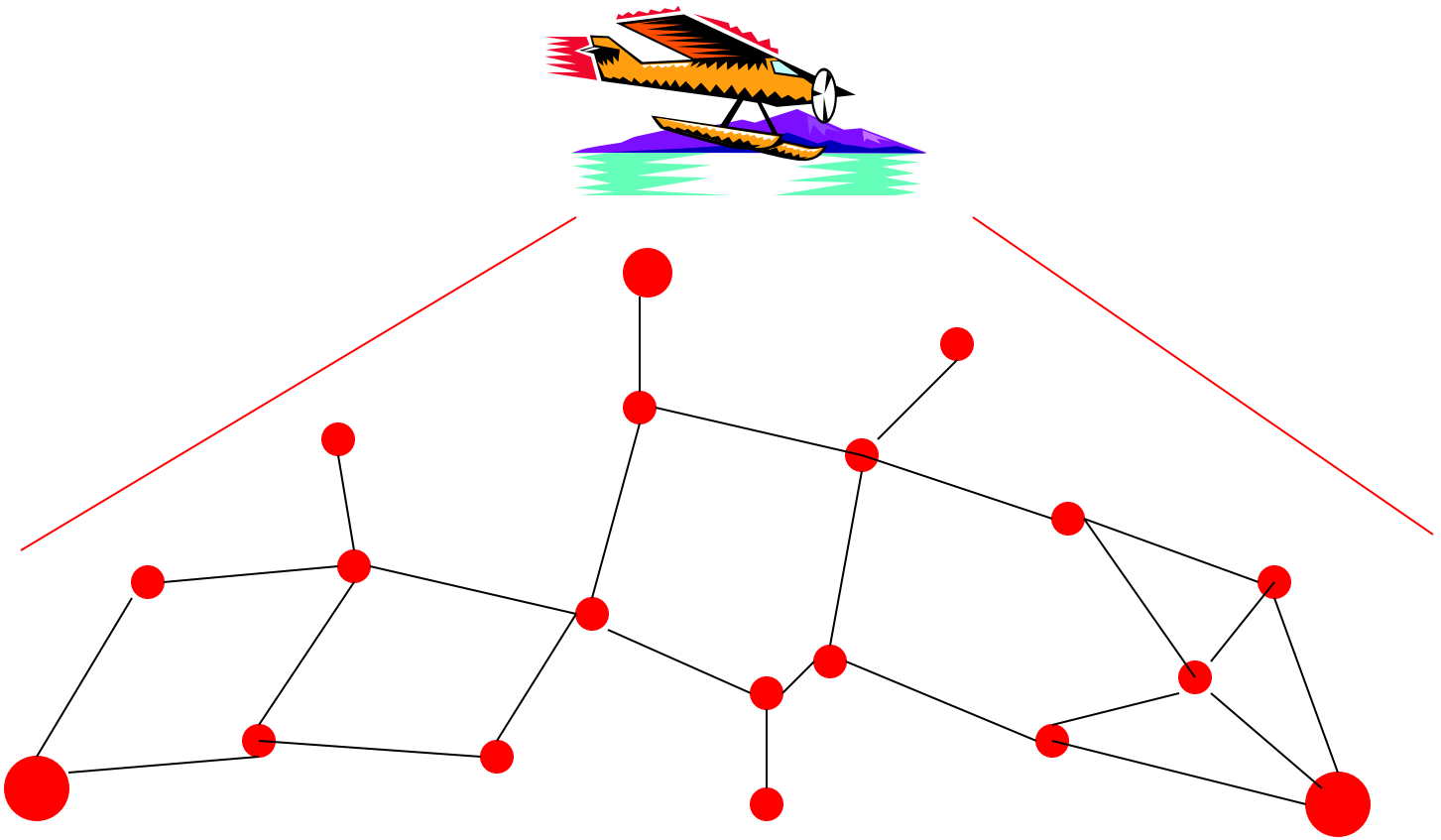


Sensors



Deploy

Wireless Sensor Network



Communication Architecture

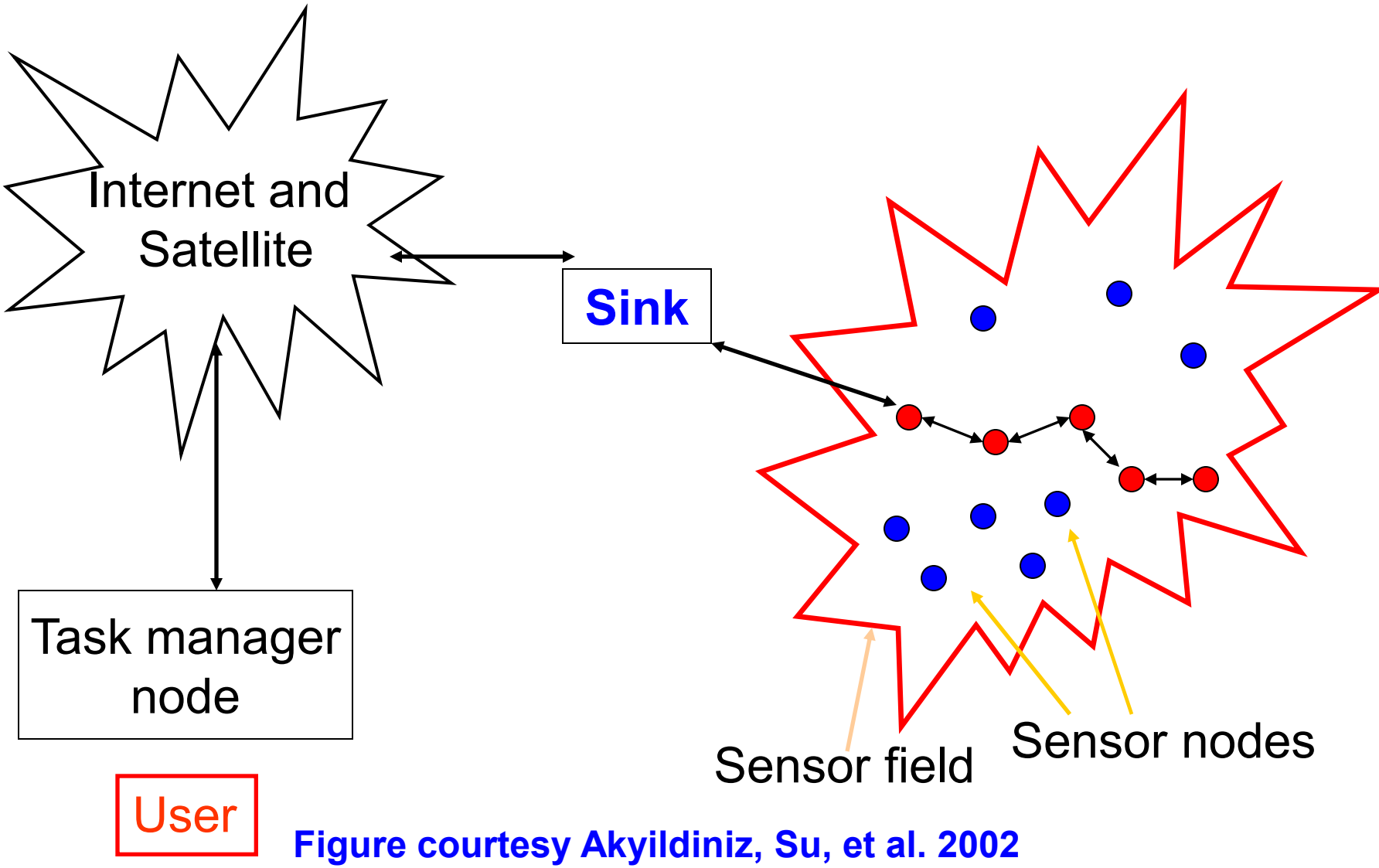


Figure courtesy Akyildiniz, Su, et al. 2002

Wireless Sensors

- **What's the difference from ad hoc networks?**
- **Density: Sensor nodes are densely deployed**
- **Errors: Sensor nodes are prone to 'failures'**
  - Sensor nodes save energy by long sleeping periods
  - Run out of energy (or other resources)
  - Nodes are mobile

Wireless Sensors

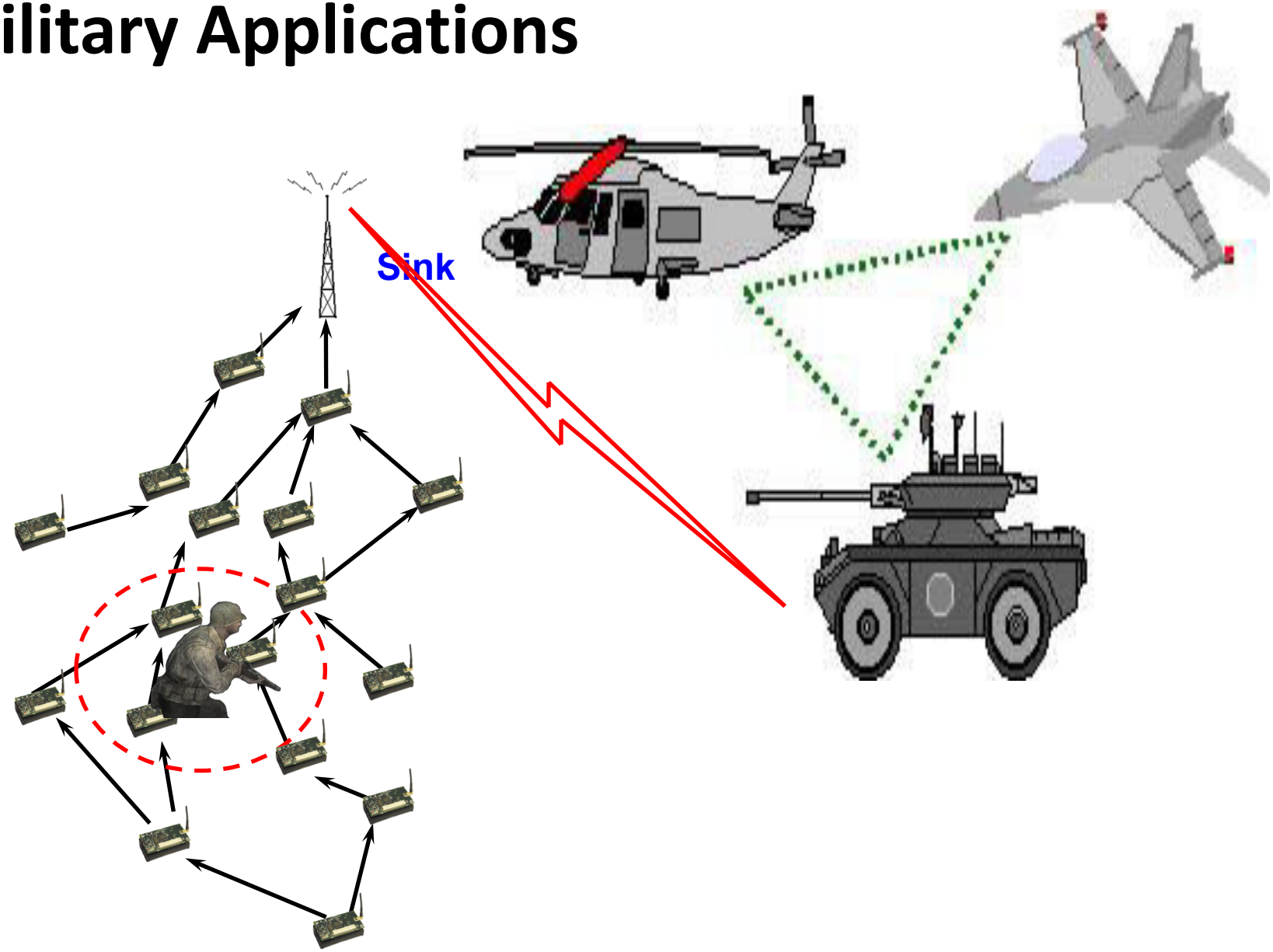
- **Routing: Routing within sensor network is different**
  - **Sensor nodes may not have global ID**
  - Broadcast, geographical, data centric
  - Most ad hoc networks are based on p2p.
- **Resources: Sensor nodes are severely limited in resources**
  - Low data rate, short range communication
  - power, computational capacities and memory.

