INSTITUTE OF AERONAUTICAL ENGINEERING
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COMPUTER SCIENCE AND ENGINEERING

Ad hoc & Sensor Networks
IV year II sem

UNIT –I

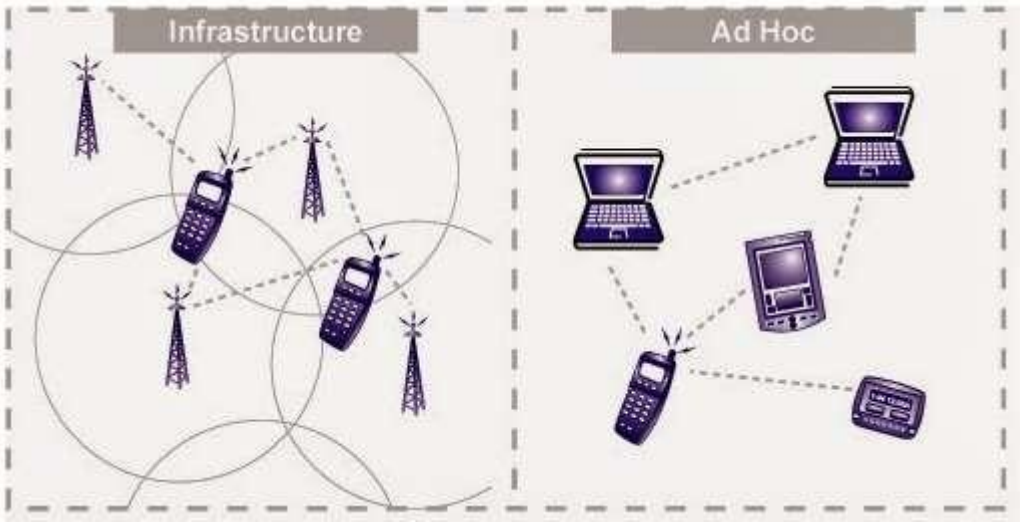
Introduction to Ad Hoc Wireless Networks

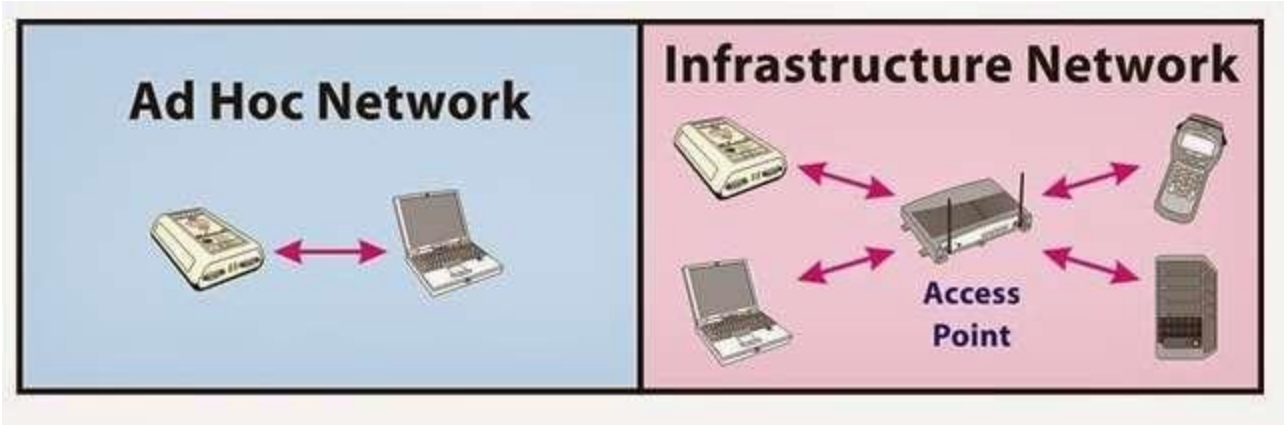
Definition

"It is an autonomous system of mobile hosts(MHs)(also serving as routers) connected by wireless links."

Ad Hoc networks do not need support from any existing infrastructure, like Base Station, Access Point, etc.

Ad Hoc Model


Infrastructure
Ad Hoc


Ad Hoc Network
Infrastructure Network
Access
Point

Infrastructure VsAd HocNetwork

Infrastructure networks	Ad-hoc wireless networks
Fixed infrastructure	No infrastructure
Single-hop wireless links	Multi-hop wireless links
High cost and time of deployment	Very quick and cost-effective
Reuse of frequency via channel reuse	Dynamic frequency sharing
Nowadays applications: civilian, commercial	Nowadays applications: military, rescue
High cost of network maintenance	Maintenance operations are built-in
Low complexity of mobile devices	Intelligent mobile devices are required
Widely deployed, evolves	Still under development in commercial sector

What makes ad hoc so attractive:

- quick deployment;
- inexpensive deployment and operation.

Technical challenges

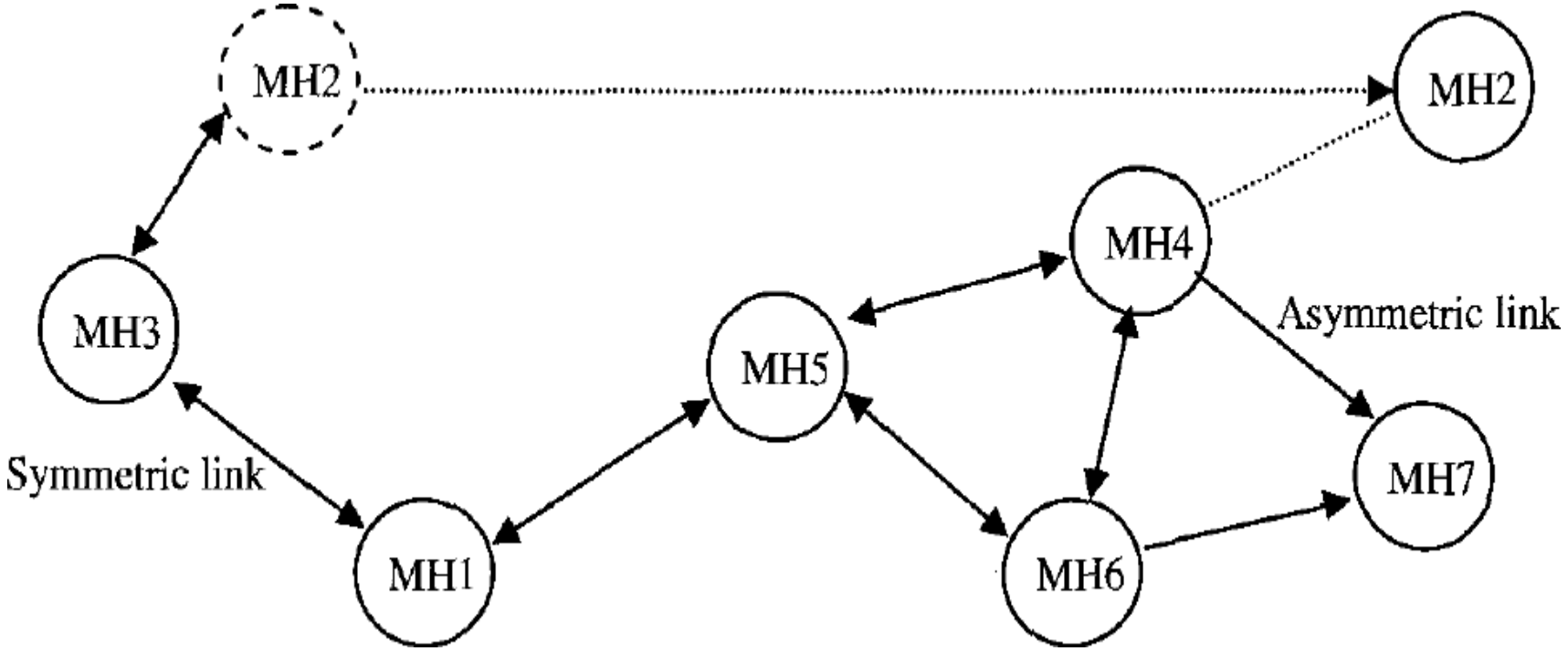
There are many challenges in design, deployment, and performance of ad hoc:

1. Medium access scheme;
2. Routing and multicasting;
3. Transport layer protocol;
4. Quality of service provisioning;
5. Self Organizing
6. Security;
7. Energy management;
8. Addressing and service discovery;
9. Scalability;
10. Deployment considerations.

Note! no good solutions for these challenges.

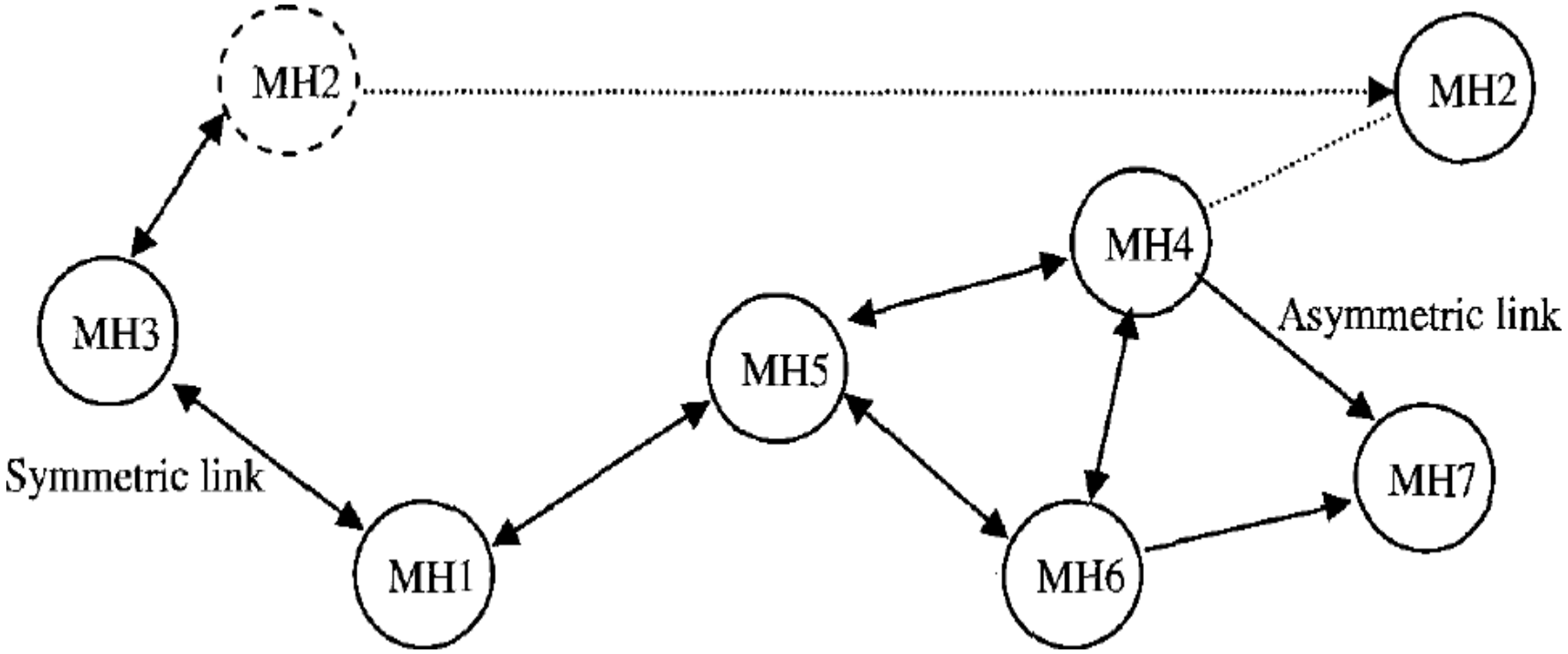
mode of operation

Ad hoc networks are basically peer-to-peer multi-hop mobile wireless networks where information packets are transmitted in a store-and-forward manner from a source to an arbitrary destination, via intermediate nodes as shown in Figure



As the MHs move, the resulting change in network topology must be made known to the other nodes so that outdated topology information can be updated or removed.

For example, as the MH2 in the above Figure changes its point of attachment from MH3 to MH4 other nodes part of the network should use this new route to forward packets to MH2.



Important characteristics of a MANET

- Dynamic Topologies : nodes move randomly with different speeds, network topology changes
- Energy-constrained Operation: nodes also involve in network management, system and applications be designed to save the energy
- Limited Bandwidth: Transmission rate is low
- Security Threats: Mobile wireless networks are generally more prone to physical security threats than fixed-cable nets. Security services be designed carefully

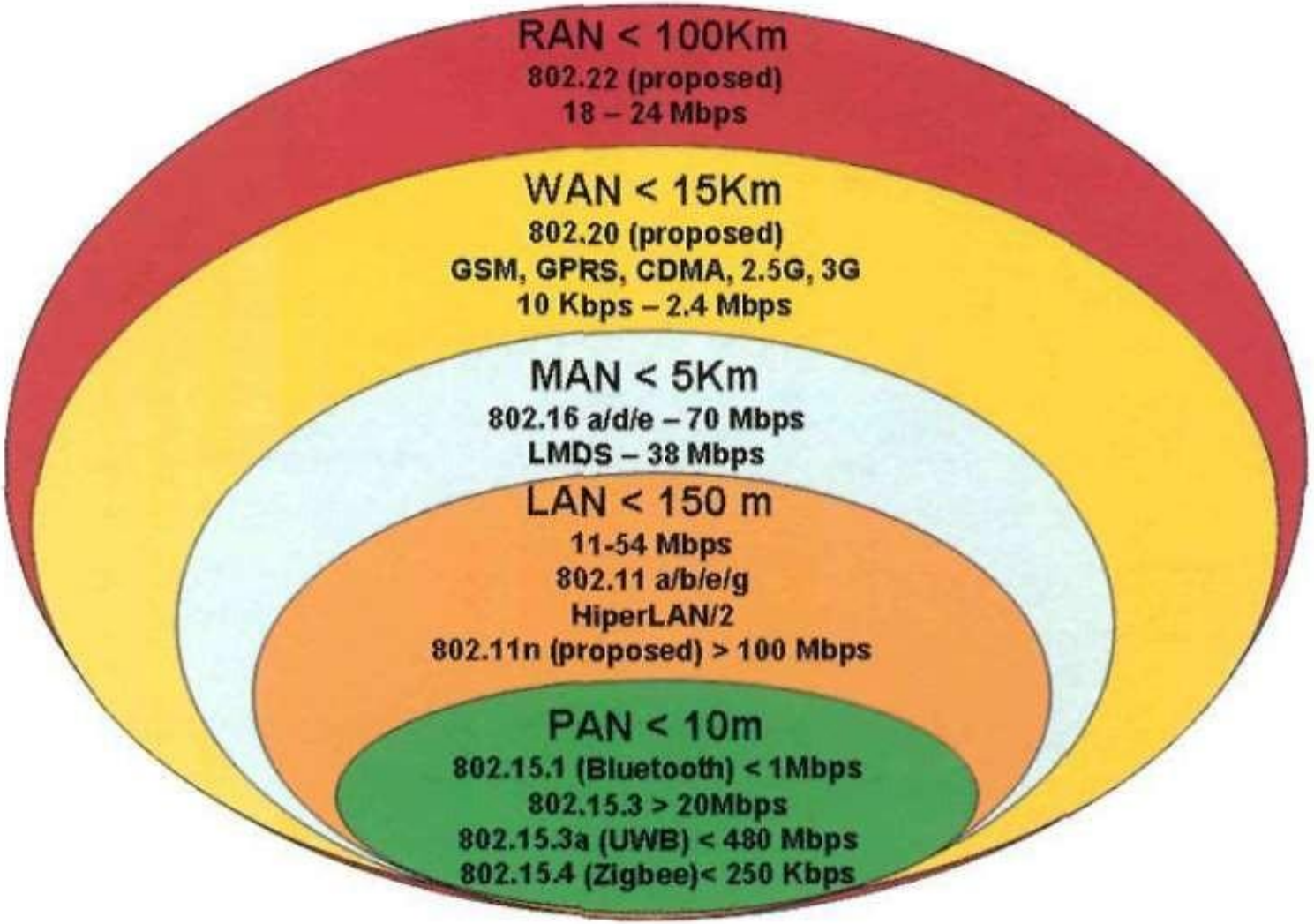
The Communication Puzzle

- There are different types of wireless networks with different transmission speeds and ranges
- Personal Area Network (PAN) personal objects
- Local Area Network(LAN) single building or campus
- Metropolitan Area Networks (MAN) towns and cities
- Wide Area Network (WAN) states, countries, continents
- Regional Area Network (RAN) to provide coverage ranges in the order of tens of kilometers with applications in rural and remote areas

All these are differed by the physical distance that the network spans

LAN, MAN and WAN were originally started as wired network, PANs and RANs, on the other hand, have been introduced with wireless connectivity in mind

- Figure below compares various wireless networks in terms of the popular standards, speeds, communication ranges and applications



- Ad hoc networks are mostly within the framework of Wireless LANs and Wireless PANs, a lot of movement is currently undergoing as to integrate ad hoc networks with MANs and WWANs
- With this it would be easy to connect the ad hoc network with the outside world (e.g., Internet)
- While the mobile devices are equipped with dual mode and dual band radio frequencies , heterogeneous networks will become more and more common and the need to integrate them will be of paramount importance

Challenges:

- Active research is going on in Adhoc, several aspects have been explored, many problems have been arisen, still some issues to be addressed.
- Major challenges are:

  1.Scalability;

  2.Quality of service;

  3.Client server model shift;

  4.Security;

  5.Interoperation with the Internet;

  6.Energy conservation;

  7.Node cooperation;

  8.Interoperation.

Scalability

- Ad hoc networks suffer, by nature, from the scalability problems in capacity.
- In a non-cooperative network, where omni-directional antennas are being used, the through put per node decreases at a rate 1/(sqrt(N)), where N is the number of nodes.
- That is, in a network with 100 nodes, a single device gets, at most, approximately one tenth of the theoretical network data rate. The problem fixed with bi directional antennas
- As the network size increases the problems like Route acquisition, service location and encryption key exchanges need to be solved.

Quality of Service

- There are many applications for transfer of Voice, live video, and file transfer.
- QoS parameters such as delay, jitter, bandwidth, Packet loss probability, and so on need to be addressed carefully.
- Issues of QoS robustness, QoS routing policies, algorithms and protocols with multiple, including preemptive, priorities remain to be addressed.

Client-Server Model Shift

- Address allocation, name resolution, authentication and the Service location are just examples of the very basic services which are done by the servers but in ad hoc some nodes do all these and their location in the network is unknown and possibly even changing over time.
- The issue of shift from the traditional client-sever model remains to be appropriately addressed

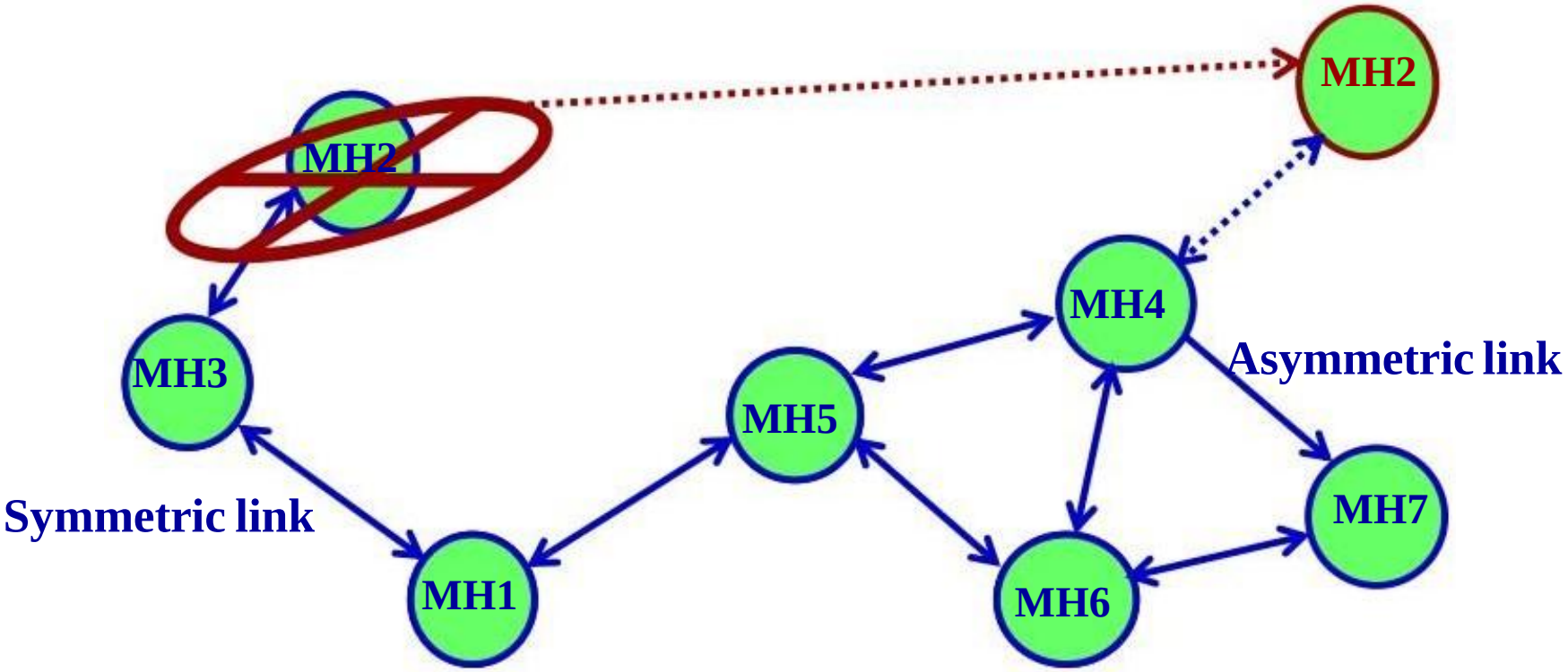
Security

- Lack of any centralized network management or certification authority makes these dynamically changing wireless structures leads security threats like infiltration, eavesdropping, interference, and so on.
- Security is indeed one of the most difficult problems to be solved, but it has received only modest attention so far

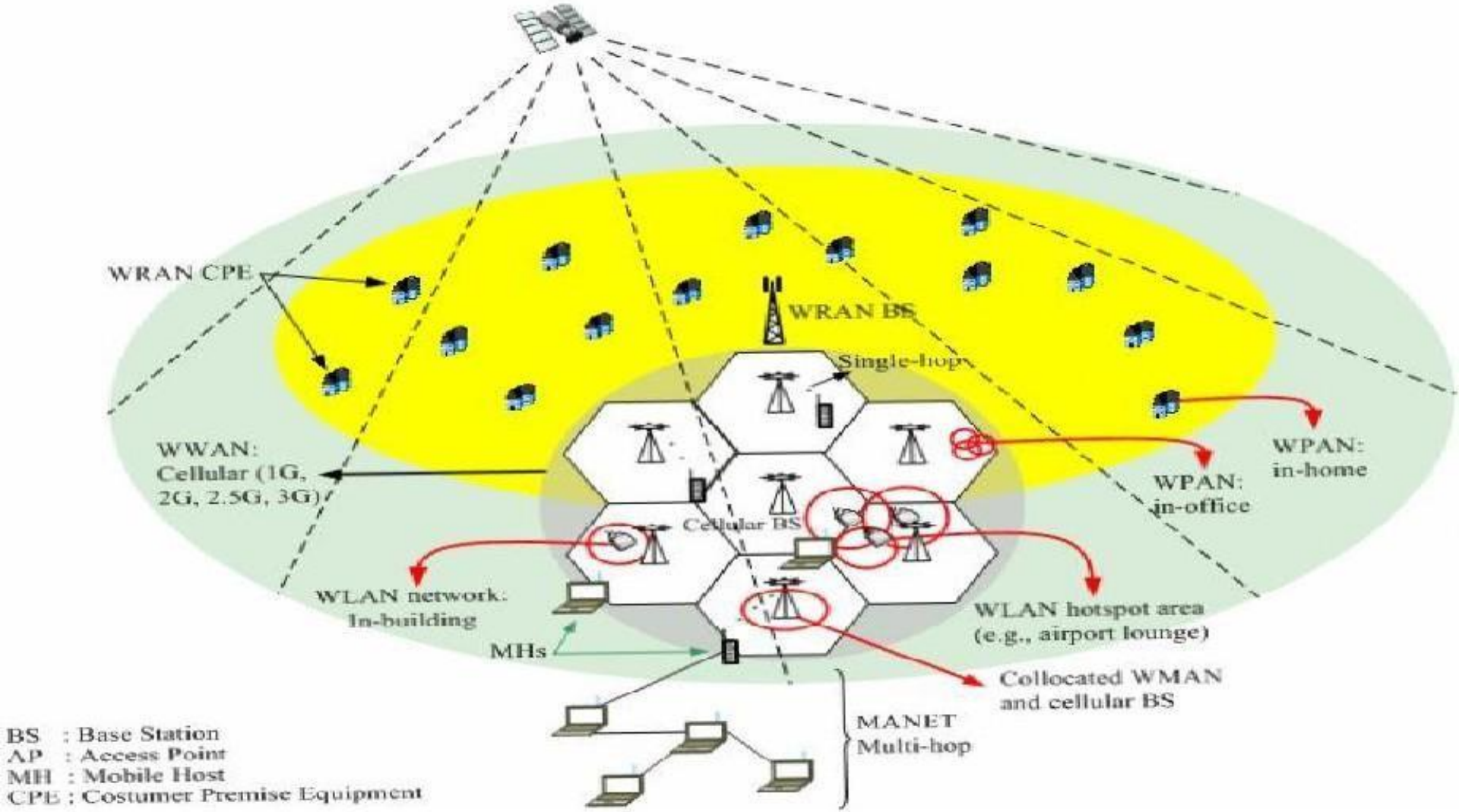
Energy Conservation

- There are two primary research topics: maximization of life time of a single node and maximization of the life time of the whole network.
- These goals can be achieved either by developing better batteries, or by making the network terminals‘ operation more energy efficient.
- The first approach is likely to give a 40% increase in battery life, remaining 60% can be achieved though the design of energy efficient protocols design

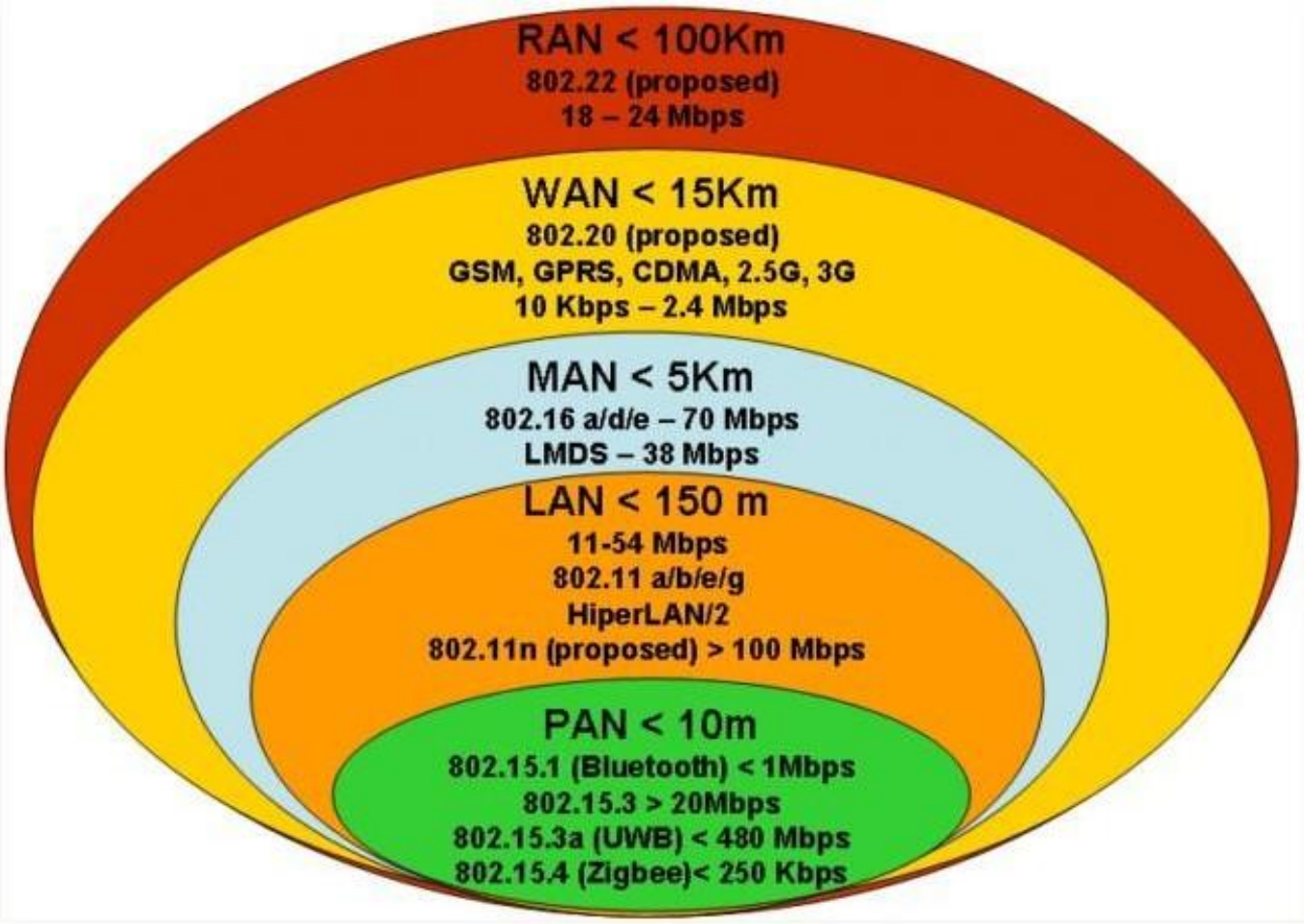
A Mobile Ad Hoc Network (MANET)



The envisioned communication puzzle of 4G and beyond



The scope of various wireless technologies



UNIT –II

Data Transmission In MANETS

MAC PROTOCOLS FOR AD HOC WIRELESS NETWORKS

Issues in designing a MAC Protocol- Classification of MAC Protocols- Contention based protocols- Contention based protocols with Reservation Mechanisms- Contention based protocols with Scheduling Mechanisms – Multi channel MAC-IEEE 802.11

Issues

- The main issues need to be addressed while designing a MAC protocol for ad hoc wireless networks:
  - **Bandwidth efficiency** is defined at the ratio of the bandwidth used for actual data transmission to the total available bandwidth. The MAC protocol for ad-hoc networks should maximize it.
  - **Quality of service** support is essential for time-critical applications. The MAC protocol for ad-hoc networks should consider the constraint of ad-hoc networks.
  - **Synchronization** can be achieved by exchange of control packets.

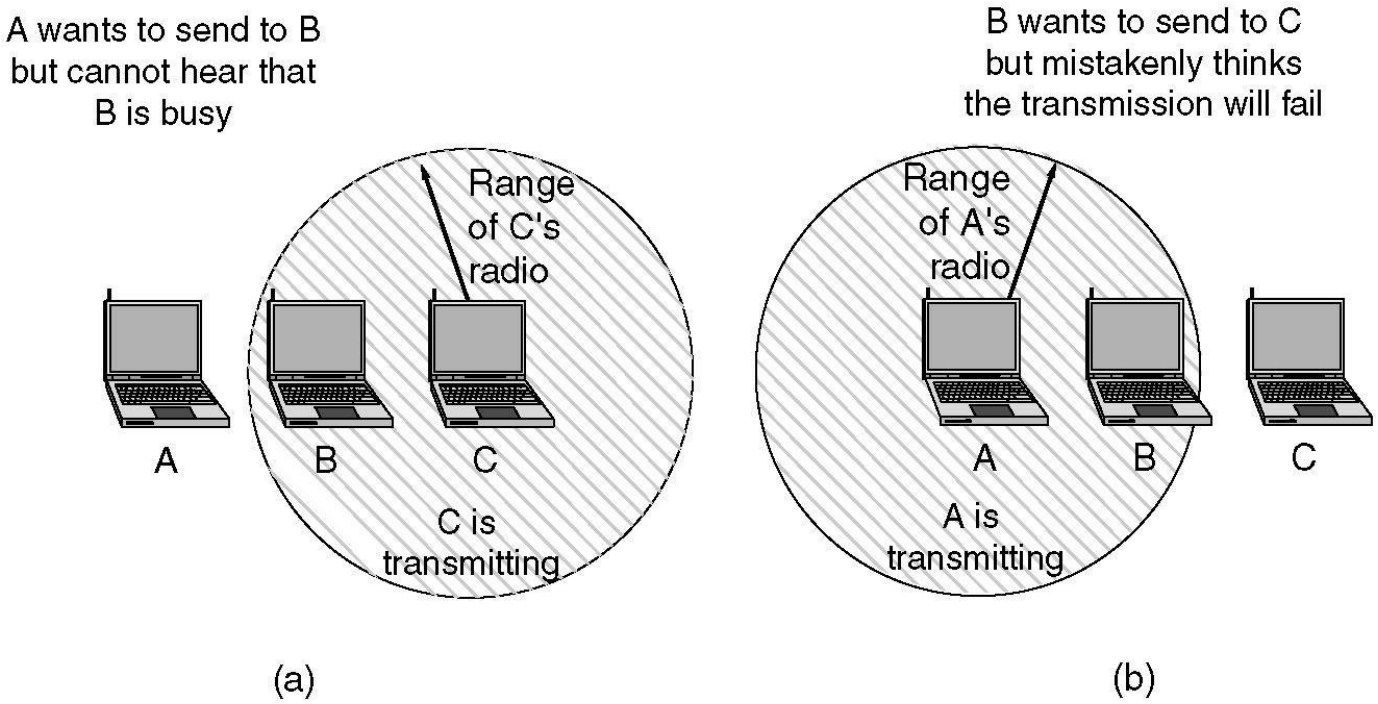
Issues

The main issues need to be addressed while designing a MAC protocol for ad hoc wireless networks:

Hidden and exposed terminal problems:**Hidden nodes:Hidden stations**: Carrier sensing may fail to detect another station. For example, A and D.**Fading**: The strength of radio signals diminished rapidly with thedistance from the transmitter. For example, A andC.**Exposed nodes:Exposed stations**: B is sending to A. C can detect it. C might want to send to E but conclude it cannot transmit because C hears B.**Collision masking**:

The local signal might drown out the remote transmission.**Error-Prone Shared Broadcast ChannelDistributed Nature/Lack of Central CoordinationMobility of Nodes**: Nodes are mobile most of the time.

Hidden & exposed terminal problem



A)THE HIDDEN STATION PROBLEM. (B) THE EXPOSEDSTATION PROBLEM.