Applications

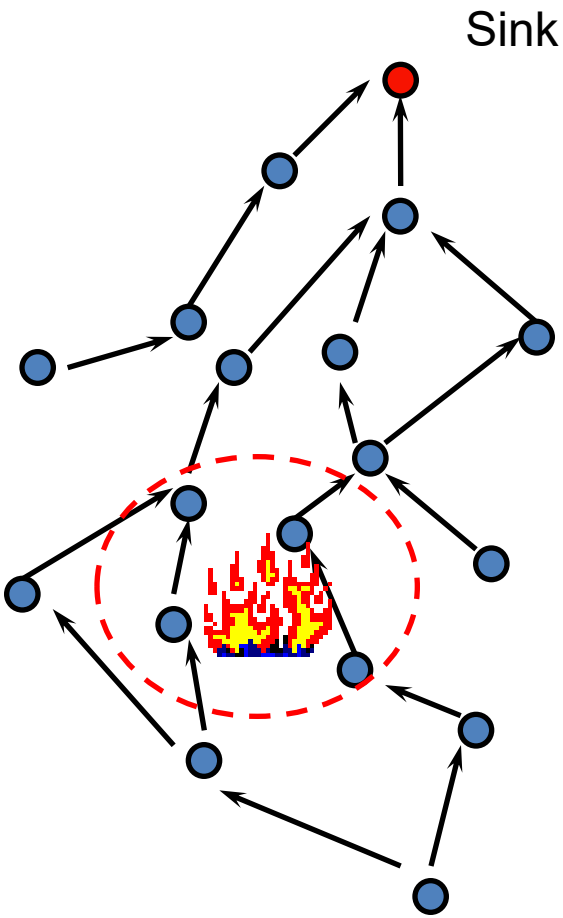
Applications

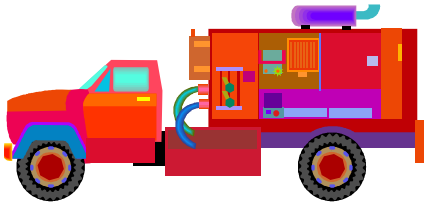
- Military applications
- Environmental monitoring
  - Forest monitoring
  - Weather monitoring
  - volcanic eruption
- Habitat monitoring
  - Animal migrate route
- Health monitoring
- Home care

Military Applications



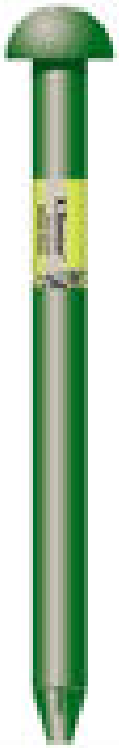
Environmental monitoring

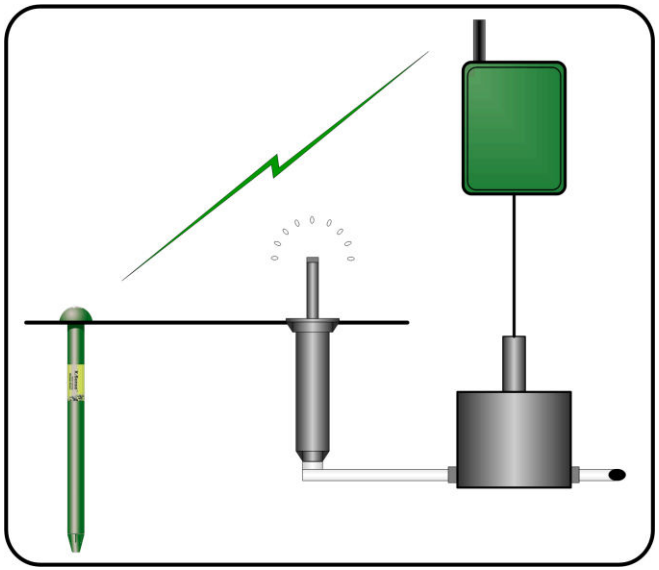




Environmental monitoring

- http://www.digitalsun.com/index.html
- Digital Sun, Inc.
- A soil moisture sensor system to keep grass green while saving water

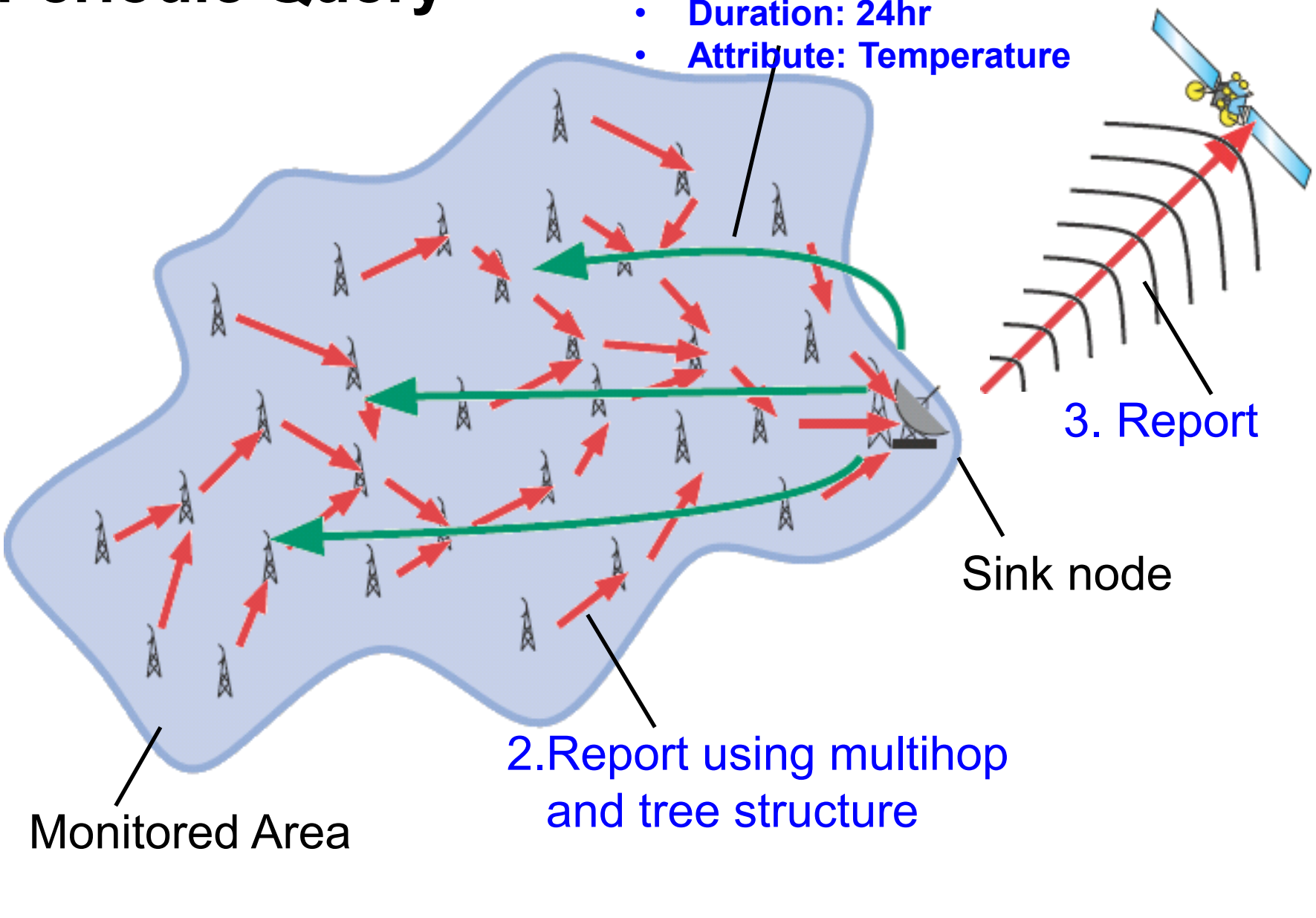




Weather monitoring

- **Periodic Query**
  - Frequency: 10/hr
  - Attributes: Temperature/Pressure
  - Region:(10,10)-(1000,1000)
  - Duration: 1 month
- **Event-driven**
  - Attributes
  - Region
  - condition