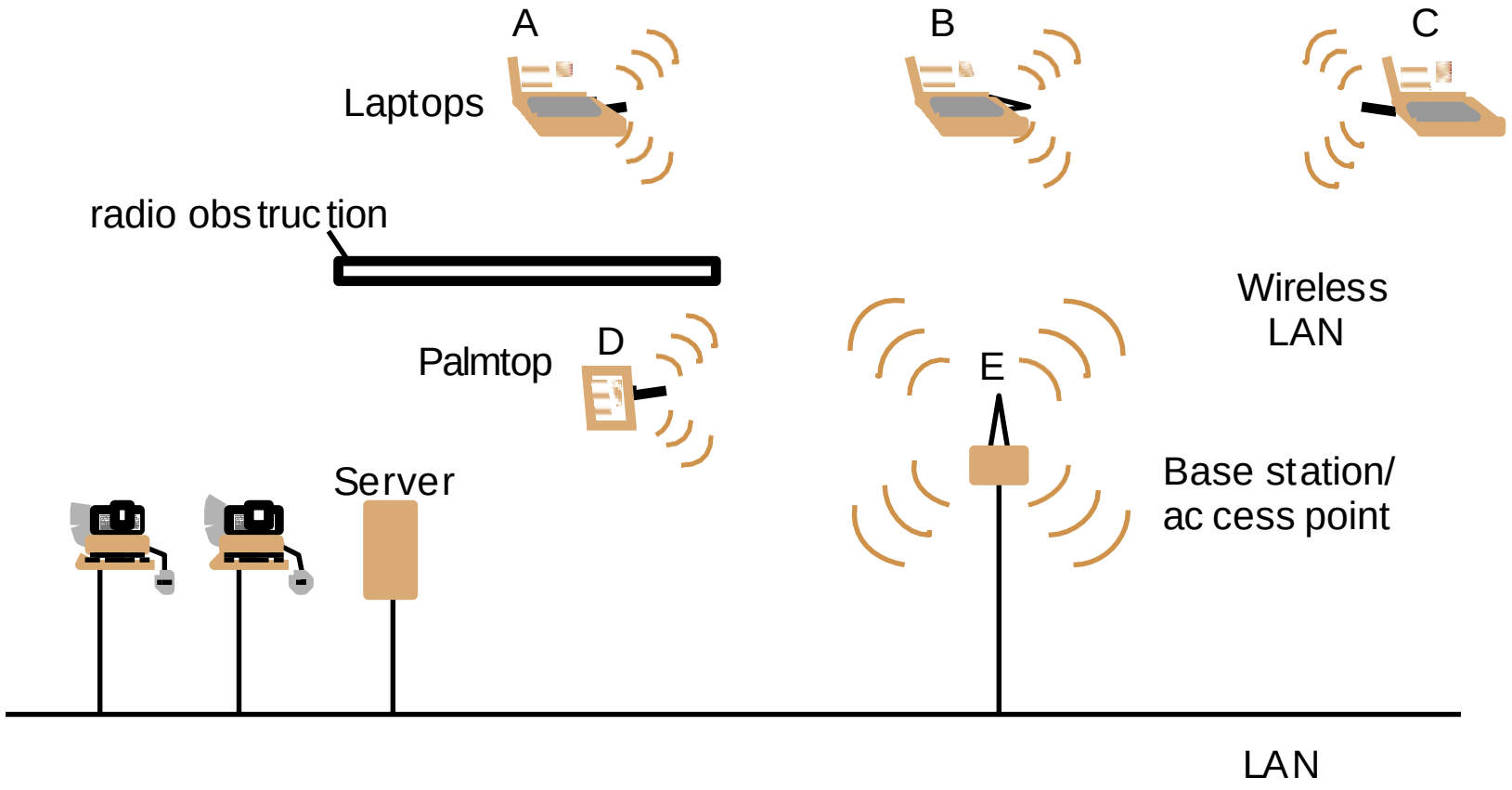
The Hidden Terminal Problem

- Wireless stations have transmission ranges and not all stations are within radio range of each other.
- Simple CSMA will not work!
- C transmits to B.
- If A "*senses*" the channel, it will not hear C's transmission and falsely conclude that A can begin a transmission to B.

The Exposed Station Problem

- The inverse problem.
- B wants to send to C and listens to the channel.
- When B hears A's transmission, B falsely assumes that it cannot send to C.

Wireless LAN configuration



Design goals of a MAC Protocol

- Design goals of a MAC protocol for ad hoc wireless networks
  - The operation of the protocol should be distributed.
  - The protocol should provide QoS support for real-time traffic.
  - The access delay, which refers to the average delay experienced by any packet to get transmitted, must be kept low.
  - The available bandwidth must be utilized efficiently.
  - The protocol should ensure fair allocation of bandwidth to nodes.

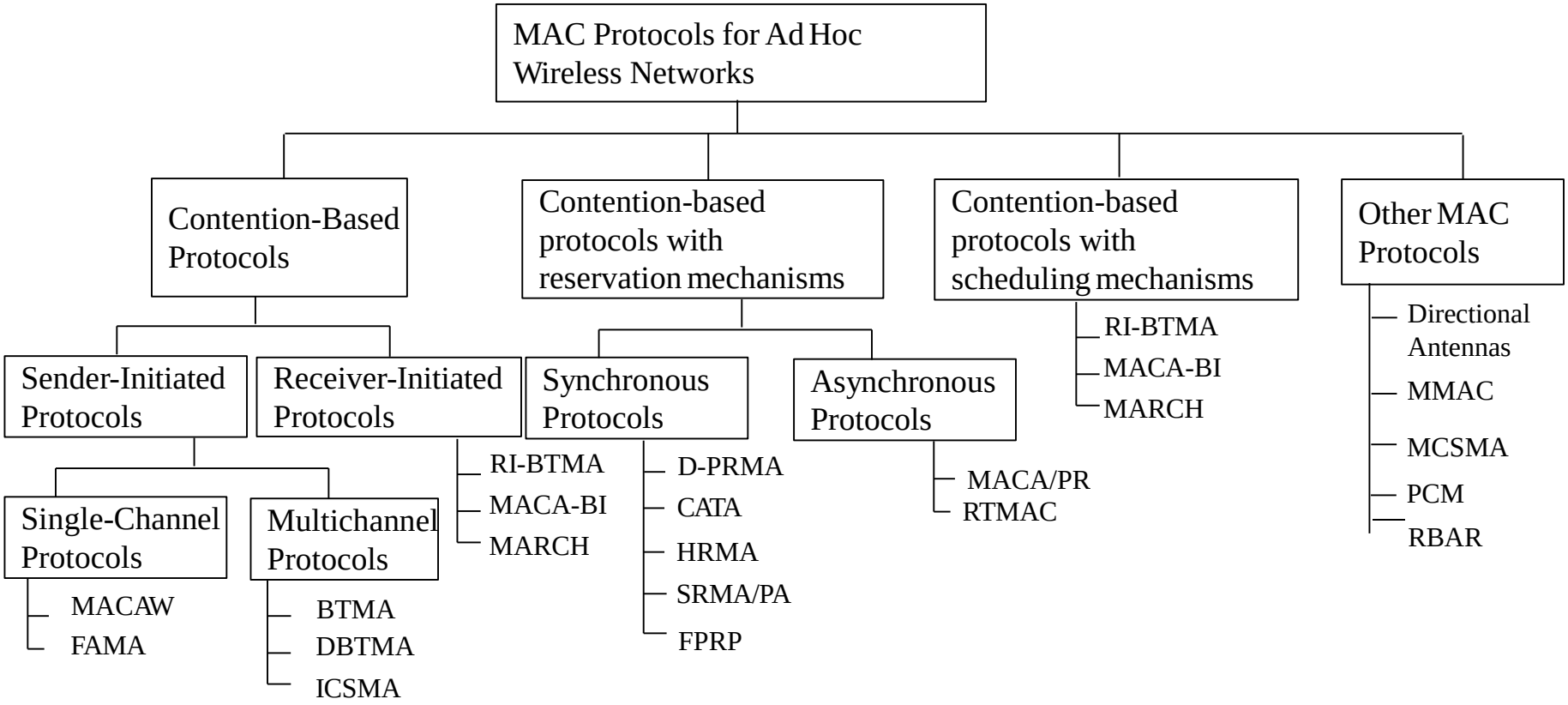
Design goals of a MAC Protocol

- Control overhead must be kept as low as possible.
- The protocol should minimize the effects of hidden and exposed terminal problems.
- The protocol must be scalable to large networks.
- It should have power control mechanisms.
- The protocol should have mechanisms for adaptive data rate control.
- It should try to use directional antennas.
- The protocol should provide synchronization among nodes.

Classifications of MAC protocols

- Ad hoc network MAC protocols can be classified into three types:
  - Contention-based protocols
  - Contention-based protocols with reservation mechanisms
  - Contention-based protocols with scheduling mechanisms
  - Other MAC protocols

Classifications of MAC protocols



Classifications of MAC Protocols

- Contention-based protocols
  - Sender-initiated protocols:
    - Packet transmissions are initiated by the sender node.
    - Single-channel sender-initiated protocols: A node that wins the contention to the channel can make use of the entire bandwidth.
    - Multichannel sender-initiated protocols: The available bandwidth is divided into multiple channels.
  - Receiver-initiated protocols:
    - The receiver node initiates the contention resolution protocol.

Classifications of MAC Protocols

- Contention-based protocols with reservation mechanisms
  - Synchronous protocols
    - All nodes need to be synchronized. Global time synchronization is difficult to achieve.
  - Asynchronous protocols
    - These protocols use relative time information for effecting reservations.

Classifications of MAC Protocols

- Contention-based protocols with scheduling mechanisms
  - Node scheduling is done in a manner so that all nodes are treated fairly and no node is starved of bandwidth.
  - Scheduling-based schemes are also used for enforcing priorities among flows whose packets are queued at nodes.
  - Some scheduling schemes also consider battery characteristics.
- Other protocols are those MAC protocols that do not strictly fall under the above categories.

Contention-based protocols

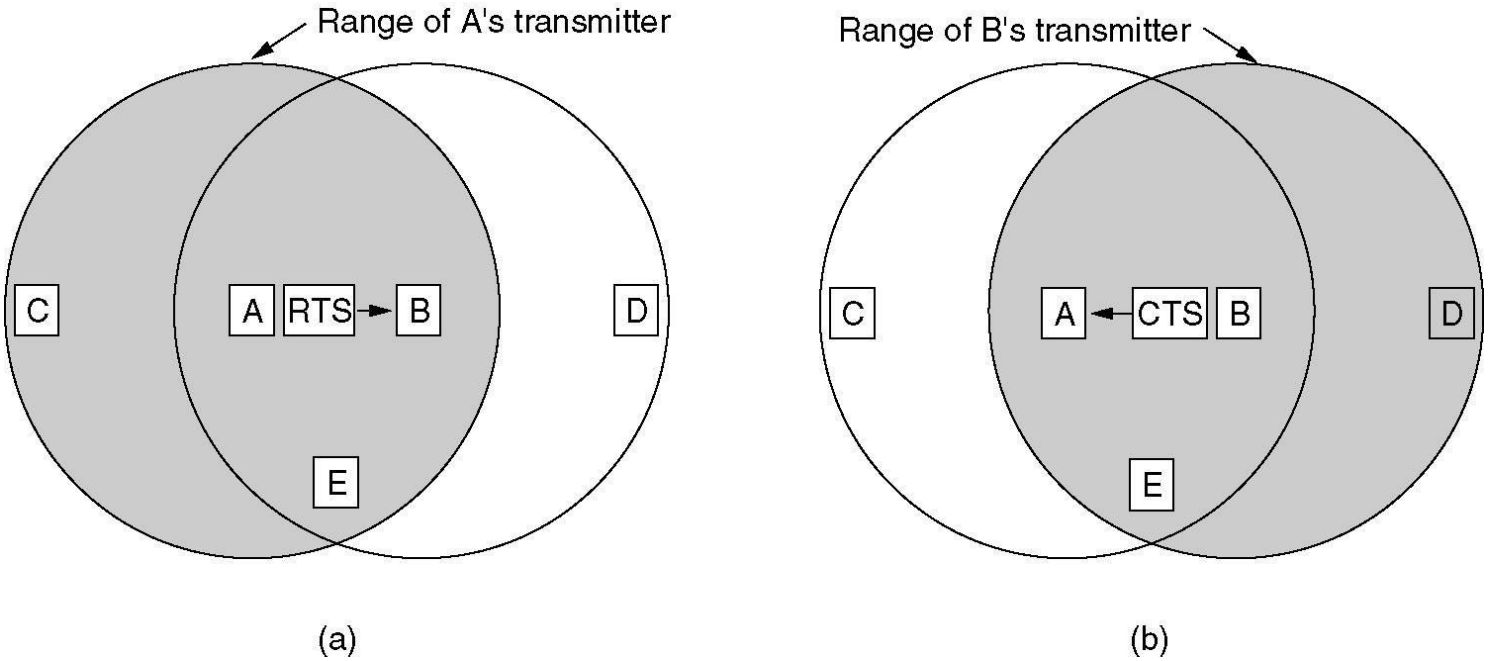
- MACAW: A Media Access Protocol for Wireless LANs is based on MACA (Multiple Access Collision Avoidance) Protocol
- MACA
  - When a node wants to transmit a data packet, it first transmit a **RTS** (**Request To Send)** frame.
  - The receiver node, on receiving the RTS packet, if it is ready to receive the data packet, transmits a **CTS (Clear to Send)** packet.

Contention-based protocols

- Once the sender receives the CTS packet without any error, it starts transmitting the data packet.
- If a packet transmitted by a node is lost, the node uses the binary exponential back-off (BEB) algorithm to back off a random interval of time before retrying.

- The binary exponential back-off mechanism used in MACA might starves flows sometimes. The problem is solved by MACAW.

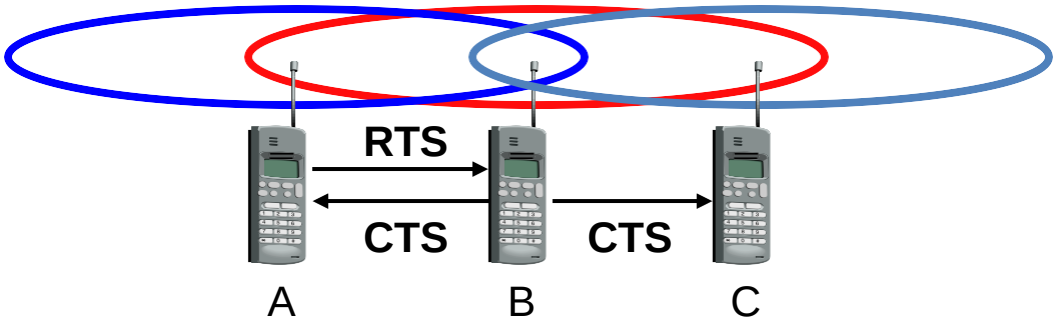
MACA Protocol



The MACA protocol. (a) A sending an RTS to B.

(b) B responding with a CTS to A.

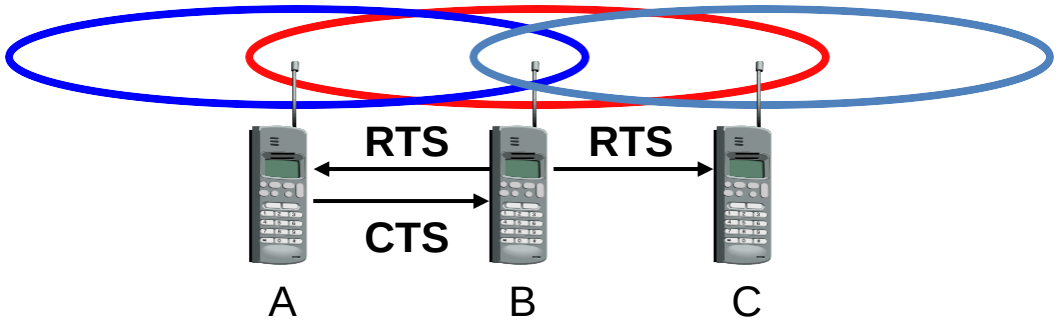
MACA examples



- MACA avoids the problem of hidden terminals
  - A and C want to send to B
  - A sends RTS first
  - C waits after receiving CTS from B

MACA examples

- MACA avoids the problem of exposed terminals
  - B wants to send to A, C to another terminal
  - now C does not have to wait for it cannot receive CTS from A



Contention-based protocols

- Floor acquisition Multiple Access Protocols (FAMA)
  - Based on a channel access discipline which consists of a carrier-sensing operation and a collision-avoidance dialog between the sender and the intended receiver of a packet.
  - Floor acquisition refers to the process of gaining control of the channel.
  - At any time only one node is assigned to use the channel.

Contention-based protocols

- Carrier-sensing by the sender, followed by the RTS-CTS control packet exchange, enables the protocol to perform as efficiently as MACA.
- Two variations of FAMA
  - RTS-CTS exchange with no carrier-sensing uses the ALOHA protocol for transmitting RTS packets.
  - RTS-CTS exchange with non-persistent carrier-sensing uses non-persistent CSMA for the same purpose.

Contention-based protocols

- Busy Tone Multiple Access Protocols (BTMA)
  - The transmission channel is split into two:
    - a data channel for data packet transmissions
    - a control channel used to transmit the busy tone signal
  - When a node is ready for transmission, it senses the channel to check whether the busy tone is active.
    - If not, it turns on the busy tone signal and starts data transmissions
    - Otherwise, it reschedules the packet for transmission after some random rescheduling delay.
    - Any other node which senses the carrier on the incoming data channel also transmits the busy tone signal on the control channel, thus, prevent two neighboring nodes from transmitting at the same time.

Contention-based protocols

- Dual Busy Tone Multiple Access Protocol (DBTMAP) is an extension of the BTMA scheme.
  - a data channel for data packet transmissions
  - a control channel used for control packet transmissions (RTS and CTS packets) and also for transmitting the busy tones.

Contention-based protocols

- Receiver-Initiated Busy Tone Multiple Access Protocol (RI-BTMA)
  - The transmission channel is split into two:
    - a data channel for data packet transmissions
    - a control channel used for transmitting the busy tone signal
  - A node can transmit on the data channel only if it finds the busy tone to be absent on the control channel.
  - The data packet is divided into two portions: a preamble and the actual data packet.

Contention-based protocols

- MACA-By Invitation (MACA-BI) is a receiver-initiated MAC protocol.
  - By eliminating the need for the RTS packet it reduces the number of control packets used in the MACA protocol which uses the three-way handshake mechanism.
- Media Access with Reduced Handshake (MARCH) is a receiver-initiated protocol.

Contention-based Protocols with Reservation Mechanisms

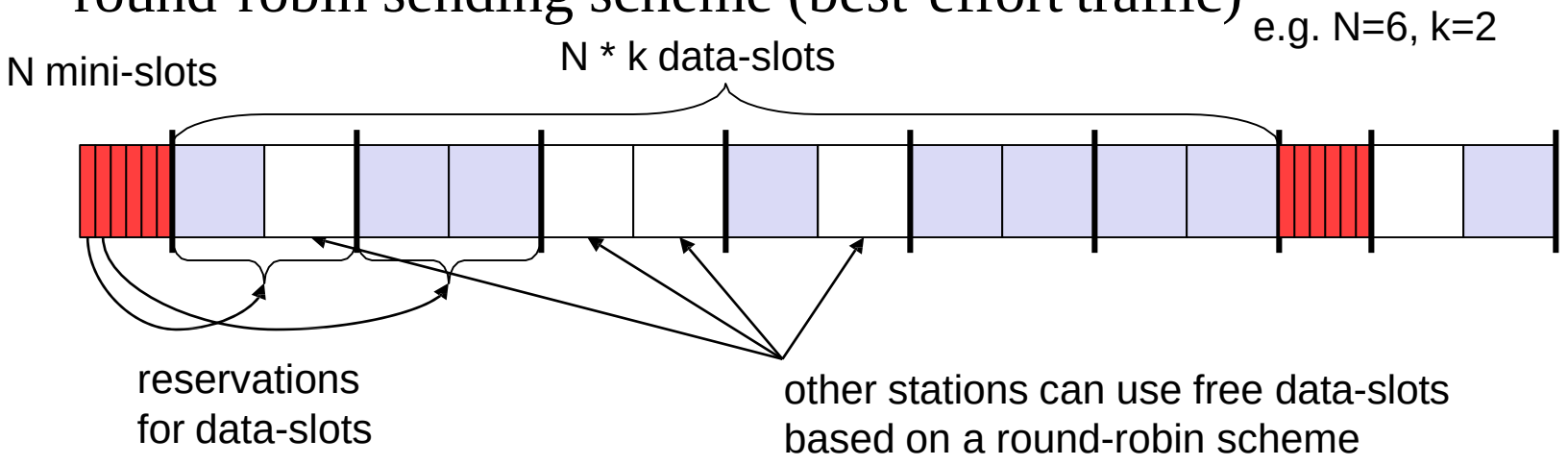
- Contention-based Protocols with Reservation Mechanisms
  - Contention occurs during the resource (bandwidth) reservation phase.
  - Once the bandwidth is reserved, the node gets exclusive access to the reserved bandwidth.
  - QoS support can be provided for real-time traffic.

Contention-based Protocols with Reservation Mechanisms

- Distributed packet reservation multiple access protocol (D-PRMA)
  - It extends the centralized packet reservation multiple access (PRMA) scheme into a distributed scheme that can be used in ad hoc wireless networks.
  - PRMA was designed in a wireless LAN with a base station.
  - D-PRMA extends PRMA protocol in a wireless LAN.
  - D-PRMA is a TDMA-based scheme. The channel is divided into fixed- and equal-sized frames along the time axis.

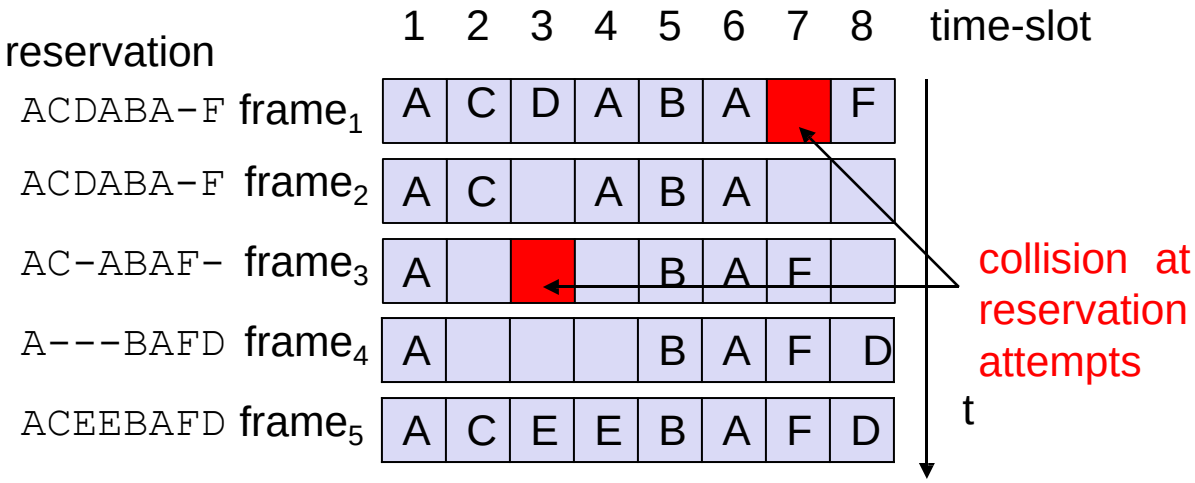
Access method DAMA: Reservation- TDMA

- Reservation Time Division Multiple Access
  - every frame consists of N mini-slots and x data-slots
  - every station has its own mini-slot and can reserve up to k data-slots using this mini-slot (i.e. x = N * k).
  - other stations can send data in unused data-slots according to a round-robin sending scheme (best-effort traffic)



Distributed Packet Reservation Multiple Access Protocol (D-PRMA)

Implicitreservation(PRMA-Packet Reservation Multiple Access)



Distributed Packet Reservation Multiple Access Protocol (D-PRMA)

- a certain number of slots form a frame, frames are repeated
- stations compete for empty slots according to the slotted aloha principle
- once a station reserves a slot successfully, this slot is automatically assigned to this station in all following frames as long as the station has data to send
- competition for this slots starts again as soon as the slot was empty in the last frame

Contention-based protocols with Reservation Mechanisms

- Collision avoidance time allocation protocol (CATA)
  - based on dynamic topology-dependent transmission scheduling
  - Nodes contend for and reserve time slots by means of a distributed reservation and handshake mechanism.
  - Support broadcast, unicast, and multicast transmissions.

Contention-based protocols with Reservation Mechanisms

- The operation is based on two basic principles:
  - The receiver(s) of a flow must inform the potential source nodes about the reserved slot on which it is currently receiving packets. The source node must inform the potential destination node(s) about interferences in the slot.
  - Usage of negative acknowledgements for reservation requests, and control packet transmissions at the beginning of each slot, for distributing slot reservation information to senders of broadcast or multicast sessions.

Contention-based protocols with Reservation Mechanisms

- Hop reservation multiple access protocol (HRMA)
  - a multichannel MAC protocol which is based on half-duplex, very slow frequency-hopping spread spectrum (FHSS) radios
  - uses a reservation and handshake mechanism to enable a pair of communicating nodes to reserve a frequency hop, thereby guaranteeing collision-free data transmission.
  - can be viewed as a time slot reservation protocol where each time slot is assigned a separate frequency channel.

Contention-based protocols with Reservation Mechanisms

- Soft reservation multiple access with priority assignment (SRMA/PA)
  - Developed with the main objective of supporting integrated services of real-time and non-real-time application in ad hoc networks, at the same time maximizing the statistical multiplexing gain.
  - Nodes use a collision-avoidance handshake mechanism and a soft reservation mechanism.

Contention-based protocols with Reservation Mechanisms

- Five-Phase Reservation Protocol (FPRP)
  - a single-channel time division multiple access (TDMA)-based broadcast scheduling protocol.
  - Nodes uses a contention mechanism in order to acquire time slots.
  - The protocol assumes the availability of global time at all nodes.
  - The reservation takes five phases: reservation, collision report, reservation confirmation, reservation acknowledgement, and packing and elimination phase.

Contention-based protocols with Reservation Mechanisms

- MACA with Piggy-Backed Reservation (MACA/PR)
  - Provide real-time traffic support in multi-hop wireless networks
  - Based on the MACAW protocol with non-persistent CSMA
  - The main components of MACA/PR are:
    - A MAC protocol
    - A reservation protocol
    - A QoS routing protocol

Contention-based protocols with Reservation Mechanisms

- Real-Time Medium Access Control Protocol (RTMAC)
  - Provides a bandwidth reservation mechanism for supporting real-time traffic in ad hoc wireless networks
  - RTMAC has two components
    - A MAC layer protocol is a real-time extension of the IEEE 802.11 DCF.
      - A medium-access protocol for best-effort traffic
      - A reservation protocol for real-time traffic
    - A QoS routing protocol is responsible for end-to-end reservation and release of bandwidth resources.

Contention-based protocols with Scheduling Mechanisms

- Protocols in this category focus on packet scheduling at the nodes and transmission scheduling of the nodes.
- The factors that affects scheduling decisions
  - Delay targets of packets
  - Traffic load at nodes
  - Battery power

Contention-based protocols with Scheduling Mechanisms

- Distributed priority scheduling and medium access in Ad Hoc Networks present two mechanisms for providing quality of service (QoS)
  - Distributed priority scheduling (DPS) – piggy-backs the priority tag of a node's current and head-of-line packets o the control and data packets
  - Multi-hop coordination – extends the DPS scheme to carry out scheduling over multi-hop paths.

Contention-based protocols with Scheduling Mechanisms

- Distributed Wireless Ordering Protocol (DWOP)
  - A media access scheme along with a scheduling mechanism
  - Based on the distributed priority scheduling scheme

Contention-based protocols with Scheduling Mechanisms

- Distributed Laxity-based Priority Scheduling (DLPS) Scheme
  - Scheduling decisions are made based on
  - The states of neighboring nodes and feed back from destination nodes regarding packet losses
  - Packets are recorded based on their uniform laxity budgets (ULBs) and the packet delivery ratios of the flows. The laxity of a packet is the time remaining before its deadline.

MAC Protocols that use directional Antennas

- MAC protocols that use directional antennas several advantages:
  - Reduce signal interference
  - Increase in the system throughput
  - Improved channel reuse
- MAC protocol using directional antennas
  - Make use of an RTS/CTS exchange mechanism
  - Use directional antennas for transmitting and receiving data packets

MAC Protocols that use directional Antennas

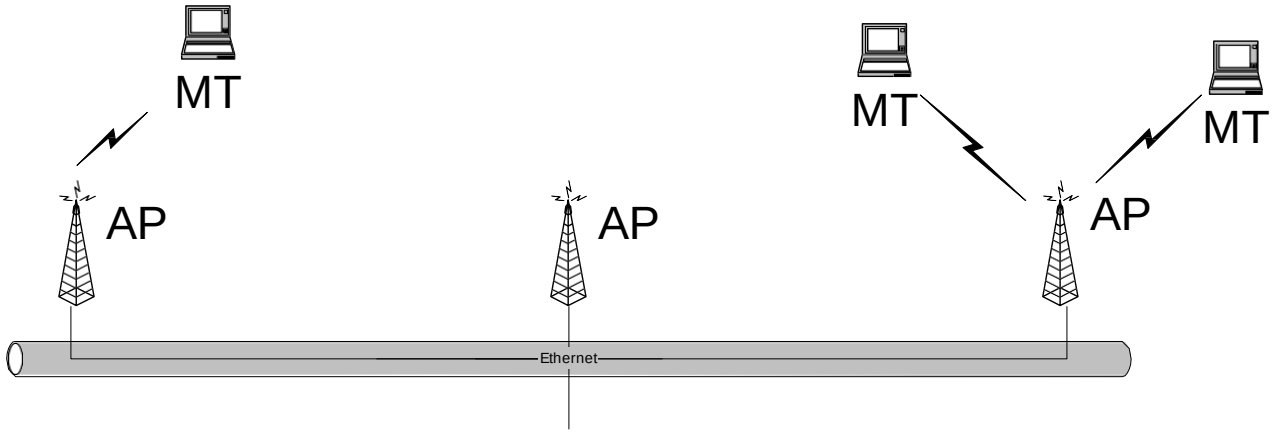
- Directional Busy Tone-based MAC Protocol (DBTMA)
  - It uses directional antennas for transmitting the RTS, CTS, data frames, and the busy tones.
- Directional MAC Protocols for Ad Hoc Wireless Networks
  - DMAC-1, a directional antenna is used for transmitting RTS packets and omni-directional antenna for CTS packets.
  - DMAC-1, both directional RTS and omni-directional RTS transmission are used.

Other MAC Protocols

- Multi-channel MAC Protocol (MMAC)
  - Multiple channels for data transmission
  - There is no dedicated control channel.
  - Based on channel usage channels can be classified into three types: high preference channel (HIGH), medium preference channel (MID), low preference channel (LOW)
- Multi-channel CSMA MAC Protocol (MCSMA)
  - The available bandwidth is divided into several channels
- Power Control MAC Protocol (PCM) for Ad Hoc Networks
  - Allows nodes to vary their transmission power levels on a per-packet basis
- Receiver-based Autorate Protocol (RBAR)
  - Use a rate adaptation approach
- Interleaved Carrier-Sense Multiple Access Protocol (ICSMA)
  - The available bandwidth is split into tow equal channels
  - The handshaking process is interleaved between the two channels.

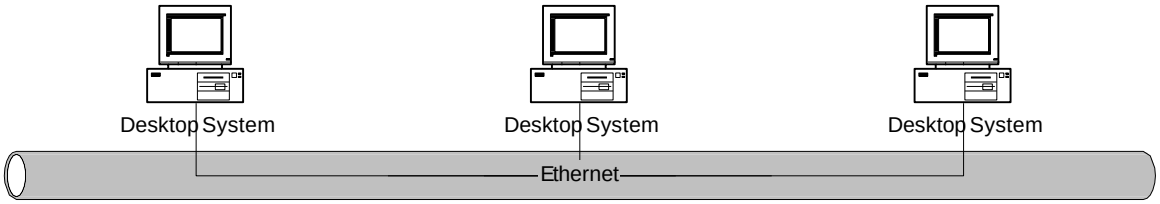
Network Setup

- Basic Network Setup is Cellular
- Mobile Terminals (MT) connect with Access Points (AP)



- Standard also supports ad-hoc networking where MT's talk directly to MT's

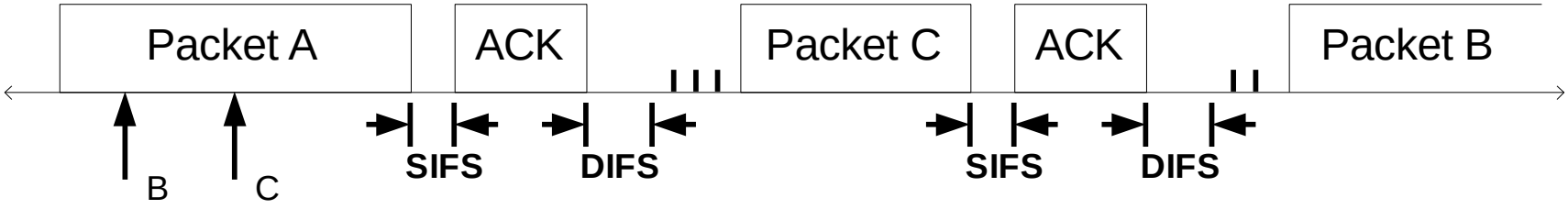
Media Access Control - Ethernet



- CSMA/CD (Carrier Sense Multiple Access with Collision Detection)
  - If media is sensed idle, transmit
  - If media is sensed busy, wait until idle and then transmit immediately
- Collisions can occur if more than one user transmits at the same time
  - If a collision is detected, stop transmitting.
  - Reschedule transmission according to exponential backoff