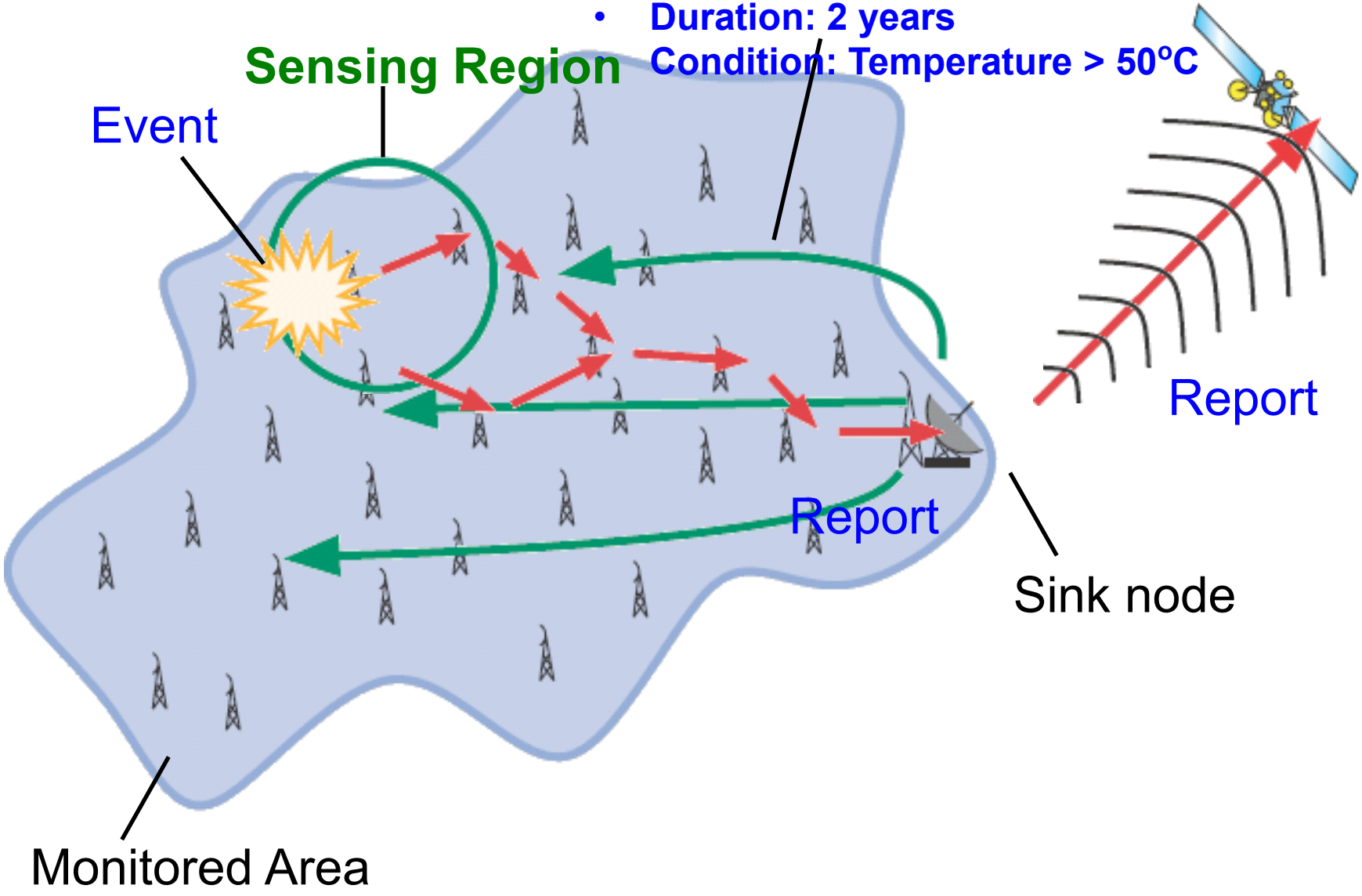
Periodic Query



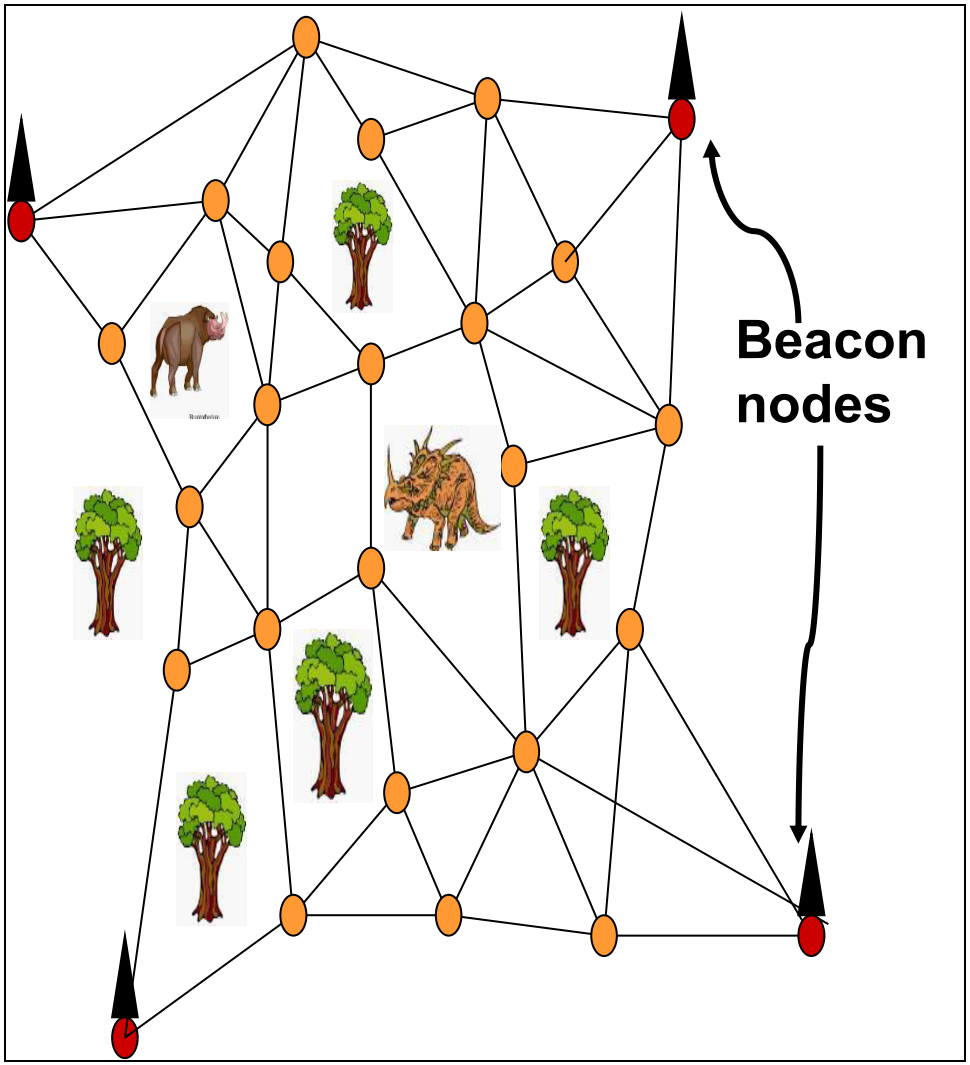
Event-driven

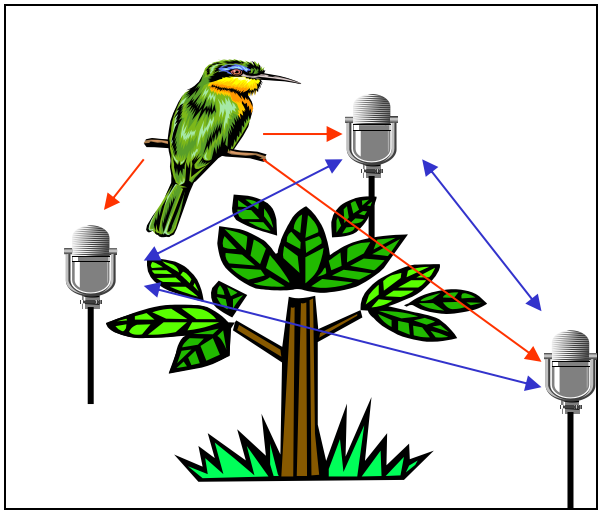
Request using flooding

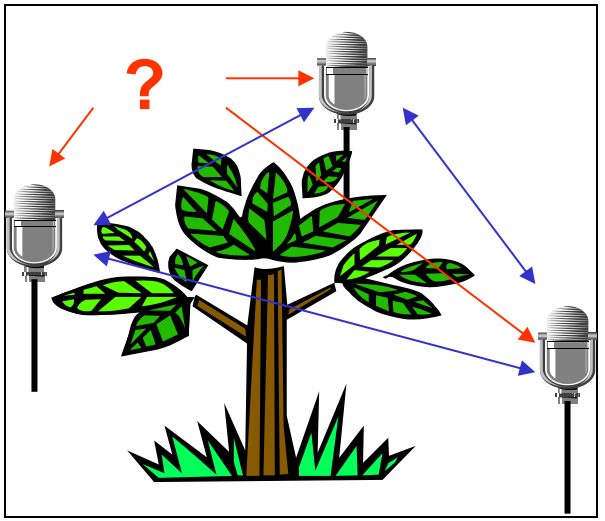
- **Attribute: Temperature**
- **Duration: 2 years**
- **Condition: Temperature > 50°C**