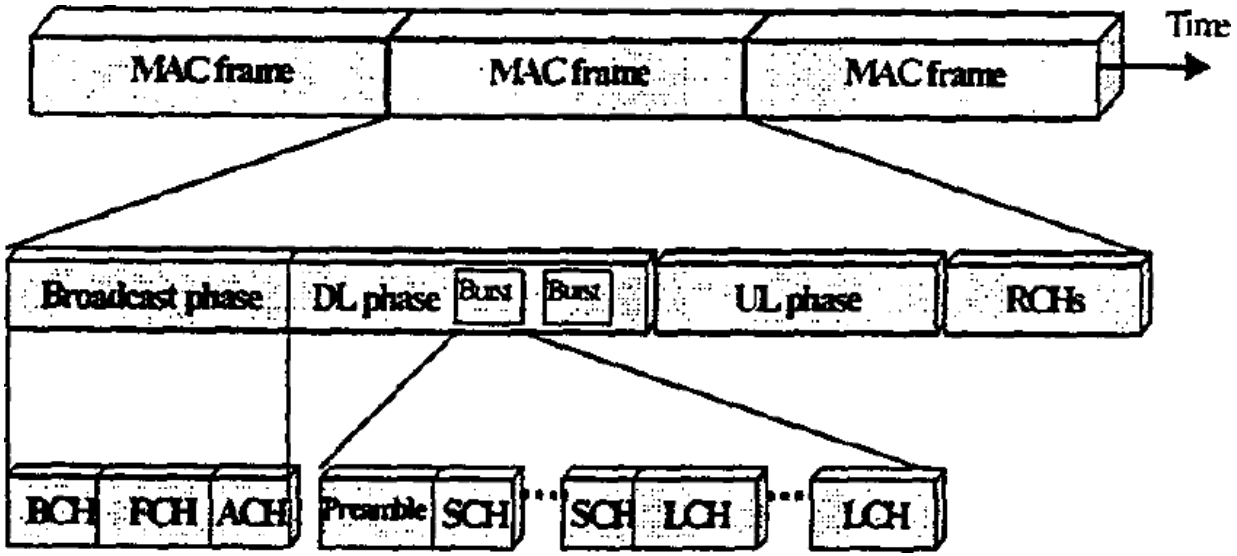
CSMA/CA Details

- SIFS (Short Interframe Space)
- DIFS (Distributed Interframe Space)



- Scenario:
- B and C want to transmit, but A currently has control of medium
- B randomly selects 7 slots of backoff, C selects 4 slots
- C transmits first, then B

HIPERLAN/2 MAC



BCH – Miscellaneous header

FCH – Details how the DL and UL phases will be allocated

ACH – Feedback on which resource requests were received

RCH – Random access resource request

Performance Comparison

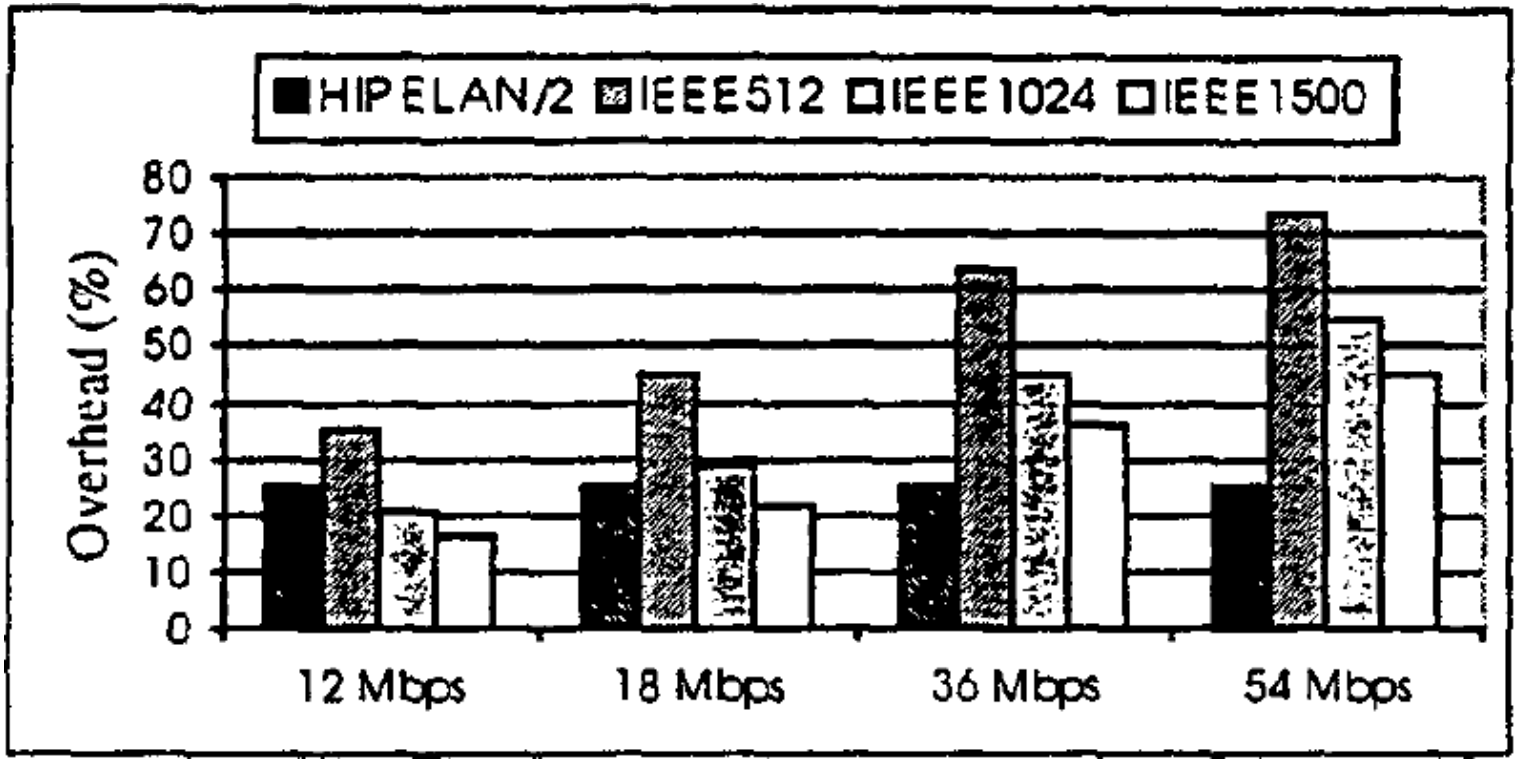
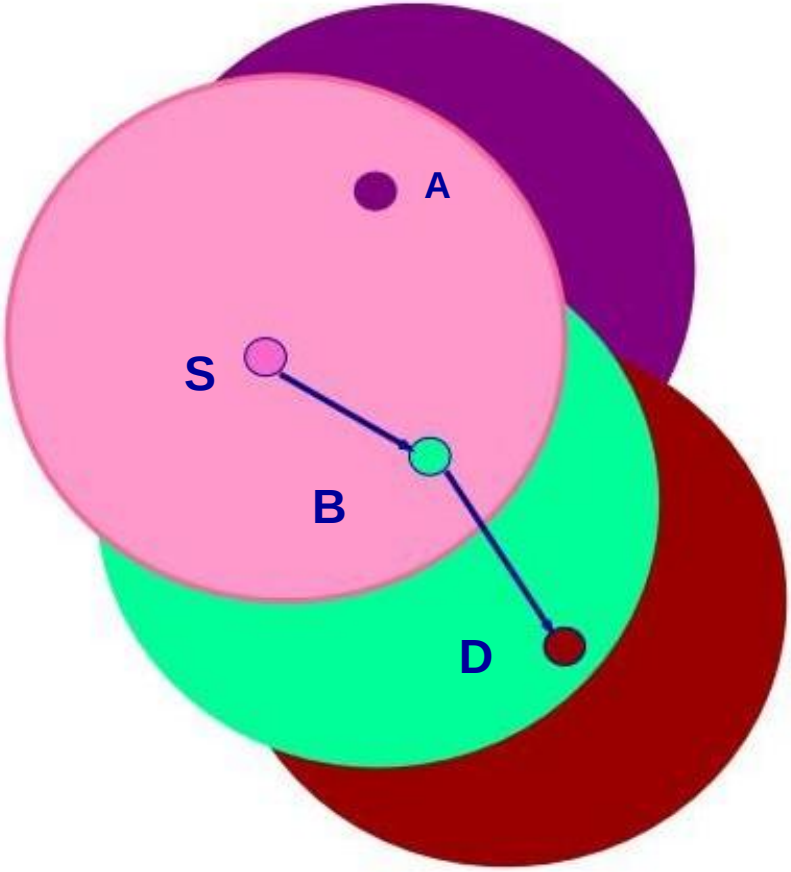
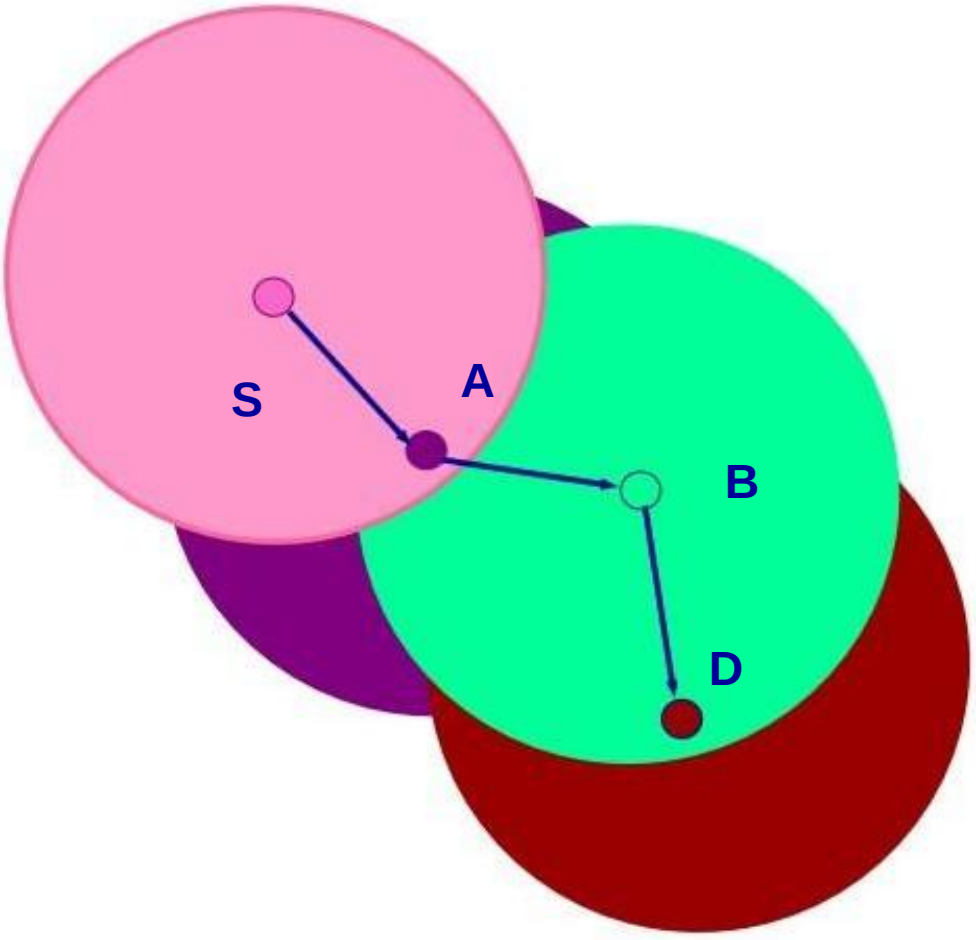


Illustration of Multi-hop MANET

Each color represents range of transmission of a device

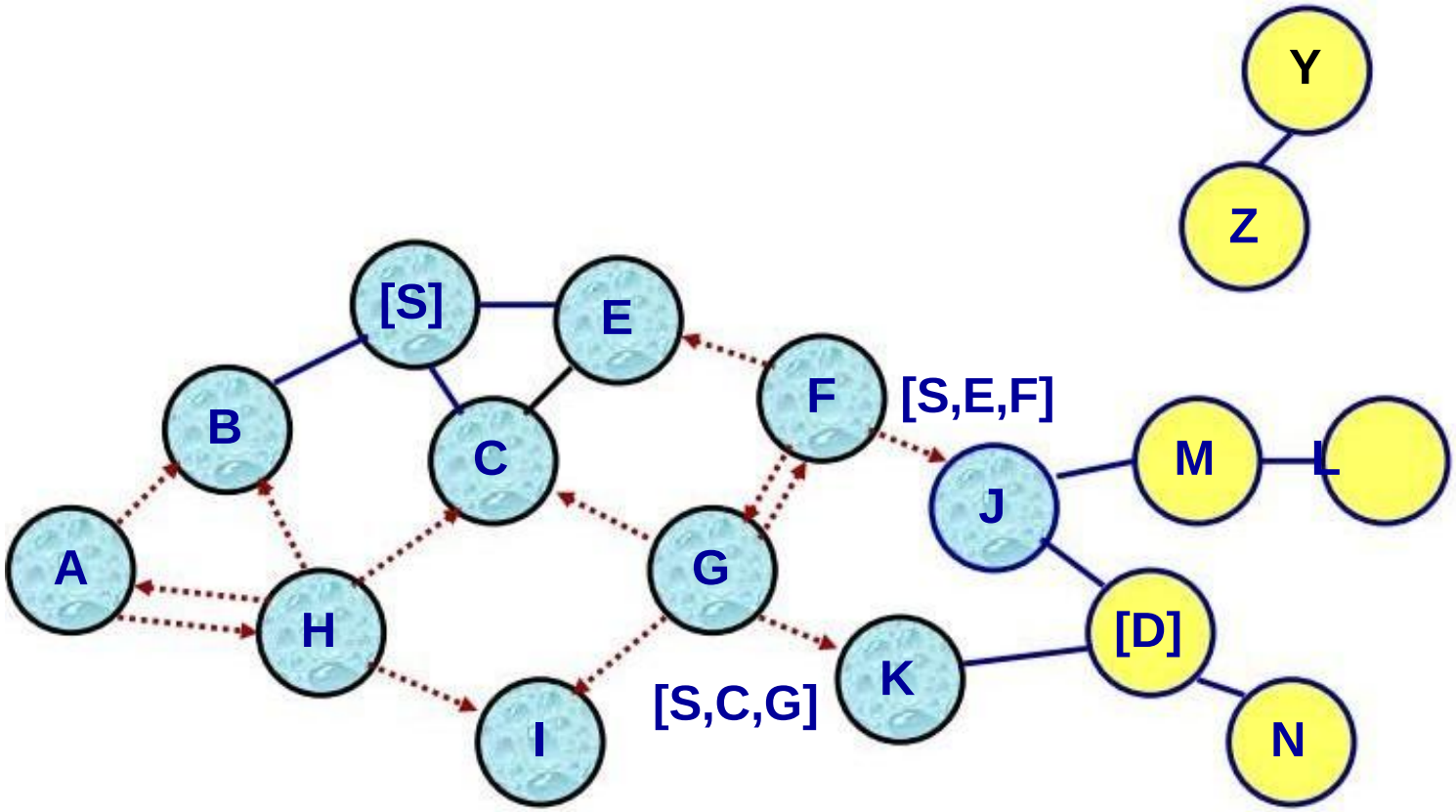


MH S uses B to communicate with MH D



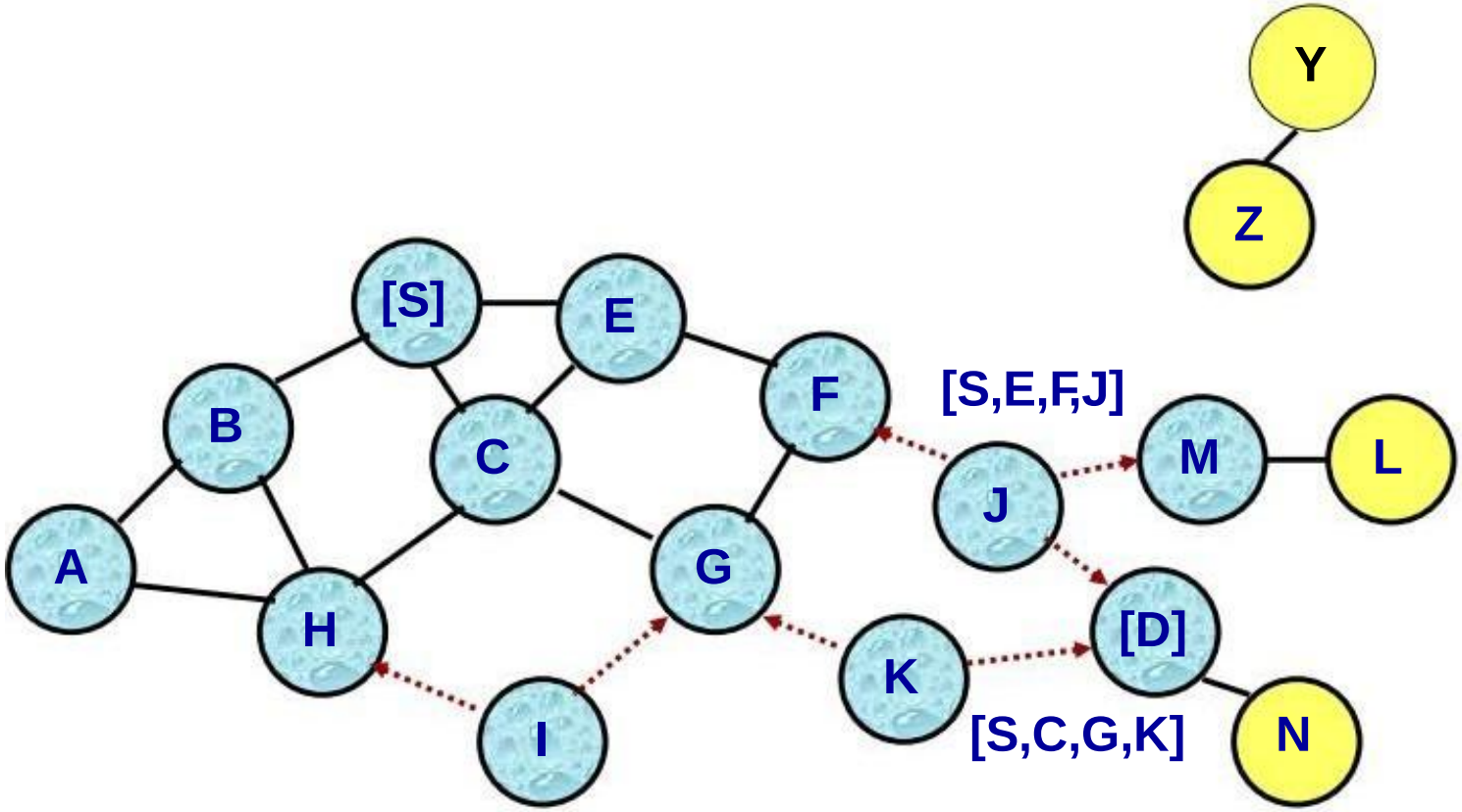
Due to movement of MHs, S now uses A and B to reach D

Route Discovery in DSR



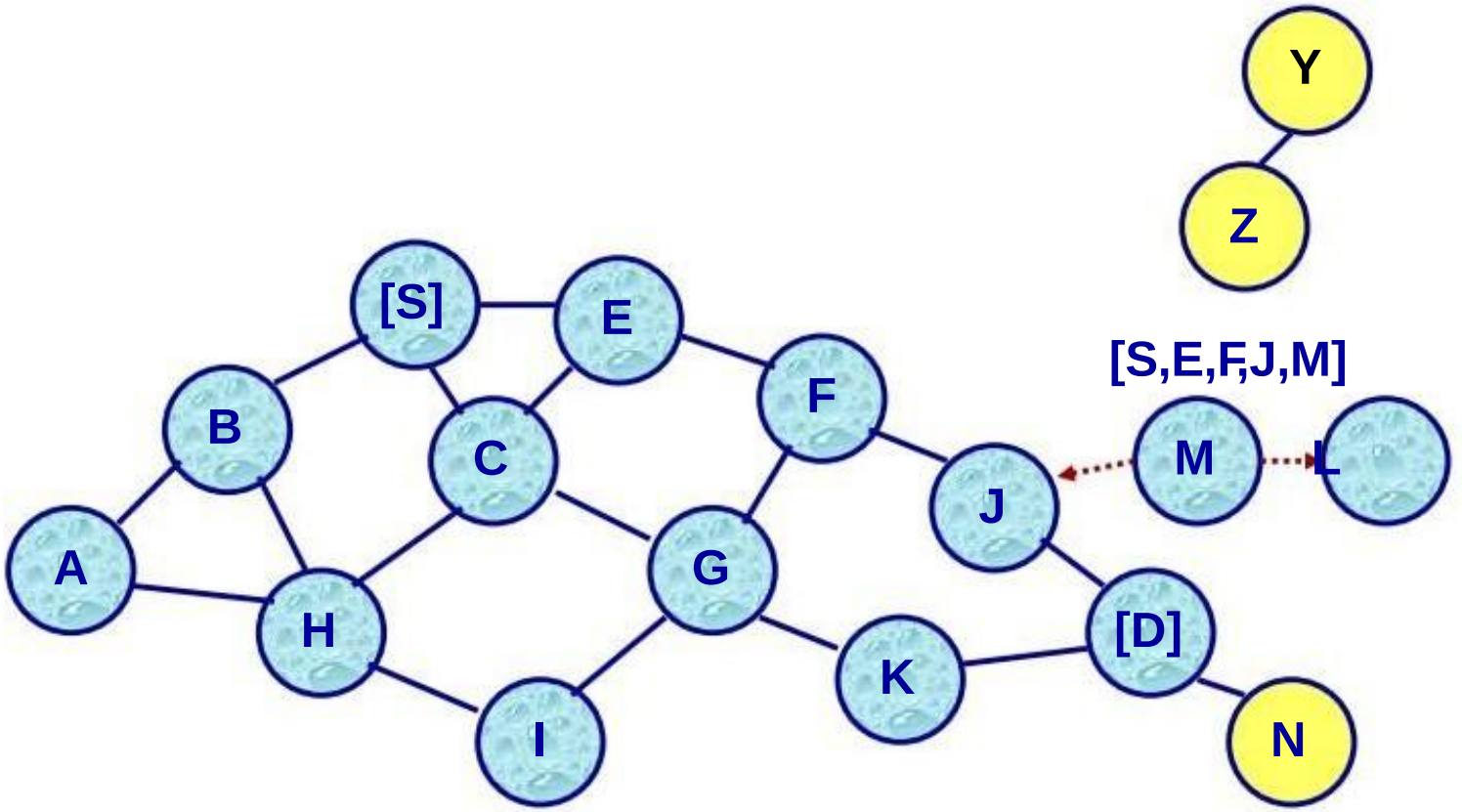
- **Node C receives RREQ from G and H, but does not forward it again, because node C has already forwarded RREQ once**

Route Discovery in DSR



- Nodes J and K both broadcast RREQ to node D
- Since nodes J and K are hidden from each other, their transmissions may collide

Route Discovery in DSR



- Node D does not forward RREQ, because node D is the intended target of the route discovery

An Overview of Protocol Characteristics

Routing Protocol	Route Acquisition	Flood for Route Discovery	Delay for Route Discovery	Multipath Capability	Upon Route Failure
DSDV	Computed a priori	No	No	No	Flood route updates throughout the network
WRP	Computed a priori	No	No	No	Ultimately, updates the routing tables of all nodes by exchanging MRL between neighbors
DSR	On-demand, only when needed	Yes, aggressive use of caching may reduce flood	Yes	Not explicitly, as the technique of salvaging may quickly restore a route	Route error propagated up to the source to erase invalid path
AODV	On-demand, only when needed	Yes, conservative use of cache to reduce route discovery delay	Yes	Not directly, however, multipath AODV (MAODV) protocol includes this support	Route error broadcasted to erase multipath
TORA	On-demand, only when needed	Usually only one flood for initial DAG construction	Yes, once the DAG is constructed, multiple paths are found	Yes	Error is recovered locally and only when alternative routes are not available
ZRP	Hybrid	Only outside a source's zone	Only if the destination is outside the source's zone	No	Hybrid of updating nodes' tables within a zone and propagating route error to the source

Position Based Routing

Three main packet forwarding schemes:

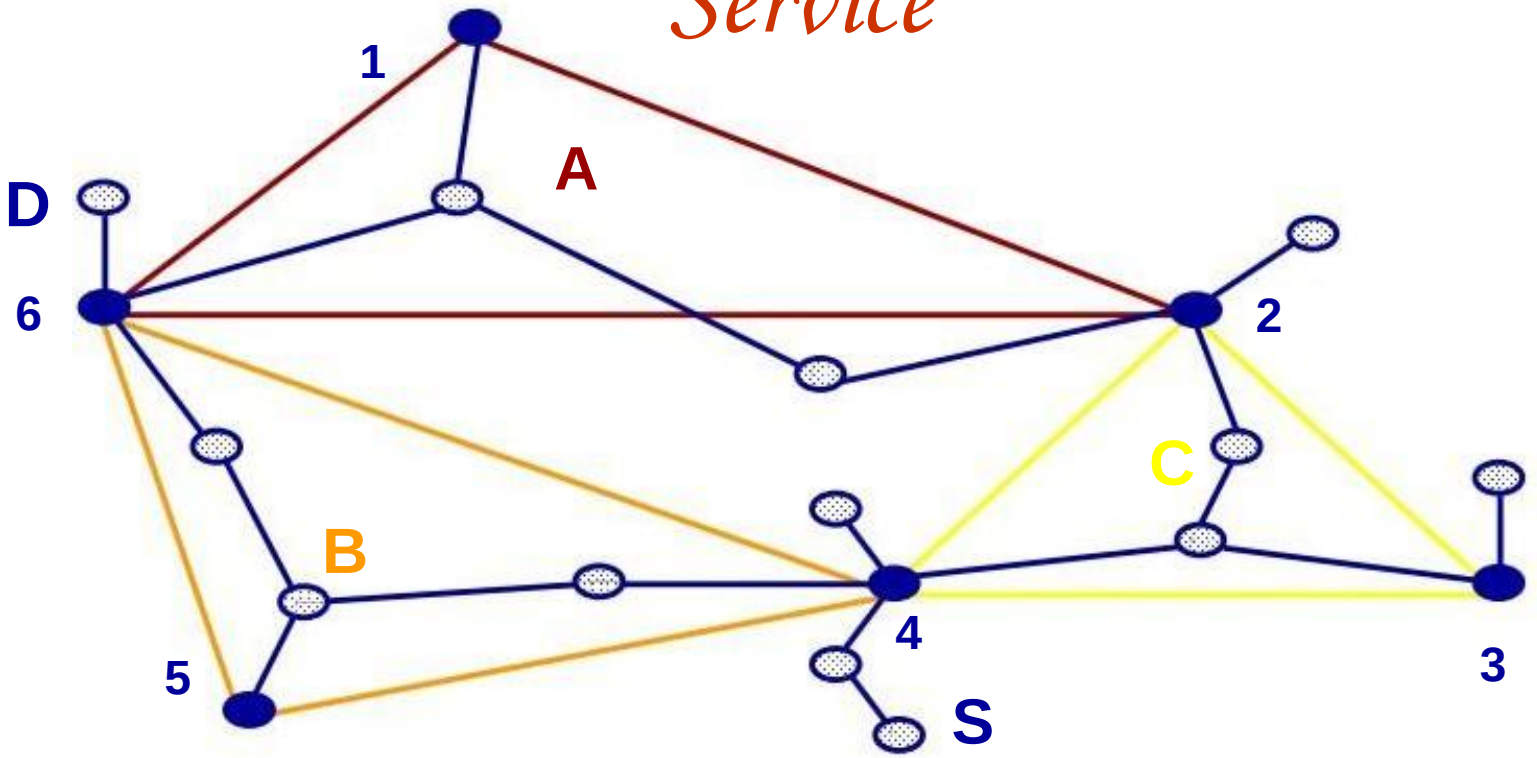
„Greedy forwarding

„Restricted directional flooding

„Hierarchical approaches

- **For the first two, a MH forwards a given packet to one (greedy forwarding) or more (restricted directional flooding) one-hop neighbors**
- **The selection of the neighbor depends on the optimization criteria of the algorithm**
- **The third forwarding strategy forms a hierarchy in order to scale to a large number of MHs**

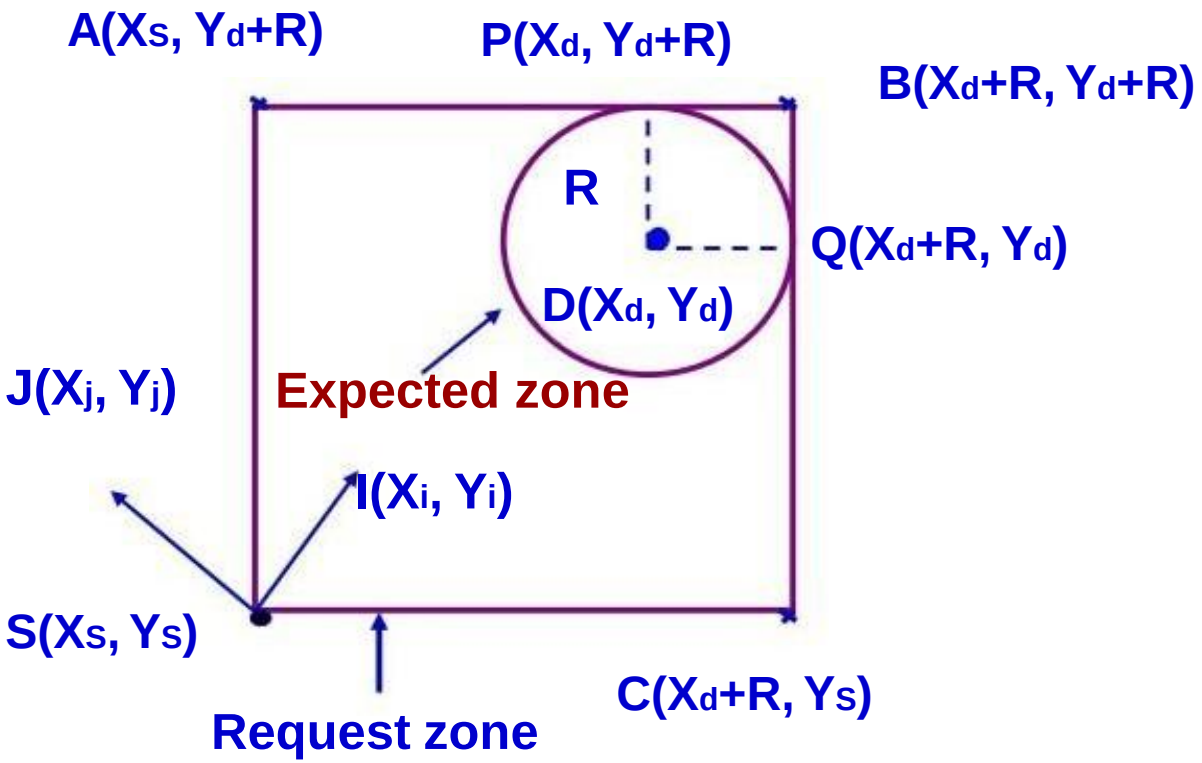
Quorum-Based Location Service



- MH D sends its updates to node 6, which might then select quorum Awith nodes 1, 2, and 6 to host the information
- For example, MH 4 might, choose quorum B, consisting of MHs 4, 5, and 6 for the query
- Larger the quorum set is, higher the cost for position updates and queries are
- Can be configured to operate as all-for-all, all-for-some, or some-for-some approach

Expected Zone Routing

- Request zone can be defined based on the expected zone
- Node S defines a request zone for the route request
- A node forwards a route request only if it belongs to the request zone
- To increase the probability to reach node D, the request zone should include the expected zone
- Additionally, the request zone may also include other regions around



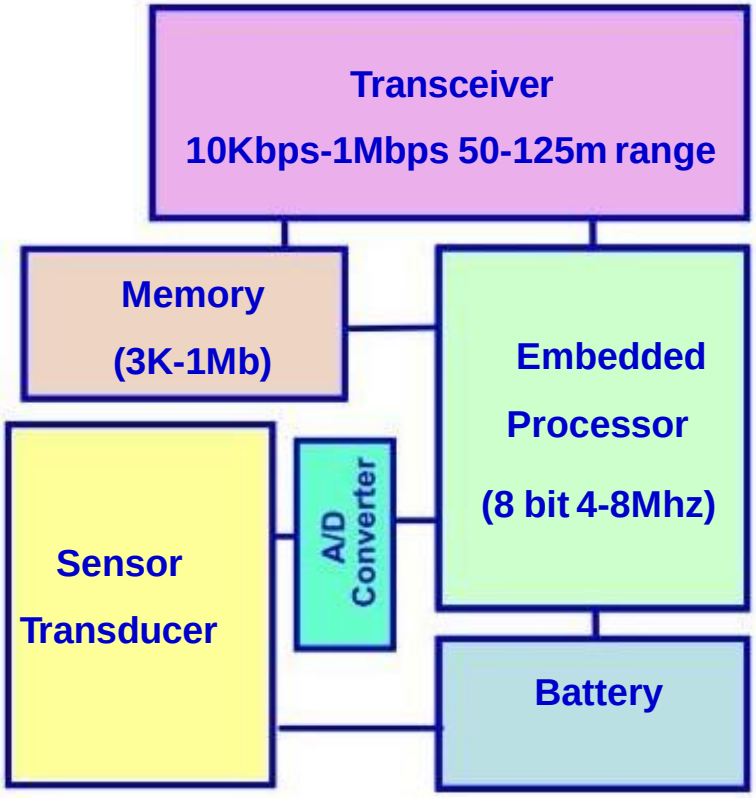
UNIT –III

Basics Of Wireless Sensors And Applications:

Introduction

- **Wireless Sensor Networks can be considered as a special case of ad hoc networks with reduced or no mobility**
- **WSNs enable reliable monitoring and analysis of unknown and untested environments**
- **These networks are "data centric", i.e., unlike traditional ad hoc networks where data is requested from a specific node, data is requested based on certain attributes such as, "which area has temperature over 35°C or 95°F"**
- **A sensor has many functional components as shown in Figure 8.1**
- **A typical sensor consists of a transducer to sense a given physical quantity, an embedded processor, small memory and a wireless transceiver to transmit or receive data and an attached battery**

Functional Components: A Sensor



The Mica Mote

- **The Mica Mote is a comprehensive sensor node developed by University of California at Berkeley and marketed by Crossbow**

- **It uses an Atmel Atmega 103 microcontroller running at 4 MHz, with a radio operating at the 916 MHz frequency band with bidirectional communication at 40 kbps when energized with a pair of AAbatteries**

- **Mica Board is stacked to the processor board via the 51 pin extension connector to provide temperature, photo resistor, barometer, humidity, and thermopile sensors**

- **To conserve energy, later designs include an A/D Converter and an 8x8 power switch on the sensor board**