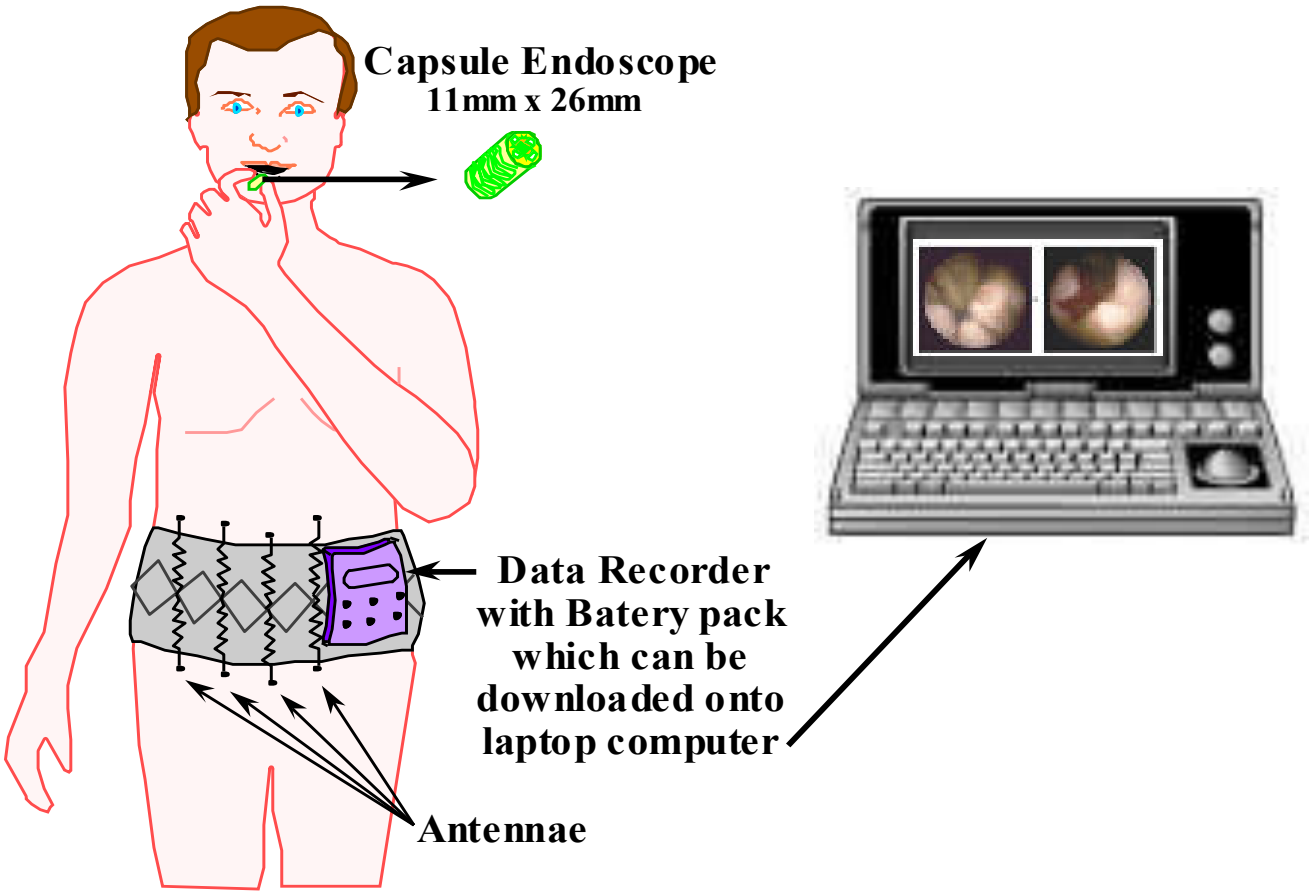
Habitat monitoring



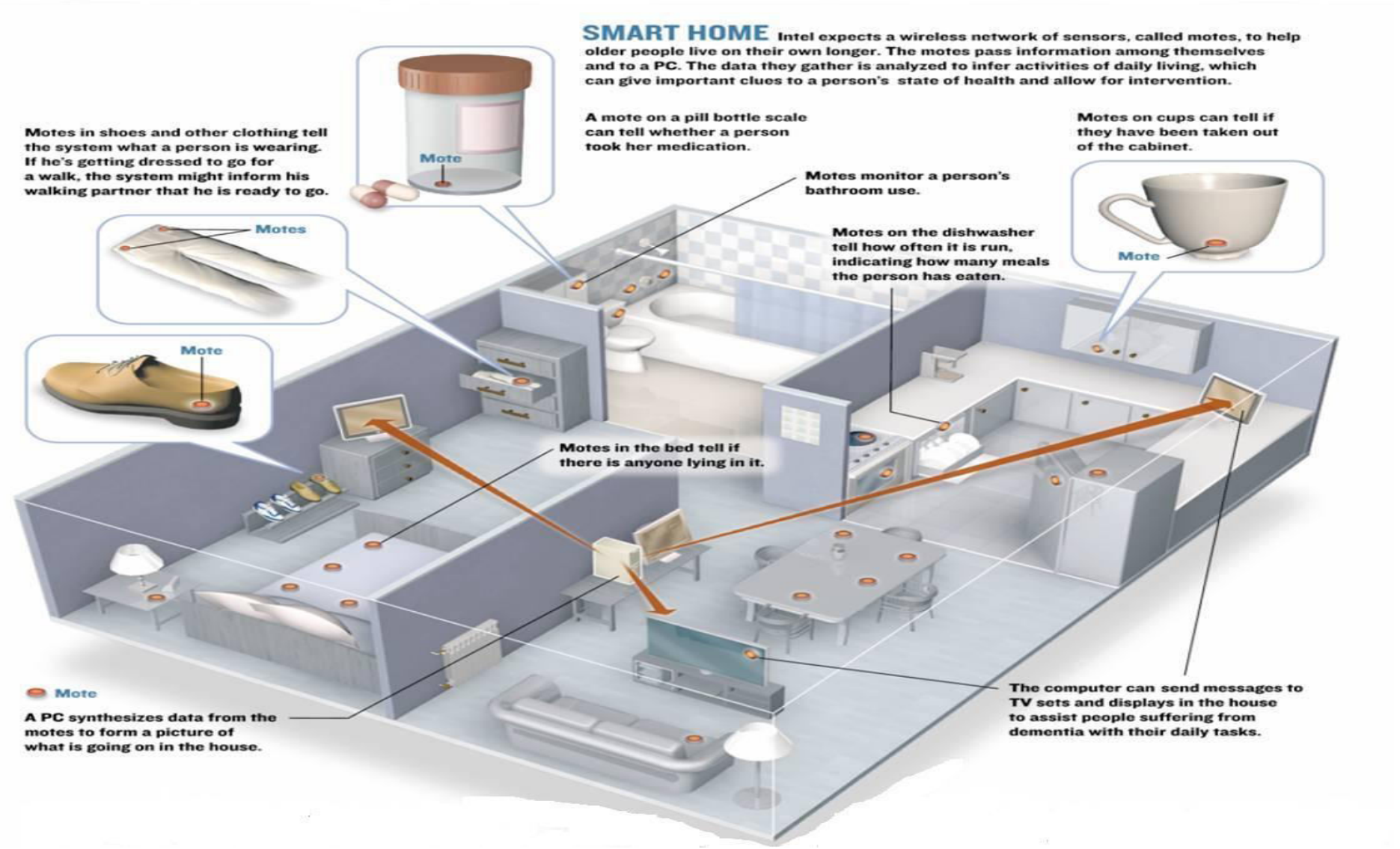




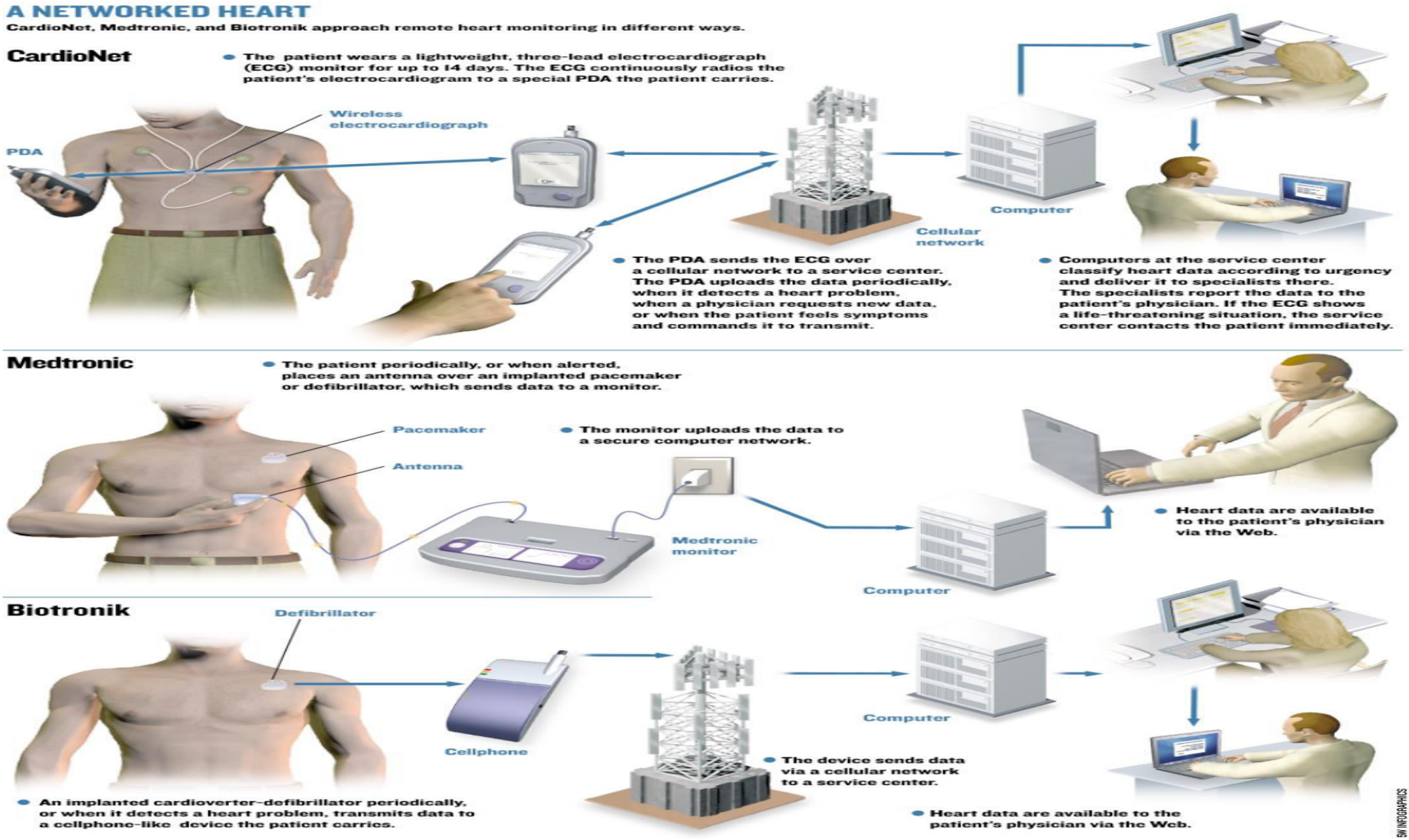
Health monitoring



Health monitoring

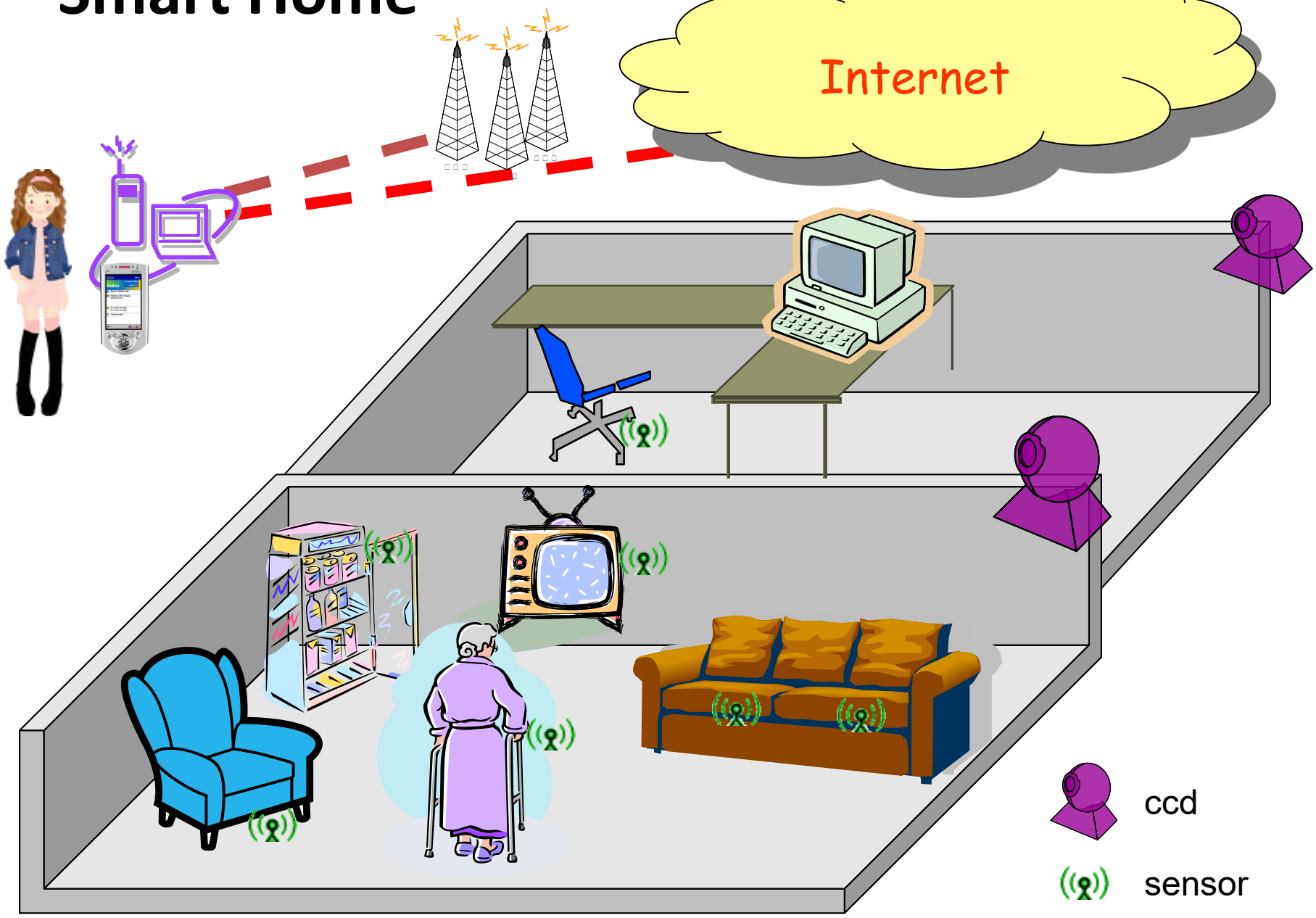


Health monitoring

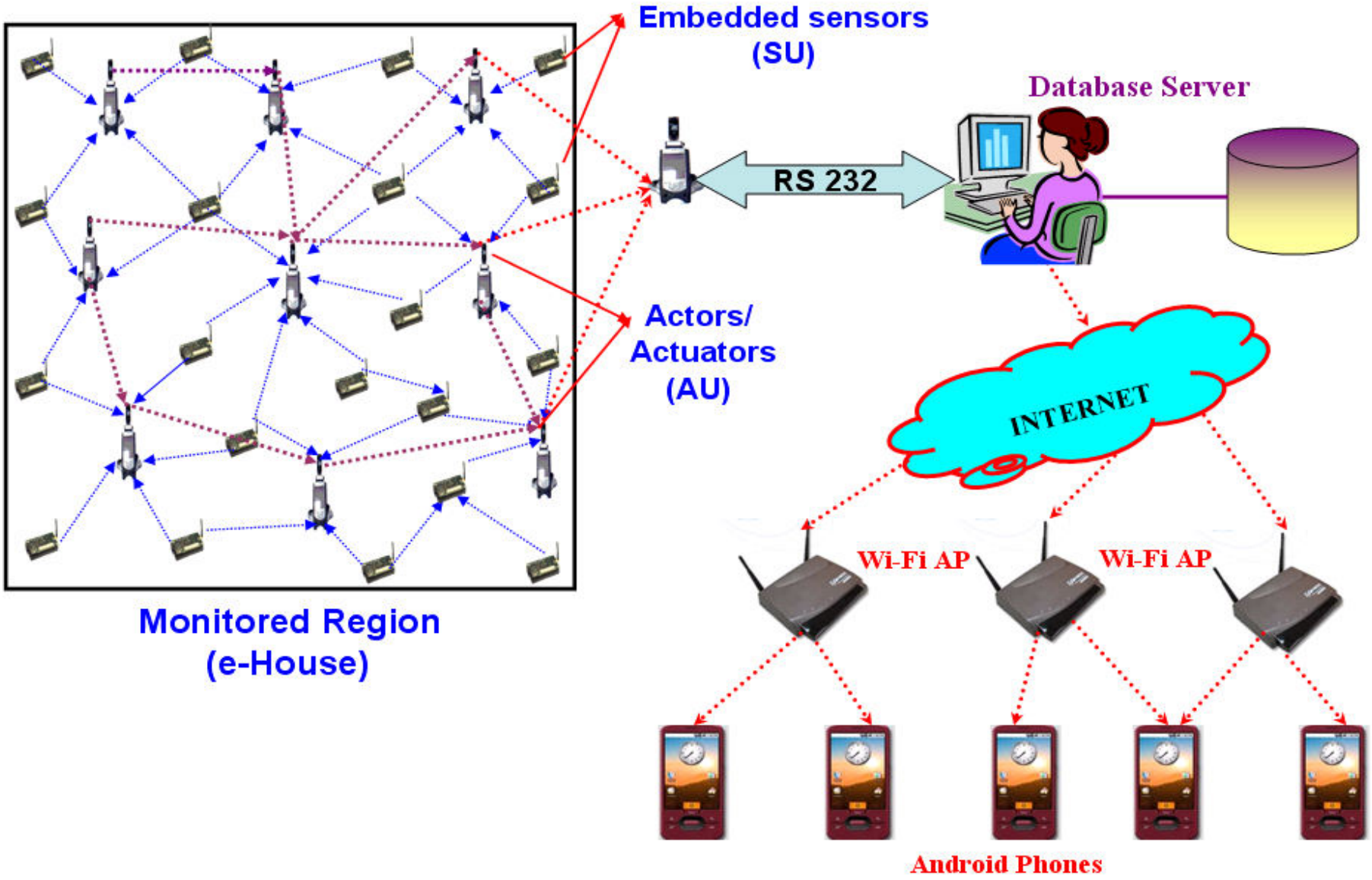


Health monitoring

Smart Home

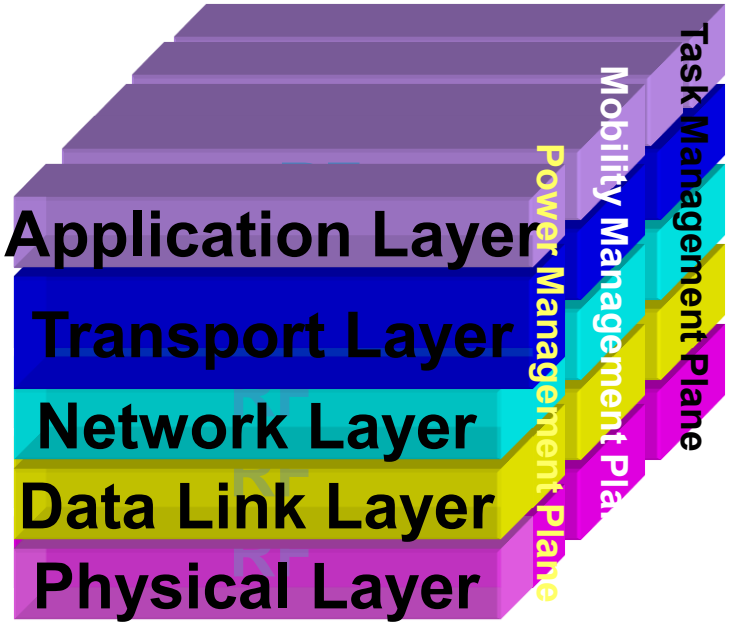


Smart Home


Embedded sensors
(SU)
Database Server
RS 232
Actors/
Actuators
(AU)
INTERNET
Wi-Fi AP
Wi-Fi AP
Monitored Region
(e-House)
Android Phones

Open Research Issues

Sensor Network Protocol Stack



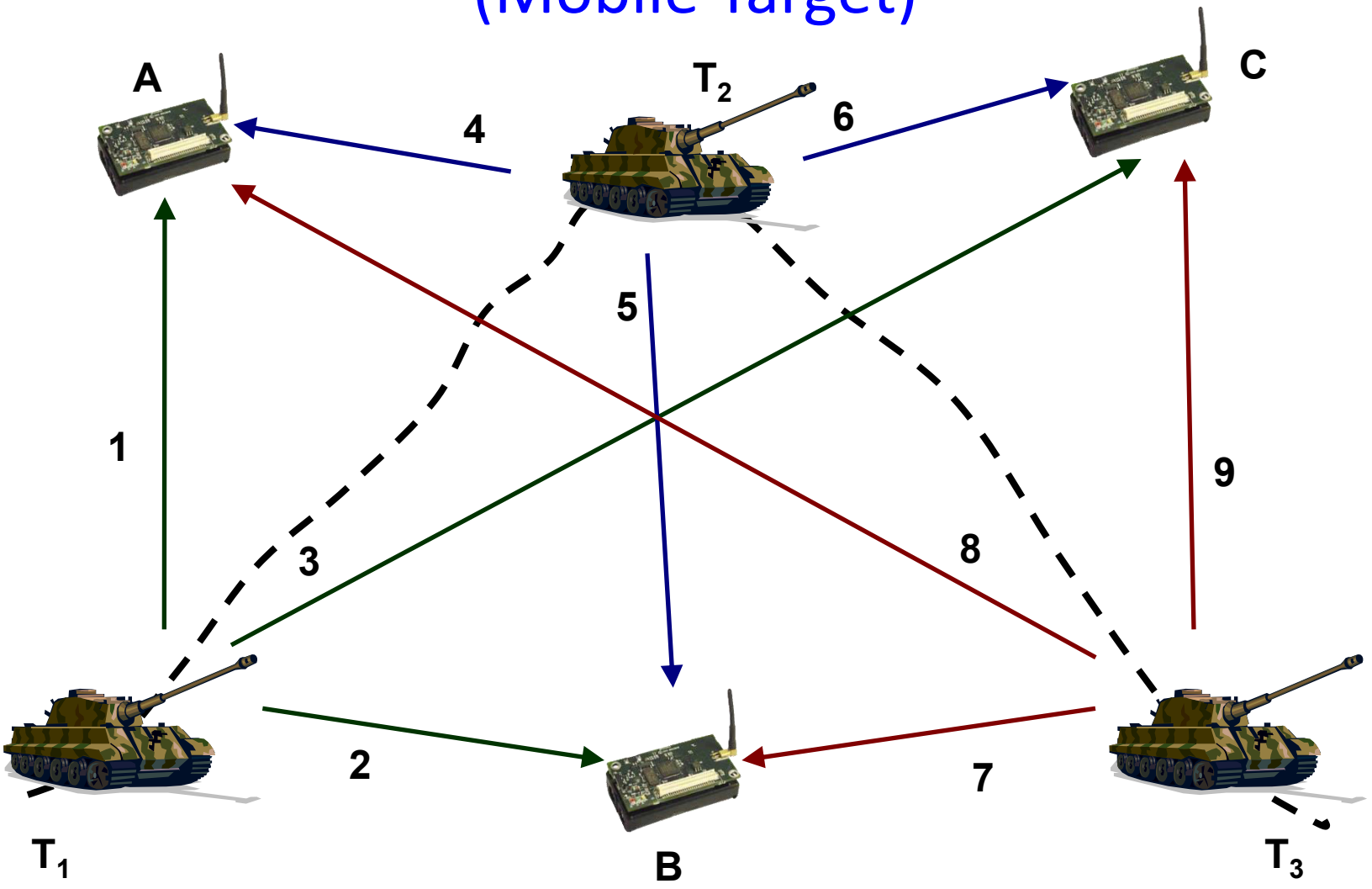
Application Layer

- **Research Issues:**
  - -- Localization Algorithms
  - -- Target Detection
  - -- Clustering Methods
  - -- Time Synchronization

Localization

- Sensor nodes need to find their locations
  - Rescue missions
  - Geographic routing protocols.
- Constraints
  - GPS: Very expensive
  - Low cost

Localization
(Mobile Target)



Localization
(Static Target)

- **n** is target node to find position

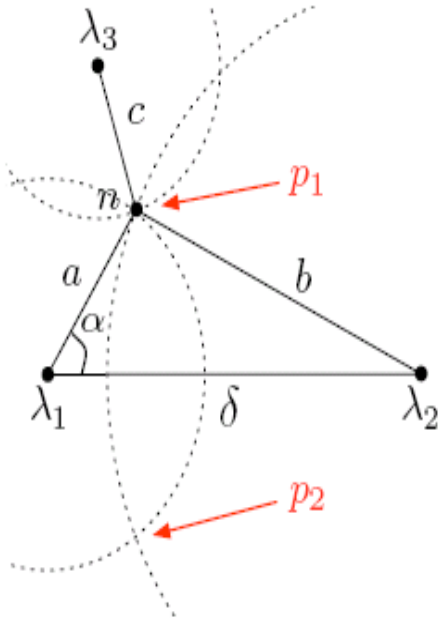


Fig. 2. This figure shows how n's coordinates are computed.

$$\alpha = \arccos\left(\frac{a^2 + \delta^2 - b^2}{2a^2\delta^2}\right)$$

$$\begin{cases} x_n = a\sin\alpha, \\ y_n = a\cos\alpha. \end{cases}$$

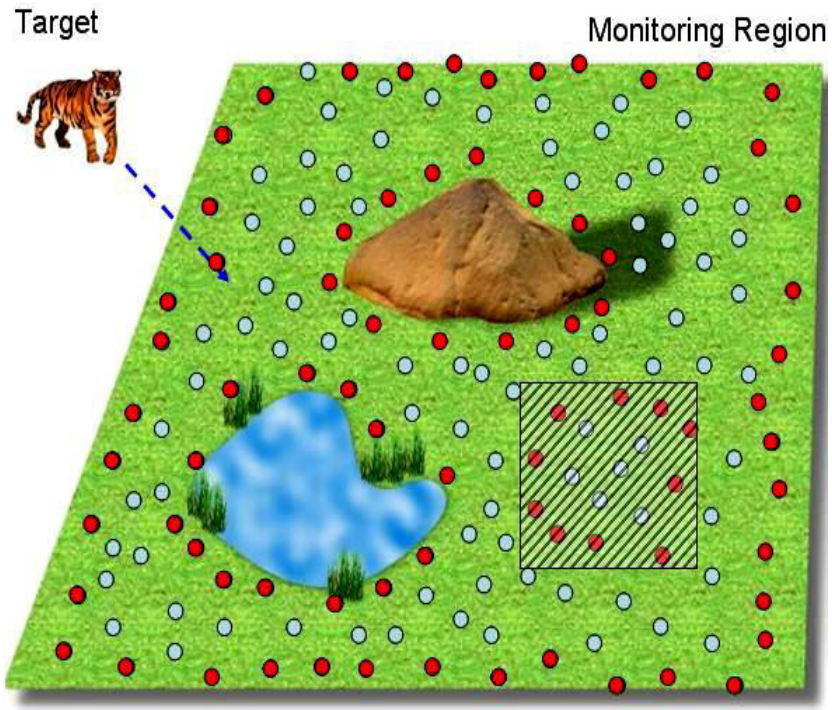
$$(x_n, y_n) = \begin{cases} p_1 & \text{if } |\, d_{p_1,\lambda_3} - c\,| < |\, d_{p_2,\lambda_3} - c\,|, \\ p_2 & \text{otherwise.} \end{cases}$$

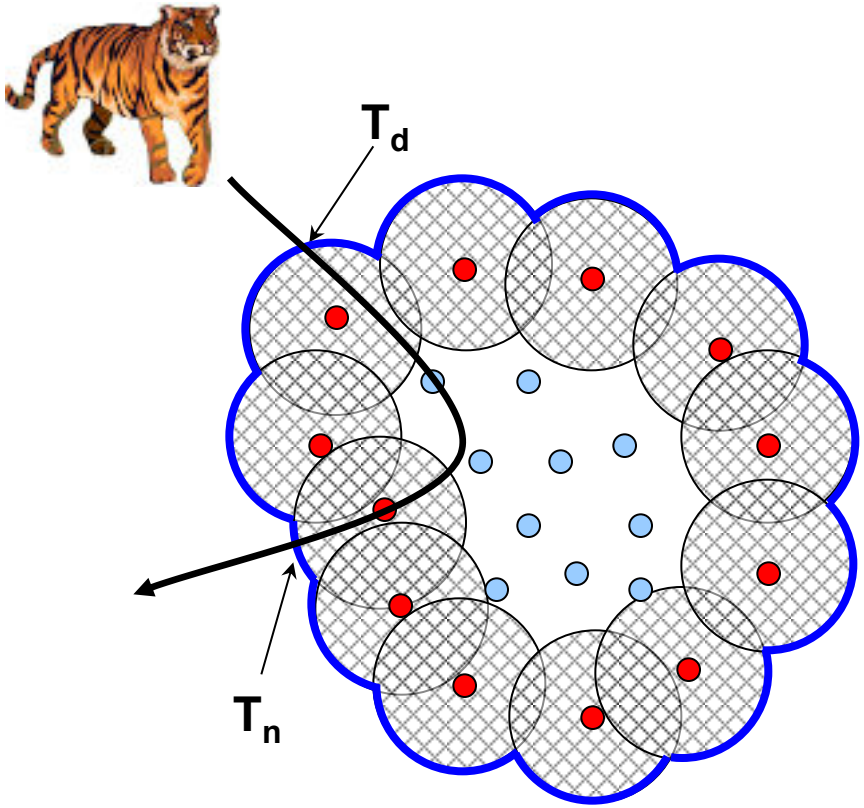
Open Problems

- **Location estimation:**

- **Indoor positioning & obstacles**
- **Using limited beacon nodes**
- **Using probabilistic method**

Target Detection





Open Problems

- Mobile target may change direction frequently
- How to correlate the data for correct detection
- How to trace the target at different points
- How to find exact location of the target
- Few boundary nodes may be dead:
- How to update the boundary node’s information.

Transport Layer

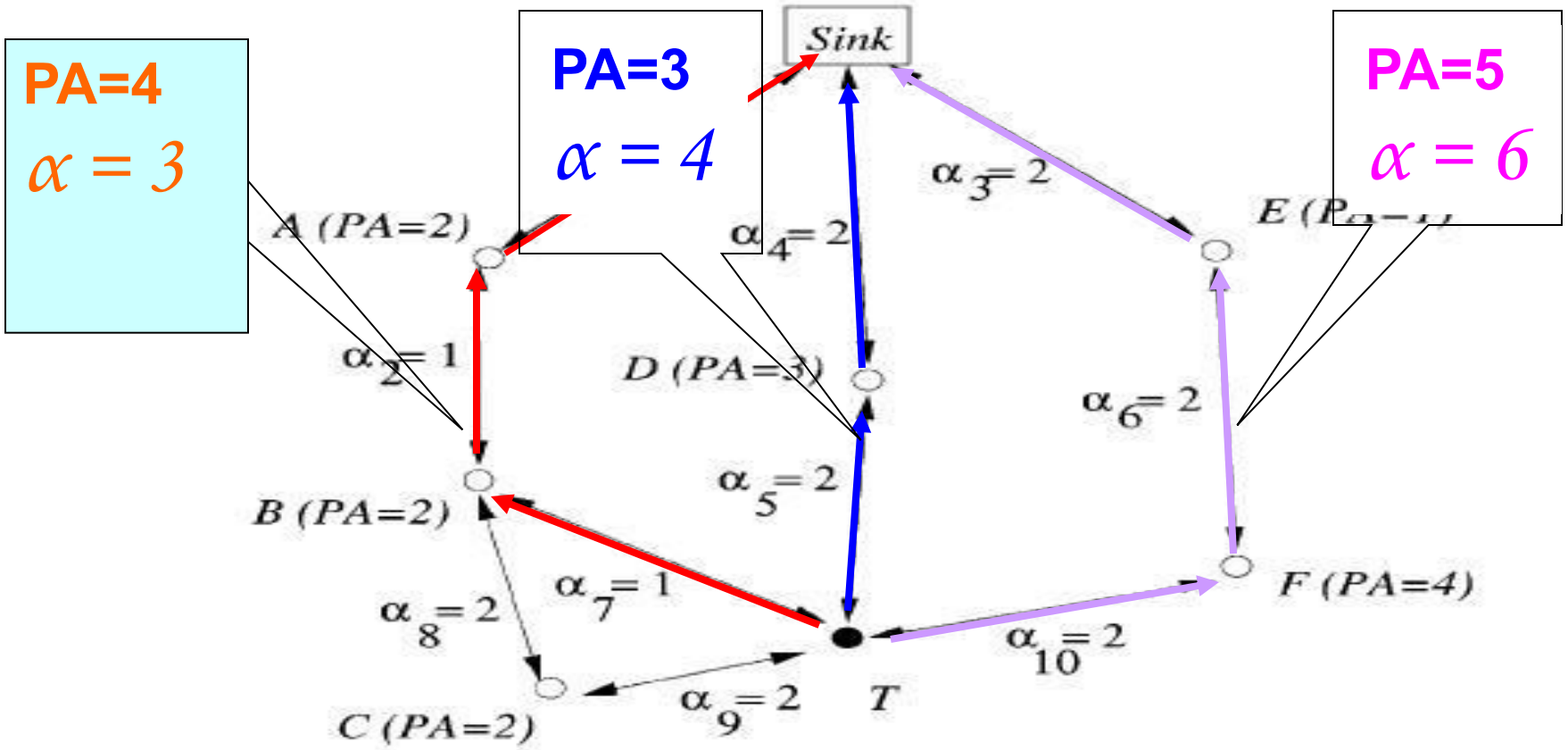
- This layer is needed when the system is required to access through Internet or any external networks.
- **Research Issues:**
- Development of transport layer protocols
- **Limitation:**