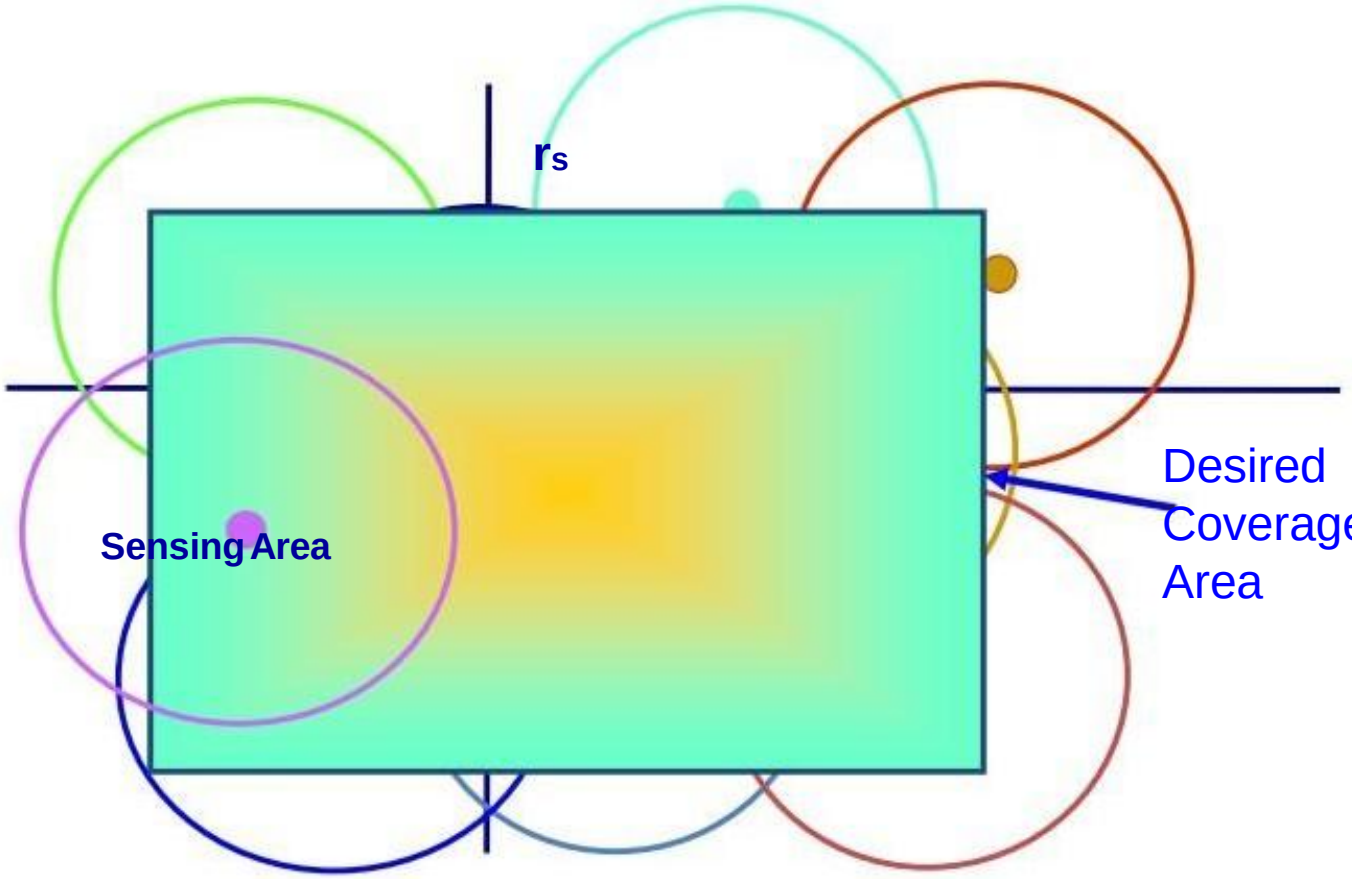
The Mica Mote

Mica Motes-2

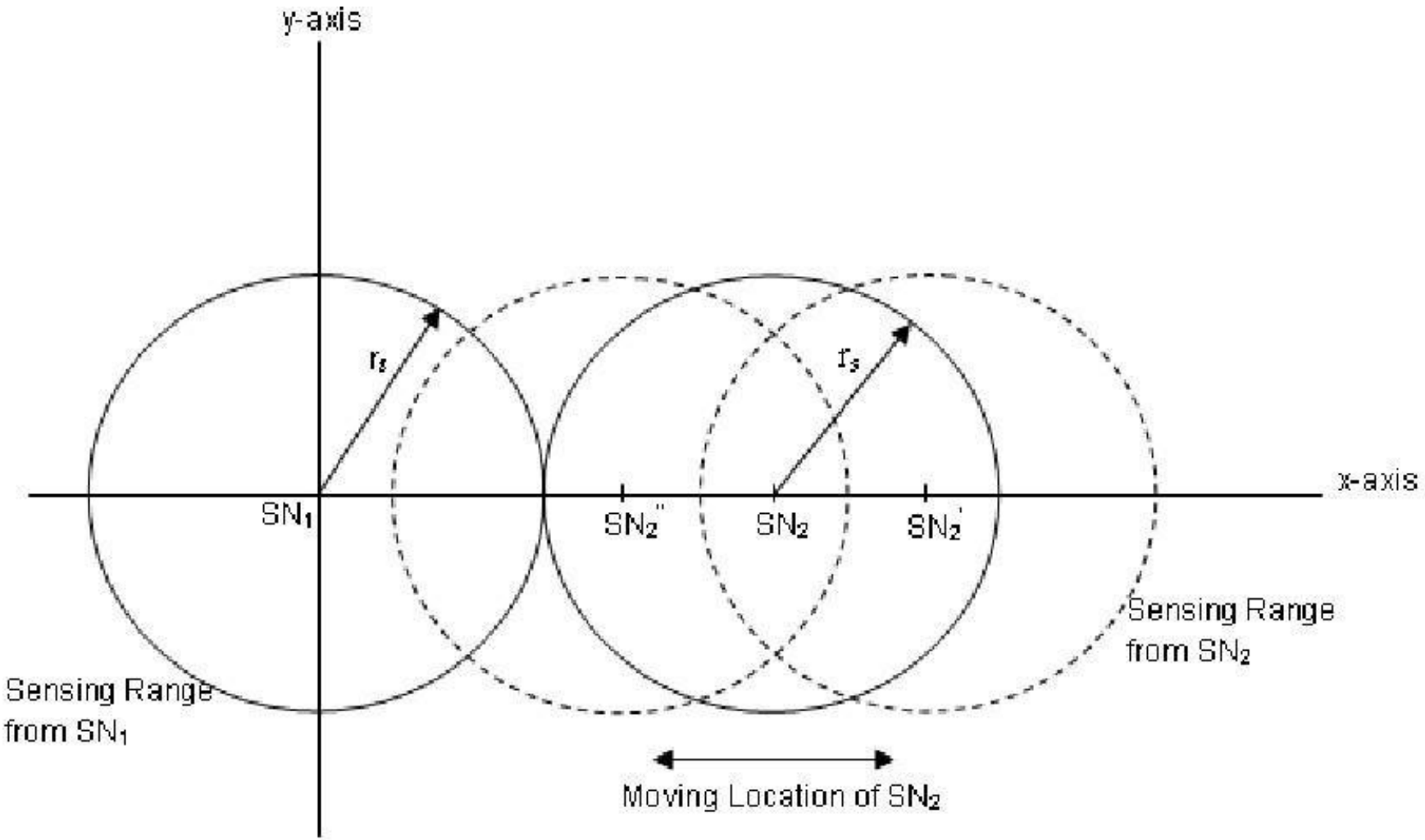
Mica Board

Sensing and Communication Range

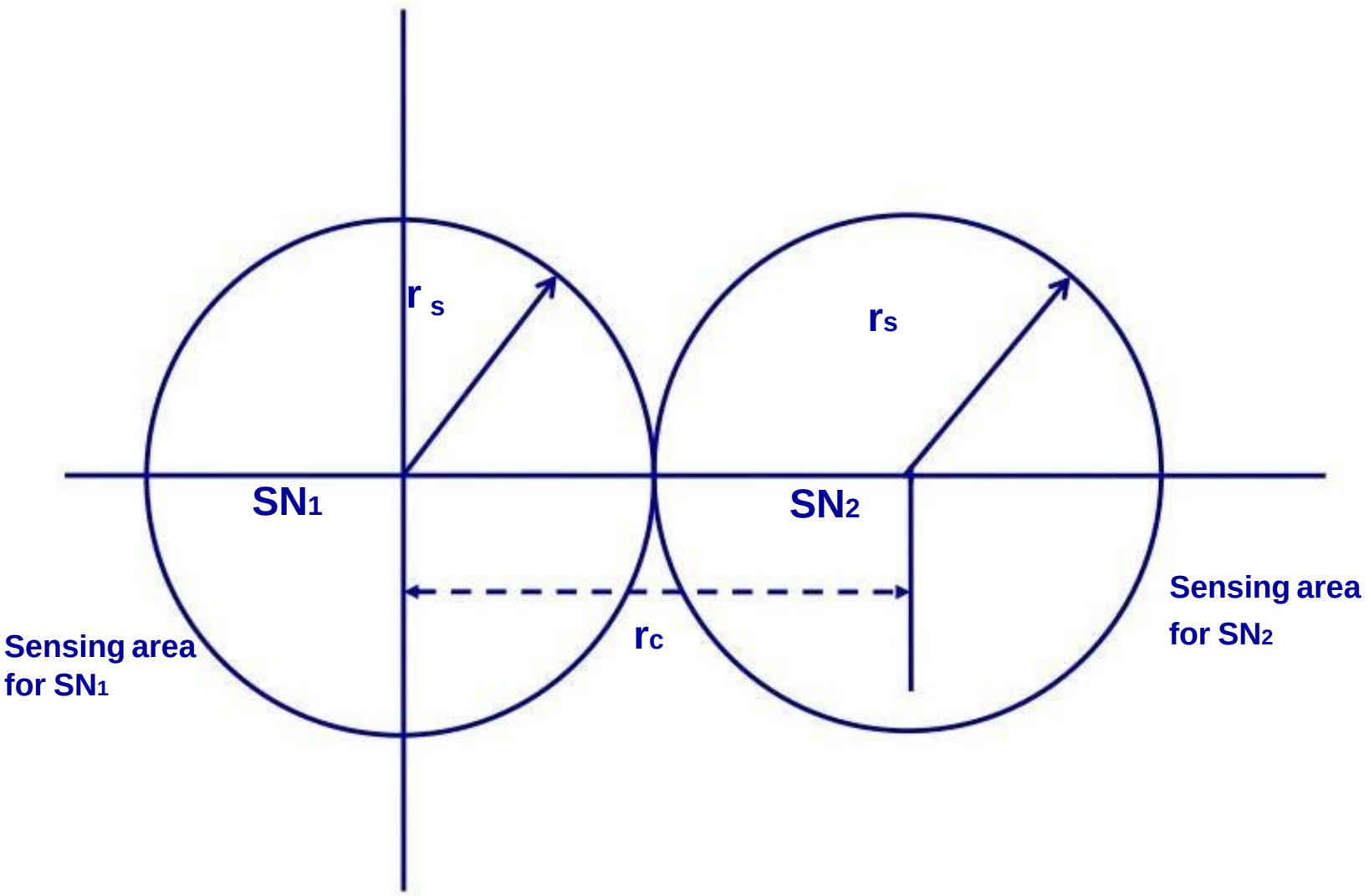
- A wireless sensor network (WSN) consists of a large number of sensor nodes (SNs)
- Adequate density of sensors is required so as to void any unsensed area



Sensing and Communication Range



Sensing and Communication Range



Sensing and Communication Range

- Transmission between adjacent SNs is feasible if there is at least one SN within the communication range of each SN

- Not just the sensing coverage, but the communication connectivity is equally important

- The wireless communication coverage of a sensor must be at least twice the sensing distance

- Data from a single SN is not adequate to make any useful decision and need to be collected from a set of SNs

Design Issues: Advantages of WSNs

- Ease of deployment - Can be dropped from a plane or placed in a factory, without any prior organization, thus reducing the installation cost and time, and increasing the flexibility of deployment

- Extended range - One huge wired sensor (macro-sensor) can be replaced by many smaller wireless sensors for the same cost

- Fault tolerant - With wireless sensors, failure of one node does not affect the network operation

- Mobility - Since these wireless sensors are equipped with battery, they can possess limited mobility (e.g., if placed on robots)

- Disadvatage: The wireless medium has a few inherent limitations such as low bandwidth, error prone transmissions, and potential collisions in channel access, etc.

Design Issues

Traditional routing protocols defined for MANETs are not well suited for wireless sensor networks due to the following reasons:

- Wireless sensor networks are "data centric", where data is requested based on particular criteria such as "which area has temperature 35ºC"

- In traditional wired and wireless networks, each node is given a unique identification and cannot be effectively used in sensor networks

- Adjacent nodes may have similar data and rather than sending data separately from each sensor node, it is desirable to aggregate similar data before sending it

- The requirements of the network change with the application and hence, it is application-specific

Desirable Features

- Attribute-based addressing: This is typically employed in sensor networks where addresses are composed of a group of attribute-value pairs

- Location awareness: Since most data collection is based on location, it is desirable that the nodes know their position

- The sensors should react immediately to drastic changes in their environment

- Query Handling: Users should be able to request data from the network through some base station (also known as a sink) or through any of the nodes, whichever is closer

Design Issues : Challenges

- Routing protocol design is heavily influenced by many challenging factors

- These challenges can be summarized as follows:

  - Ad hoc deployment - Sensor nodes are randomly deployed so that they form connections between the nodes

  - Computational capabilities - Sensor nodes have limited computing power and therefore may run simple versions of routing protocols

  - Energy consumption without losing accuracy - Sensor nodes can use up their limited energy supply carrying out computations and transmitting information

Design Issues : Challenges

- Scalability - The number of sensor nodes deployed in the sensing area may be in the order of hundreds, thousands, or more and routing scheme must be scalable enough to respond to events
- Communication range - The bandwidth of the wireless links connecting sensor nodes is often limited, hence constraining inter- sensor communication
- Fault tolerance - Some sensor nodes may fail or be blocked due to
- lack of power, physical damage, or environmental interference
- Connectivity - High node density in sensor networks precludes them from being completely isolated from each other

Design Issues : Challenges

- Transmission media -Communicating nodes are linked by a wireless medium and traditional problems associated with a wireless channel (e.g., fading, high error rate) also affect the operation

- QoS - In some applications (e.g., some military applications), the data should be delivered within a certain period of time from the moment it is sensed

- Control Overhead - When the number of retransmissions in wireless medium increases due to collisions, the latency and energy consumption also increases

- Security -Besides physical security, both authentication and encryption should be feasible while complex algorithm needs to be avoided

Energy Consumption : Clustering of SNs

- Clustering of SNs not only allows aggregation of sensed data, but limits data transmission primarily within the cluster

- The sequence starts with discovery of neighboring SNs by sending periodic Beacon Signals, determining close by SNs with some intermediate SNs, forming clusters and selecting cluster head (CH) for each cluster

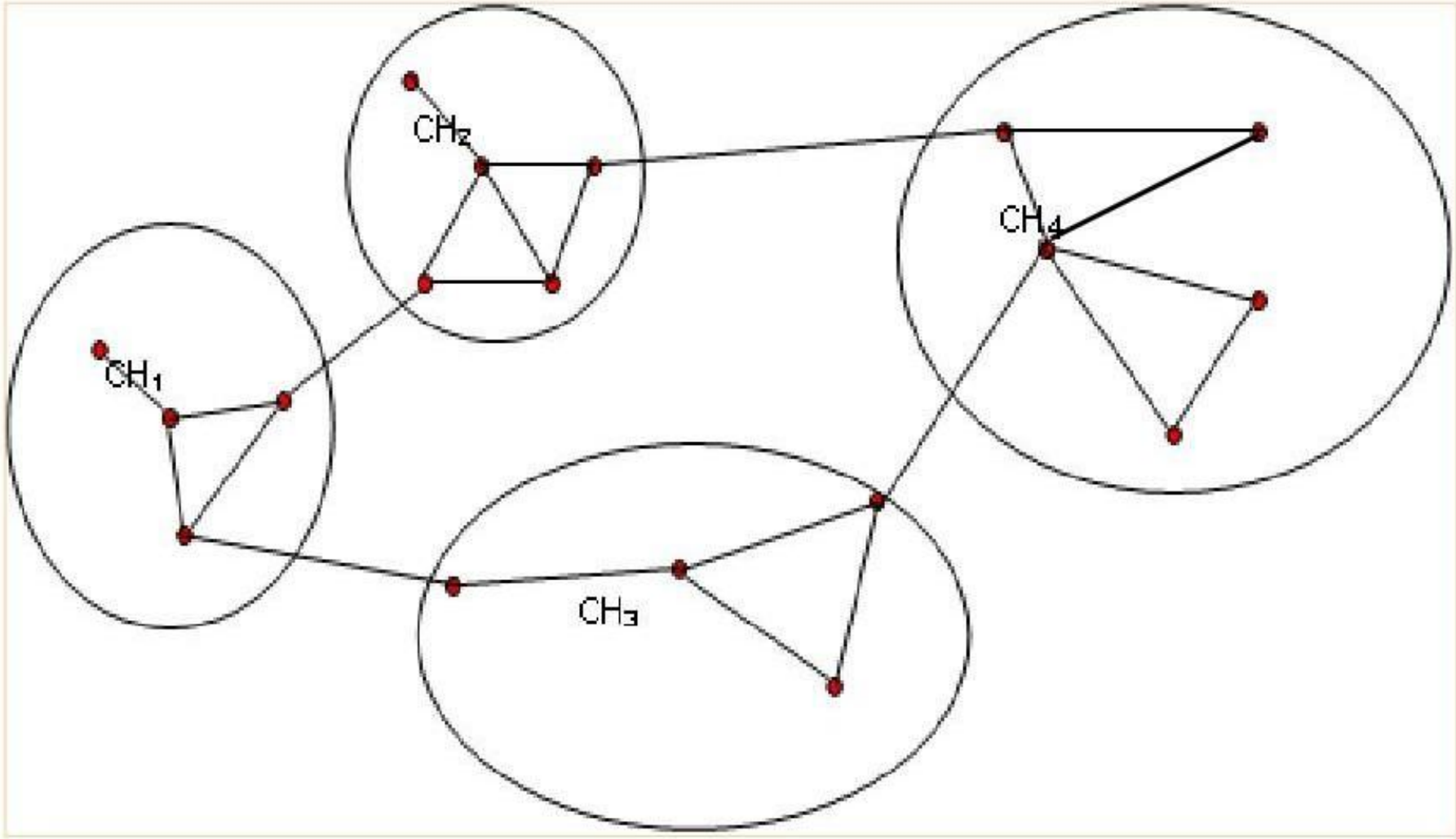
- So, the real question is how to group adjacent SNs, and how many groups should be there that could optimize some performance parameter