1. Limited Power
2. Memory
3. Global addressing (Not possible)

Network Layer

- Power efficient routing
- Coverage and Connectivity Problem
- Security Issues

Power Efficient Routing

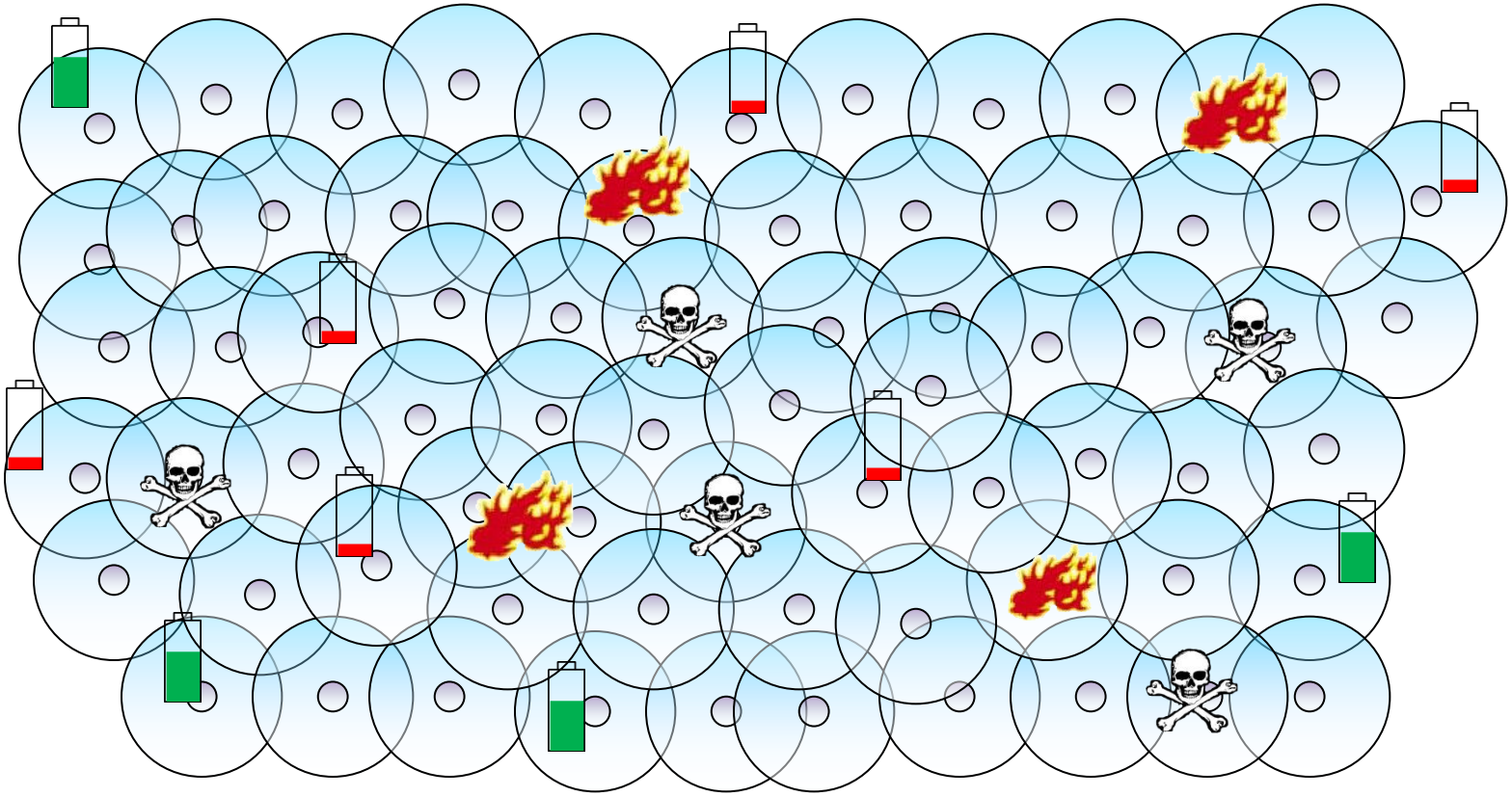


- **PA: Available Power**
- α_i : *Energy required to transmit the data packet*

Coverage Problems

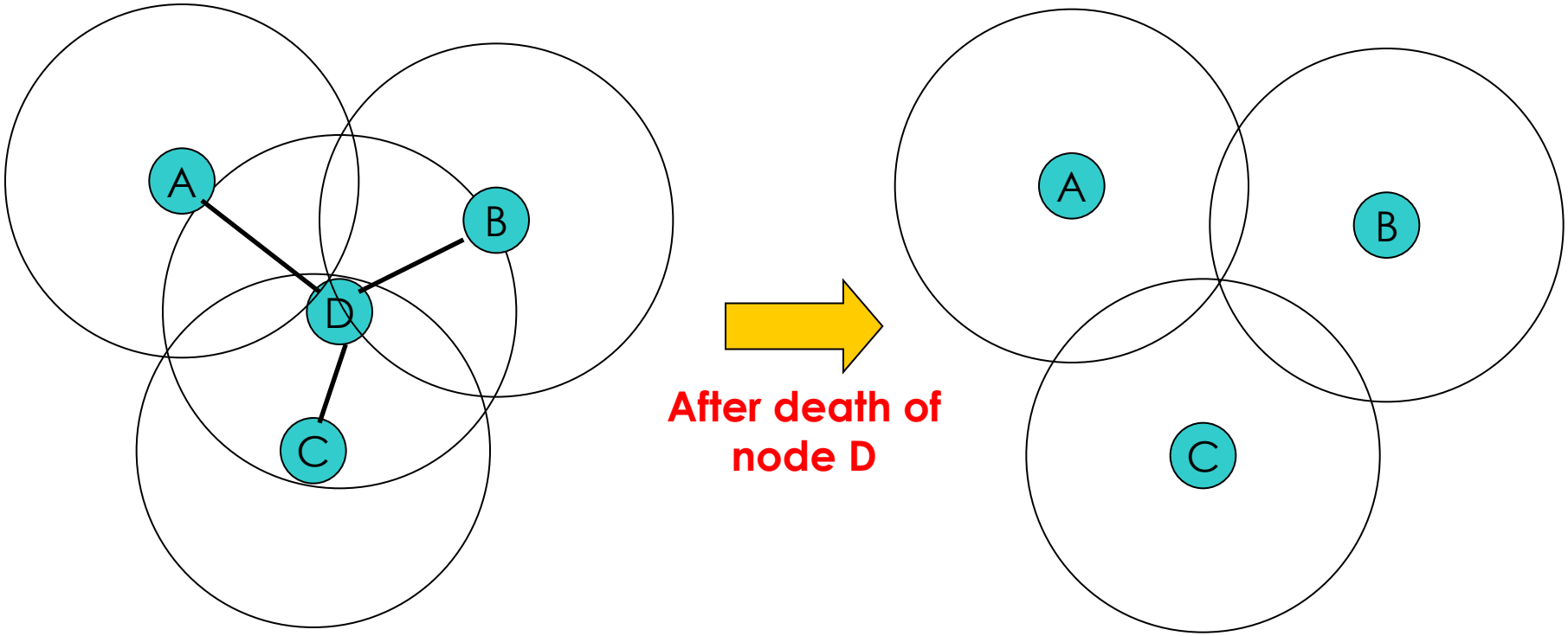
- The **full coverage** problem
- **Areas of Interest: AoI**
  - aims at covering the whole area.

Coverage Problems



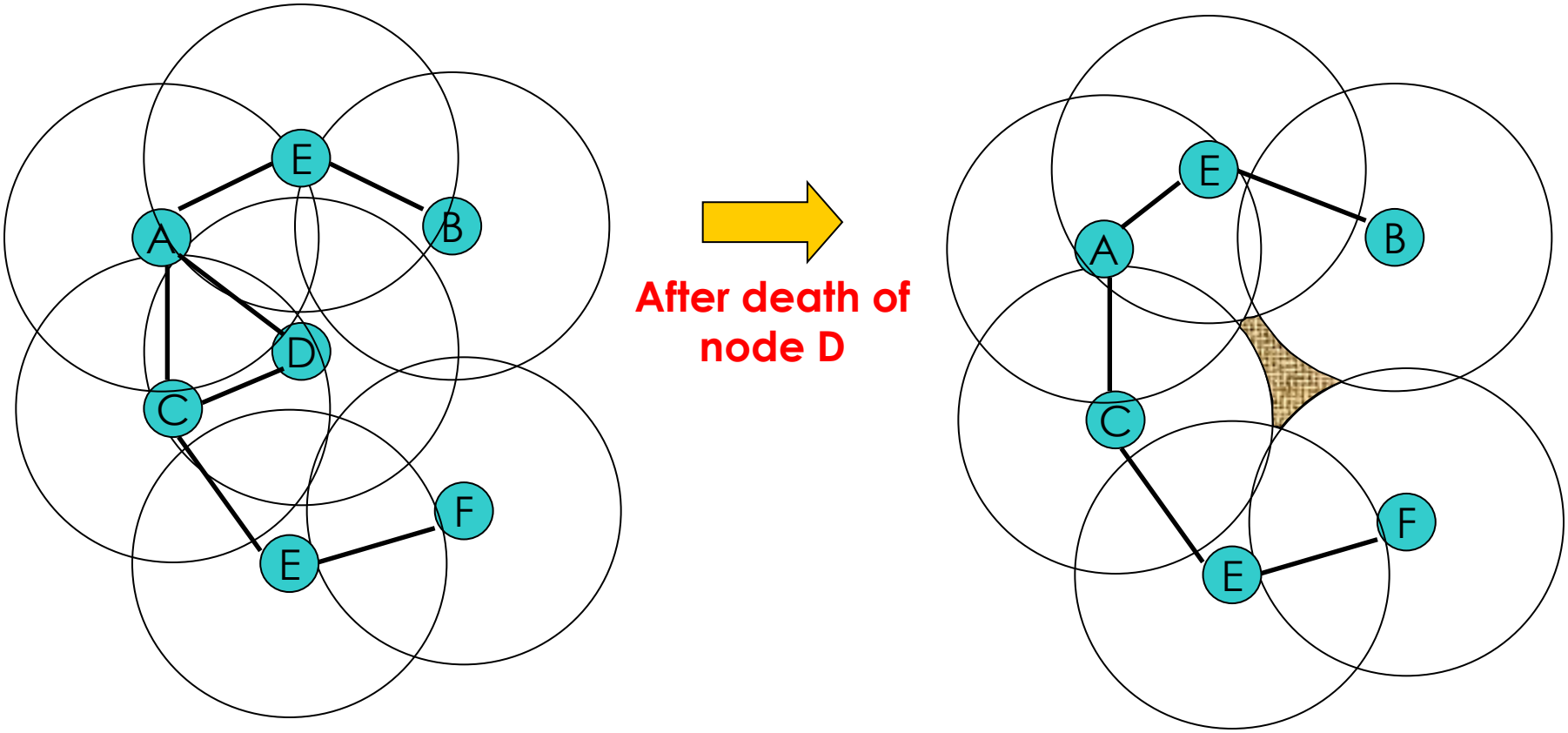
Coverage and Connectivity Algorithms

Connectivity Problem



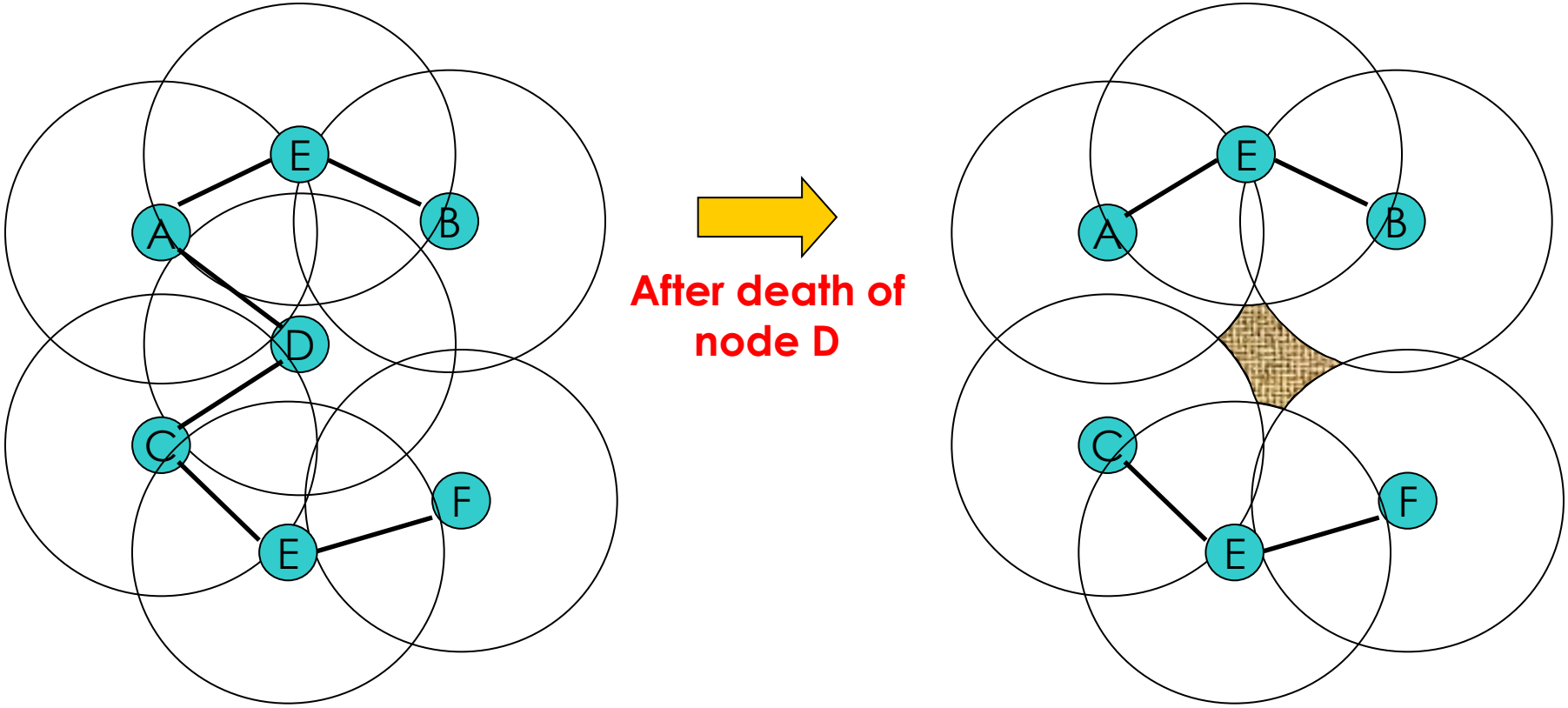
Coverage and Connectivity Algorithms

Coverage Problem



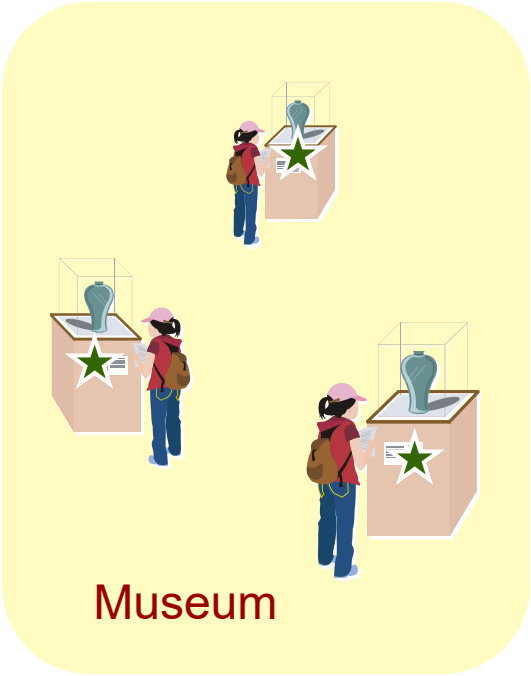
Coverage and Connectivity Algorithms

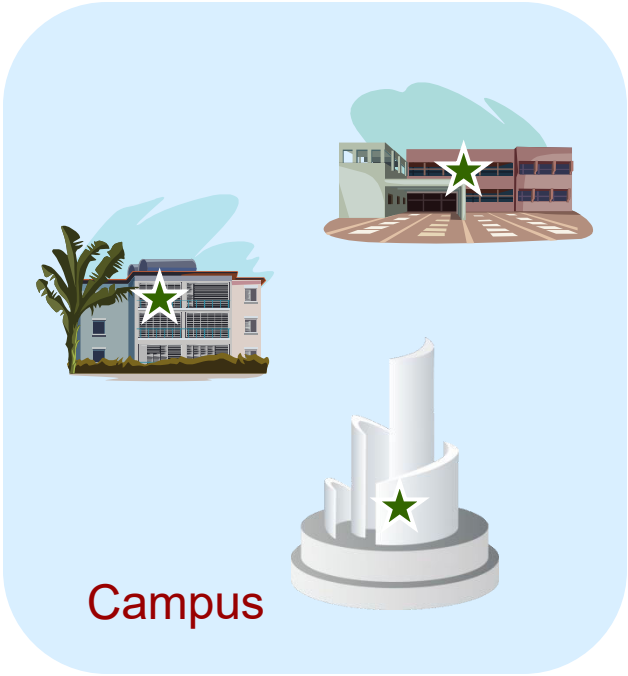
Coverage & Connectivity Problem

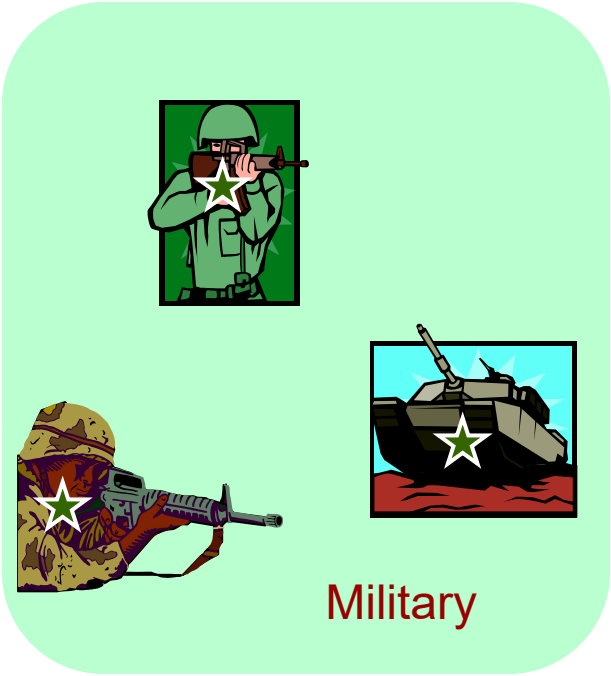


Coverage Problems

- The target coverage problem:
- Points of Interest: **PoI**
  - aims at monitoring specific points in the field of interest.



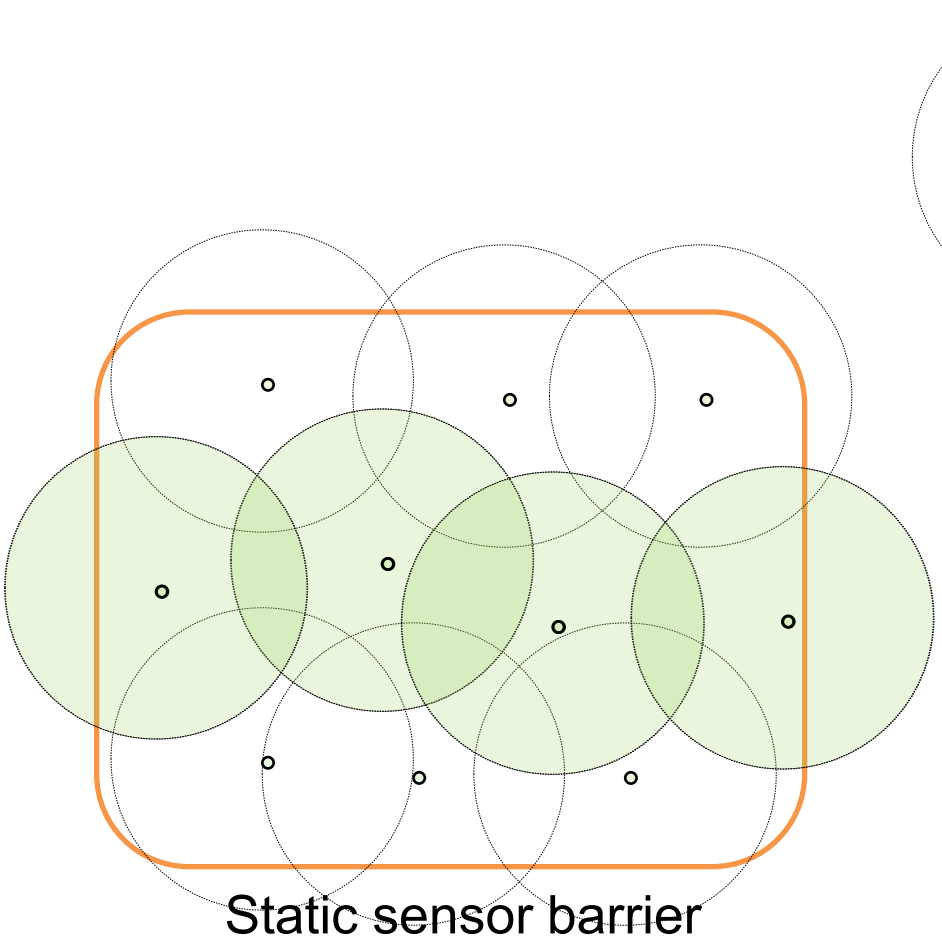




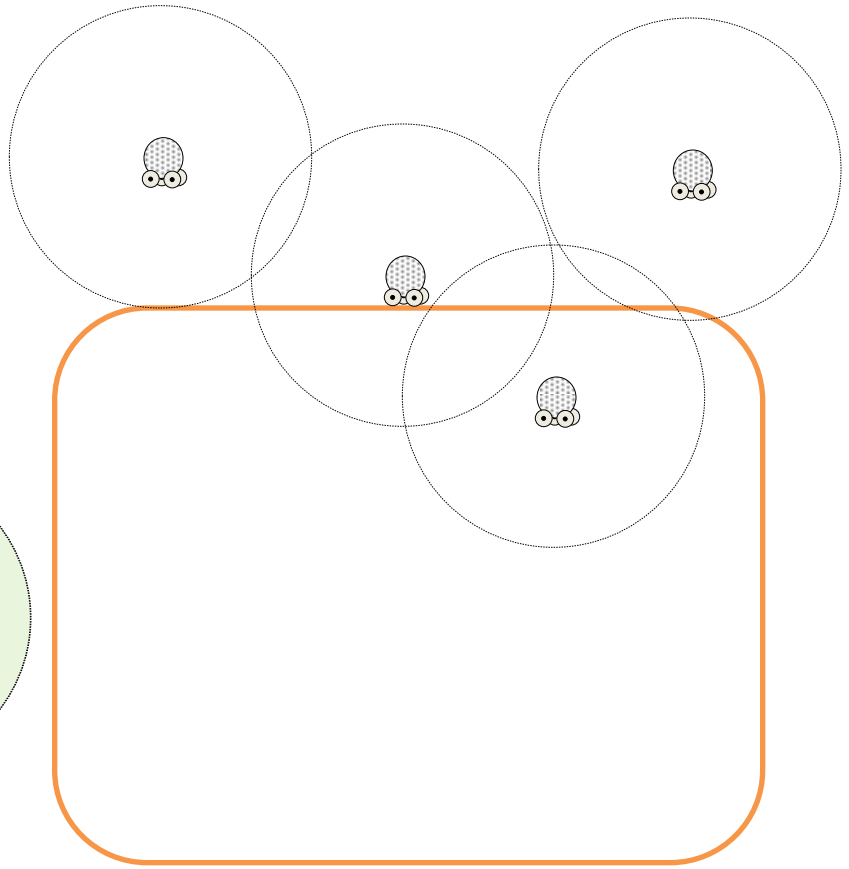
Coverage Problems

- The **barrier coverage** problem
- Lines of Interest: **LoI**
  - aims at detecting intrusion on a given area.
  - Sensors have to form a dense barrier in order to detect each event that crosses the barrier.

Static and Mobile Sensors



Static sensor barrier



Mobile sensor barrier

Security Problems

- Sensor networks use broadcasting
- Attackers can eavesdrop the message and replay it.

- Base stations are trustworthy

- Aggregation points may be trusted.

- Each node trust itself

Security Scenarios

- **Mote-class attackers:**
  - Access to fewer sensors
  - Jam the radio link among neighbors
- **Laptop-class attackers:**
  - Access to more powerful devices
  - Jam the whole network
  - Might have high bandwidth, low-latency channels

Open Problems

- **Key Establishment**
- **How can each pair of neighboring nodes find a secret key?**

- Pairwise: **secret keys are unique for each pair.**
  - **Can be used for authentication.**

Key Establishment

- **Trusted-Server Schemes**
  - Finding trusted servers is difficult.
- **Public-Key Schemes**
  - Expensive and infeasible for sensors.
- **Key Pre-distribution Schemes**

Key Establishment

- **Master-Key Approach**
  - Memory efficient, but low security.
  - Needs Tamper-Resistant Hardware.
- **Pair-wise Key Approach**
  - N-1 keys for each node.
  - Security is perfect.
  - Need a lot of memory
  - Cannot add new nodes.

Node-Specific Pre-deployed Keying

- **N: Network size, G: Groups size (G < N)**
- Number of keys necessary for forming groups of size *G :*

  N !/(N -G) ! * G!

- Total number of keys necessary for all groups of size *G or less*:

$$\sum_{g=1}^{G-1}\binom{N-1}{g}$$

- Total number of keys necessary per node for all groups of size *G or less* is:

$$\sum_{g=2}^{G}\binom{N}{g}$$

Data Link Layer

- **MAC Protocol Design**
  - Network with Single Channel
  - Network with Multiple Channel
  - Power Management
- **Performance Modeling**
  - IEEE 802.15.4 based Feedback Model
  - Queuing Model
  - Markov Chain Model

MAC Protocols Classification

- **Scheduling-Based MAC Protocols**
- **Contention-Based MAC**
- Collision Free Real Time MAC
- Hybrid MAC

Contention Based MAC

- Carrier sensing & collision avoidance
- In-band, out-band handshaking
- Busy-tone multiple access (BTMA)
- Multiple access with collision avoidance (MACA)
- High priority packets

MAC Requirements

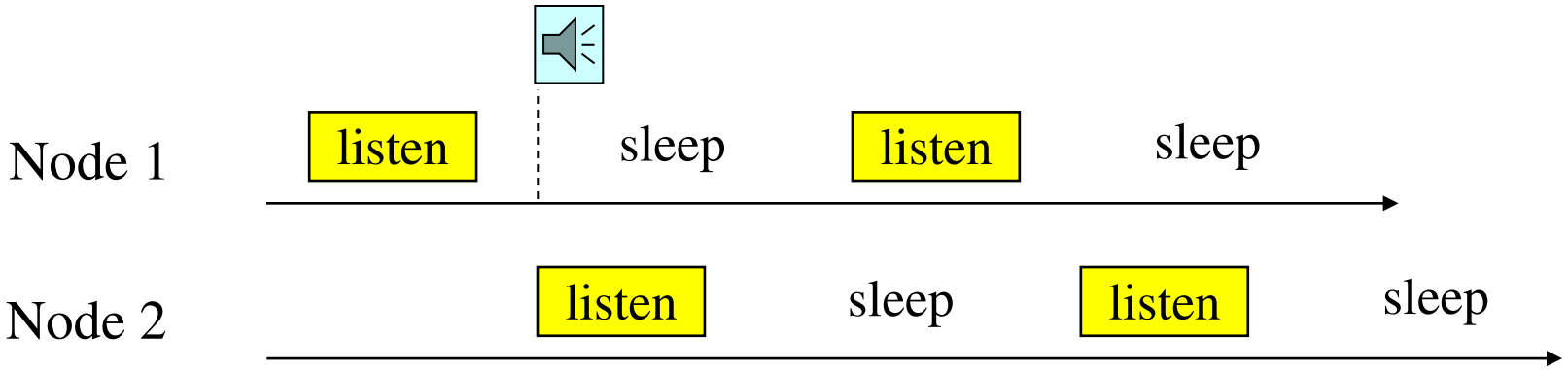
- Important requirements of MAC protocols
  - **Collision avoidance**
  - **Energy efficiency**
  - **Scalability & Adaptivity**
  - Latency
  - Fairness
  - Throughput
  - Bandwidth utilization

Primary

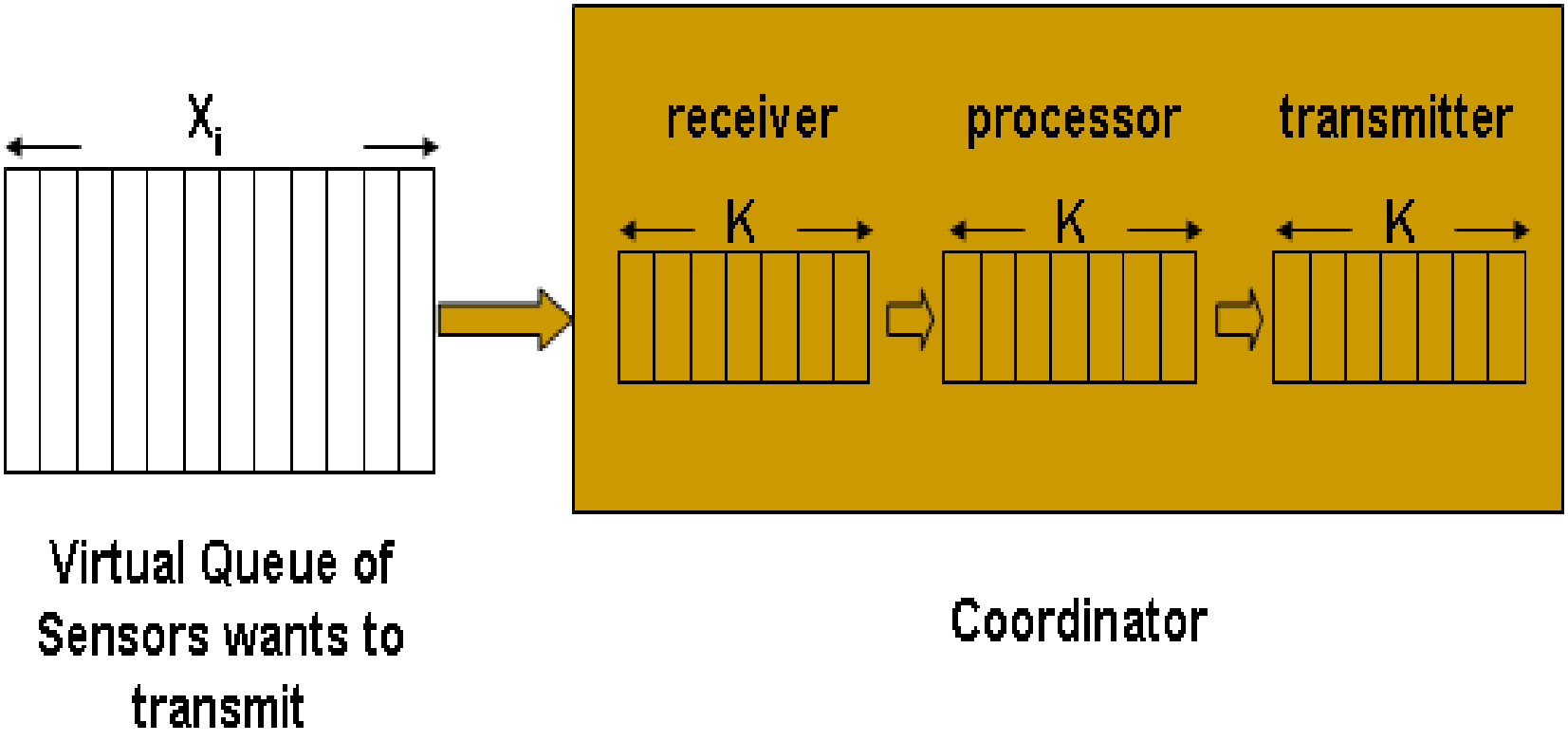
Secondary

MAC Protocol Design

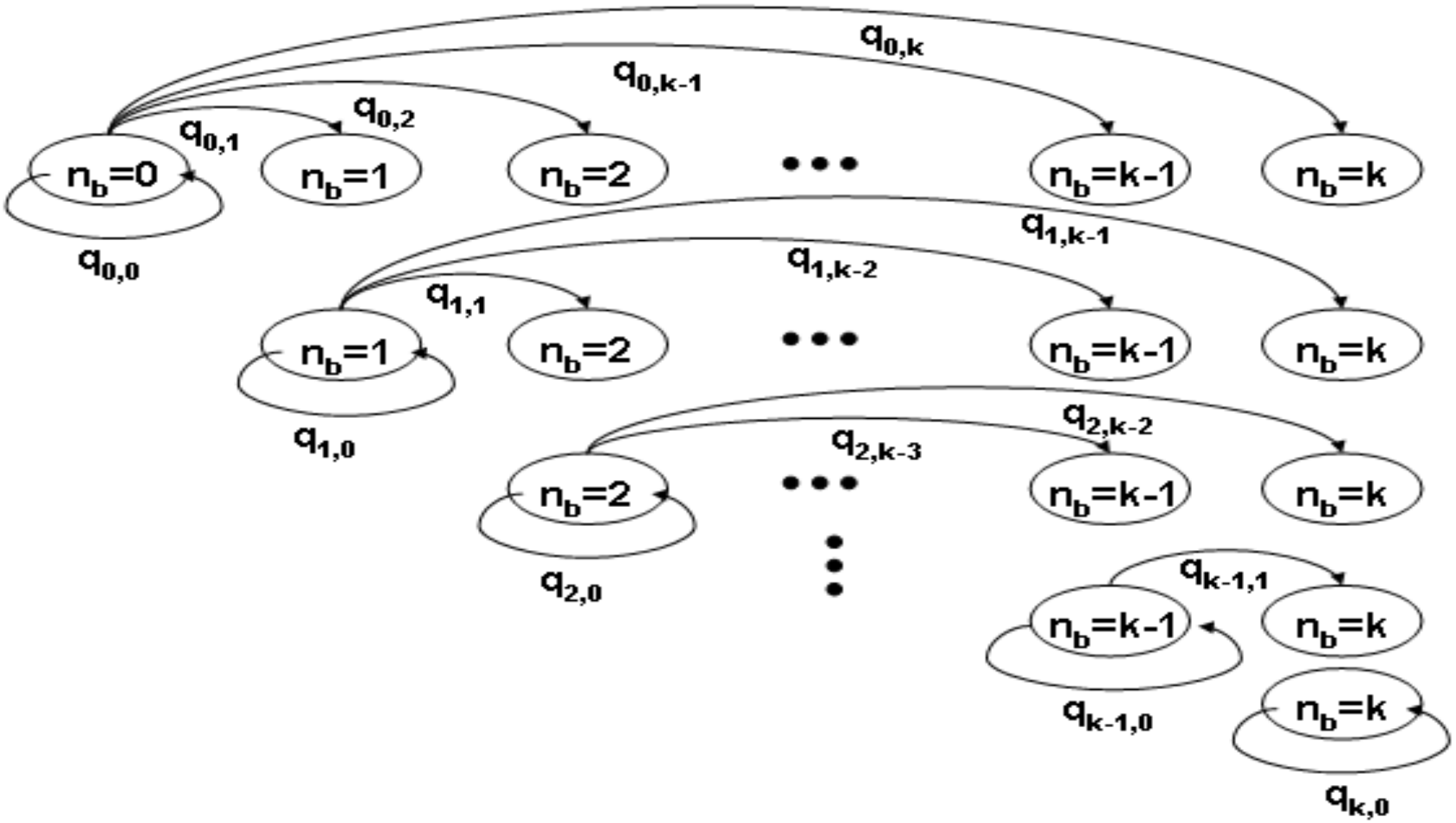
- Periodic listen and sleep
- Collision avoidance
- Overhearing avoidance
- Message passing



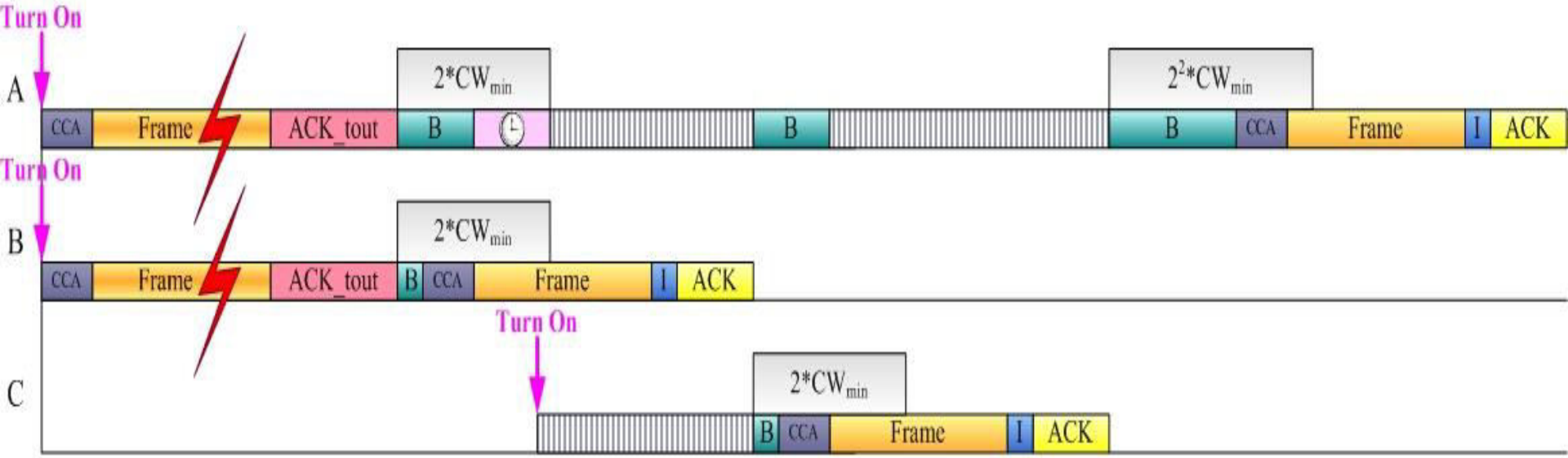
Queuing Model



Markov Chain Model



Performance Modeling



CCA : Clear Channel Assessment - Idle

: Clear Channel Assessment - Busy

B : Decreased Backoff Counter

: Halted Backoff Counter

Frame : Data Frame

CW_{min} : Initial Contention Window Size

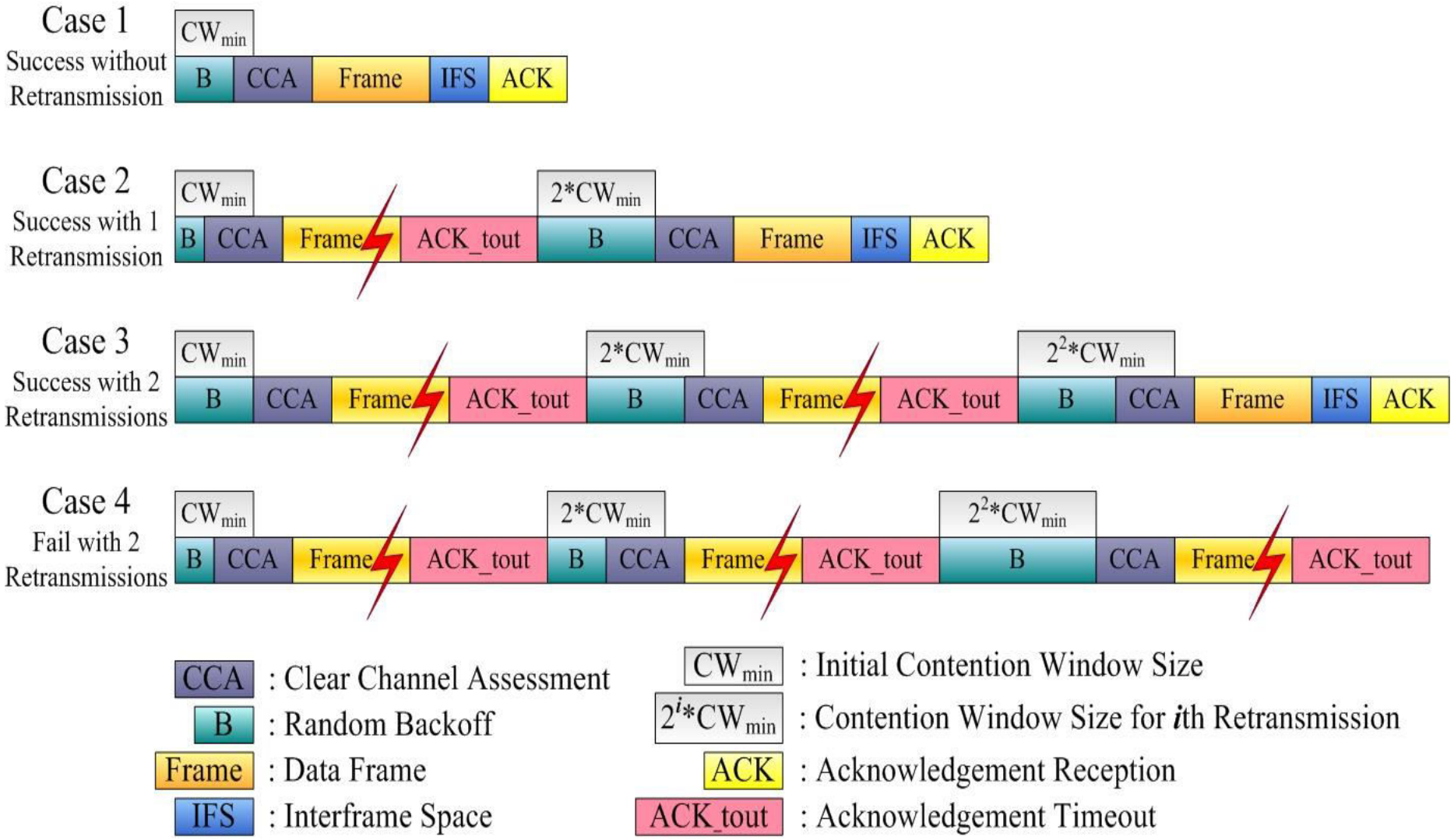
2^i*CW_{min} : Contention Window Size for *i*th Retransmission

I : Interframe Space

ACK : Acknowledgement Reception

ACK_tout : Acknowledgement Timeout

Performance Modeling



Open Problems

- How to design mathematical models:
- To estimate the latency
- To estimate the throughput
- To estimate the energy consumption
- To estimate performance of MAC protocols

Conclusions

- **Research issues in WSN are unlimited.**
- **Currently, researchers focus on:**

- **Coverage and connectivity**
- **Hole problems**
- **Energy aware scheduling to minimize energy cost**
- **Security problems**

(Limited due to limited processing and storage capability.)

THANK YOU ALL

ANY QUESTION?
PLEASE