- One approach is to partition the WSN into clusters such that all members of the clusters are directly connected to the CH

- One such example for randomly deployed SNs

- SNs in a WSN in a cluster, can transmit directly to the CH without any intermediate SN

Energy Consumption : Clustering of SNs



Clustering of Sensors

Data from SNs belonging to a single cluster can be combined together in an intelligent way (aggregation) using local transmissions

This can not only reduce the global data to be transferred and localized most traffic to within each individual cluster

A lot of research gone into testing coverage of areas by k-sensors clustering adjacent SNs and defining the size of the cluster so that the cluster heads (CHs) can communicate and get data from their own cluster members

If each cluster is covered by more than one subset of SNs all the time, then some of the SNs can be put into sleep mode so as to conserve energy while keeping full coverage

The use of a second smaller radio has been suggested for waking up the sleeping sensor, thereby conserving the power of main wireless transmitter

Clustering of Sensors: Predetermined Grid v/s Random Placement

Regularly placed sensors

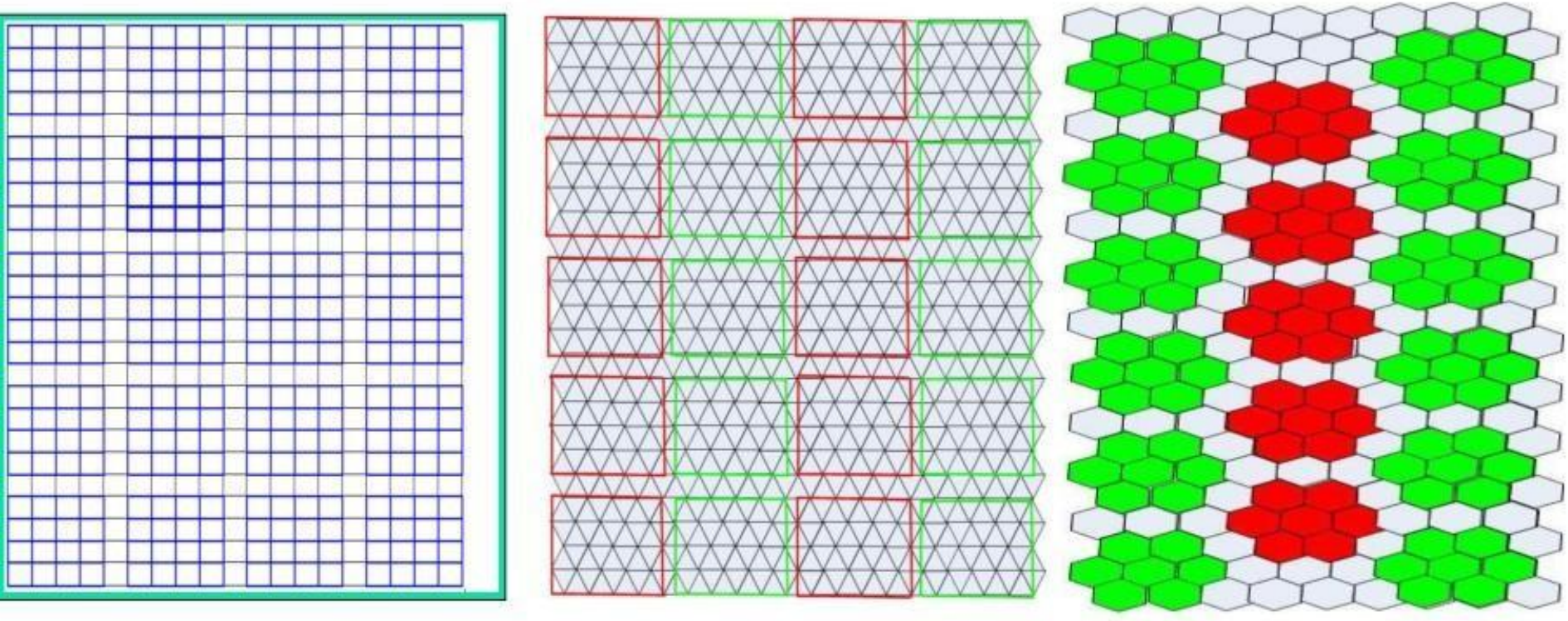
- A simple strategy is to place the sensors in the form of two-dimensional grid as such cross-point and such configuration may be very useful for uniform coverage

- Such symmetric placement allows best possible regular coverage and easy clustering of the close-by SNs

- Three such examples of SNs in rectangular, triangular and hexagonal tiles of clusters are shown

Regularly Placed Sensors

Useful for deploying in a controlled environment



- **Clusters of size 5x5, with a SN located at each intersection of lines**
- **Square, triangle, or hexagonal placement of the SNs also dictates the minimum sensing area that need to be covered by each sensor**

Regularly placed sensors

- Detailed views of three different configurations, are shown in next three slides

- For simplicity of calculation, the sensing area covered by rectangular placement is taken rectangular, while sensing are by the two configurations are assumed hexagonal and triangular respectively

- The required number of SNs in each scheme, is given in Table 8.2

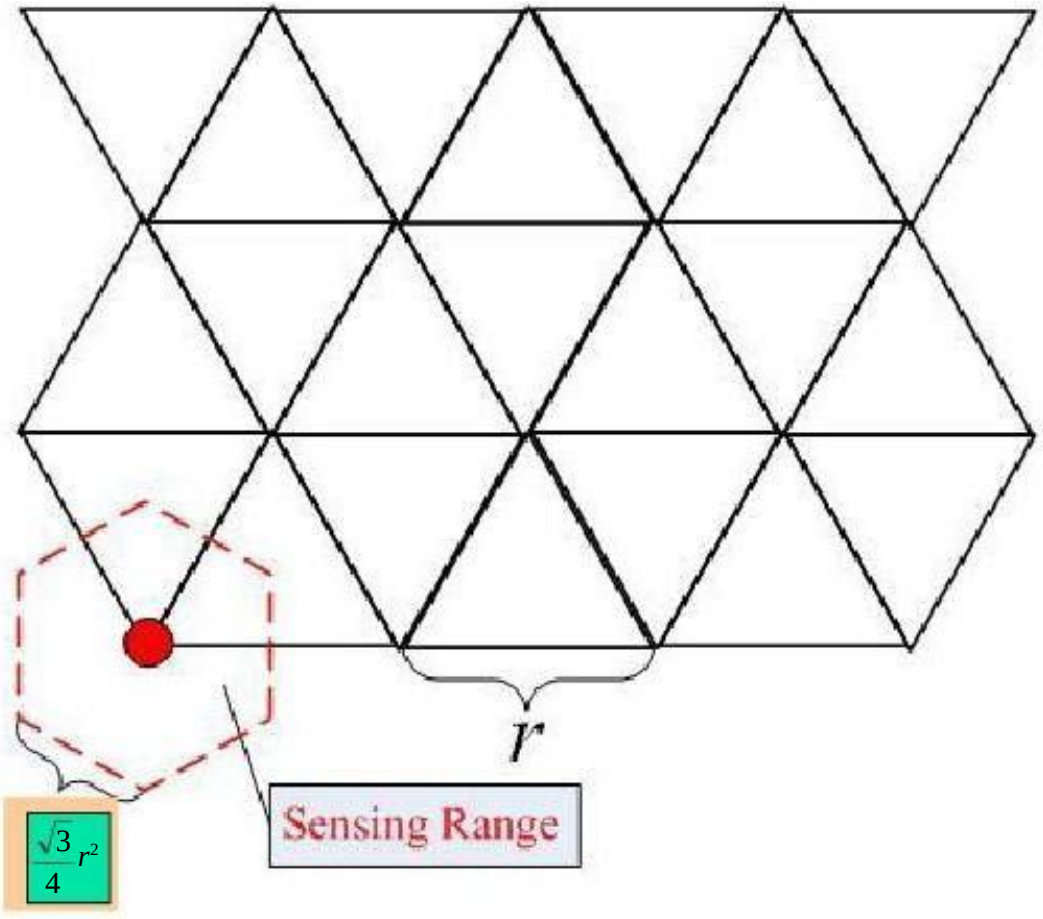
- Radio transmission distance between adjacent SNs need to be such that the sensors can receive data from adjacent sensors using wireless radio

- Clustering can be done for these configurations and the size of each cluster can be fixed as per application requirements

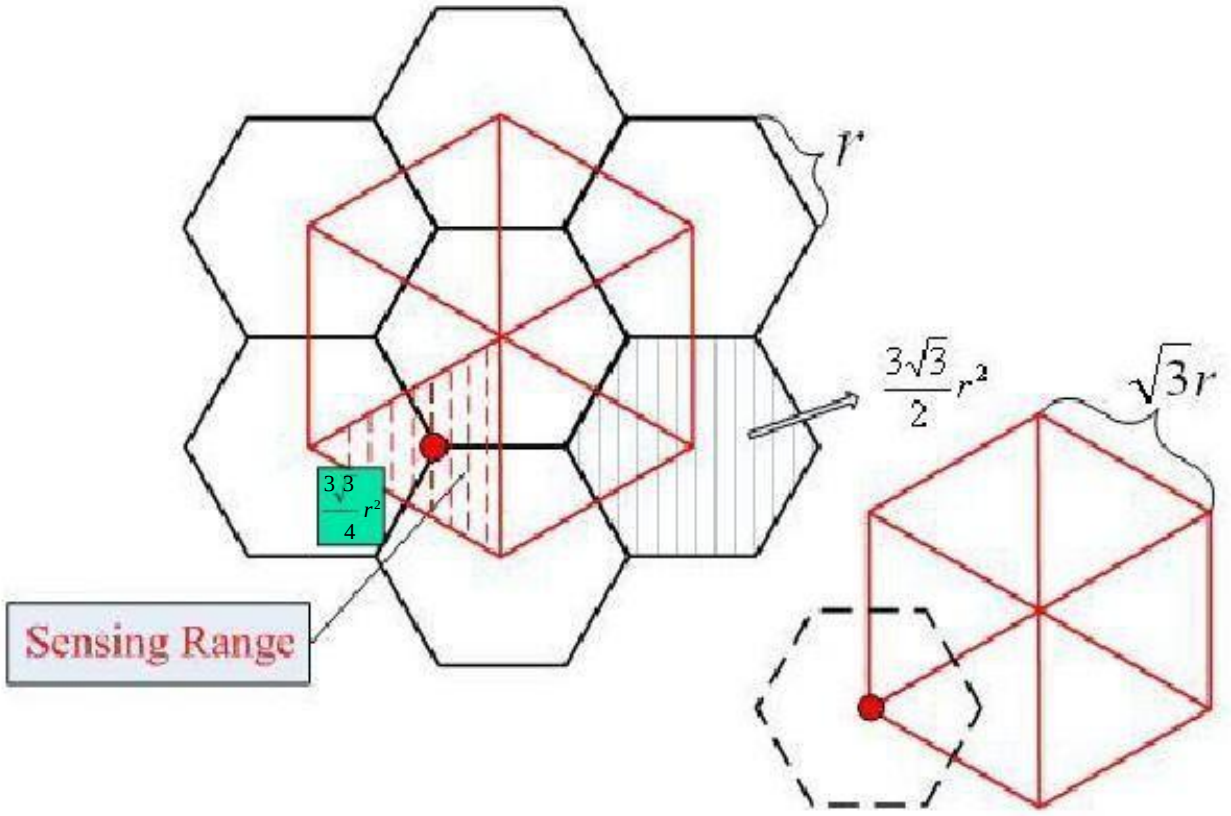
- If the sensing and radio transmission ranges are set to the minimum value, then all the SNs need to be active all the time to cover the area and function properly

- If these ranges are increased, then each sub-region can be covered by more than one sensor node and selected SNs can be allowed to go to sleep mode

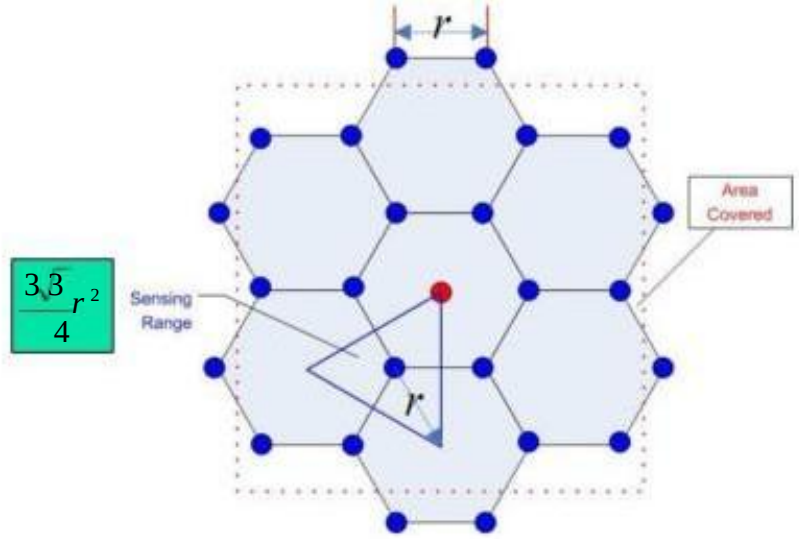
Triangular Placed Sensors

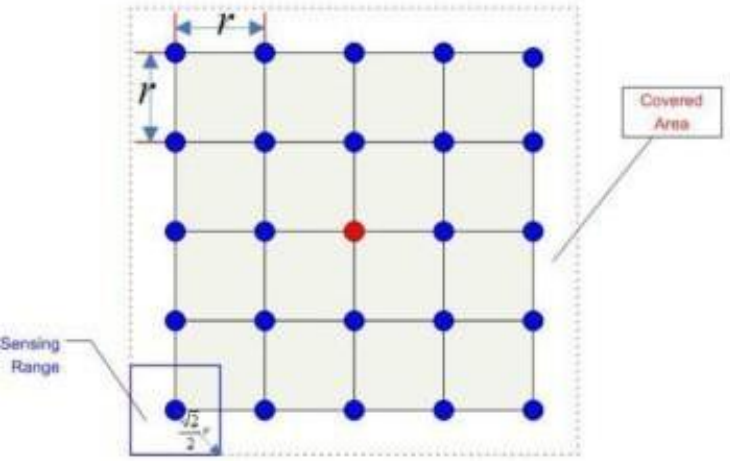


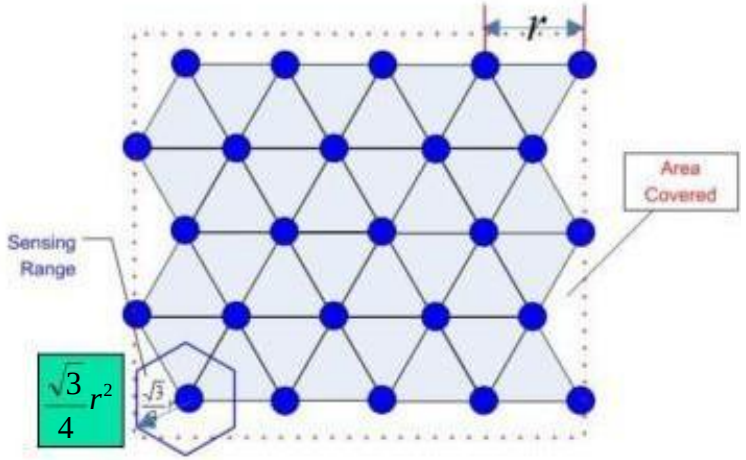
Hexagonal Placed Sensors



Regularly Placed Sensors







Placement of Sensors and Covered Sensing Area

Placement	Distance Between Adjacent Sensors	Sensing Area to be covered by each sensor	Total sensing area covered by N-Sensors
Rectangular	r	r^2	$N.r^2$
Triangular	r	$\frac{\sqrt{3}r}{4}^2$	$N.\frac{\sqrt{3}}{4}r^2$
Hexagon	r	$\frac{3\sqrt{3}}{4}r^2$	$N\frac{3\sqrt{3}}{4}r^2$

Randomly distributed sensors

- The sensors could also be used in an unknown territory or inaccessible area by deploying them from a low flying airplane or unmanned ground/aerial vehicle

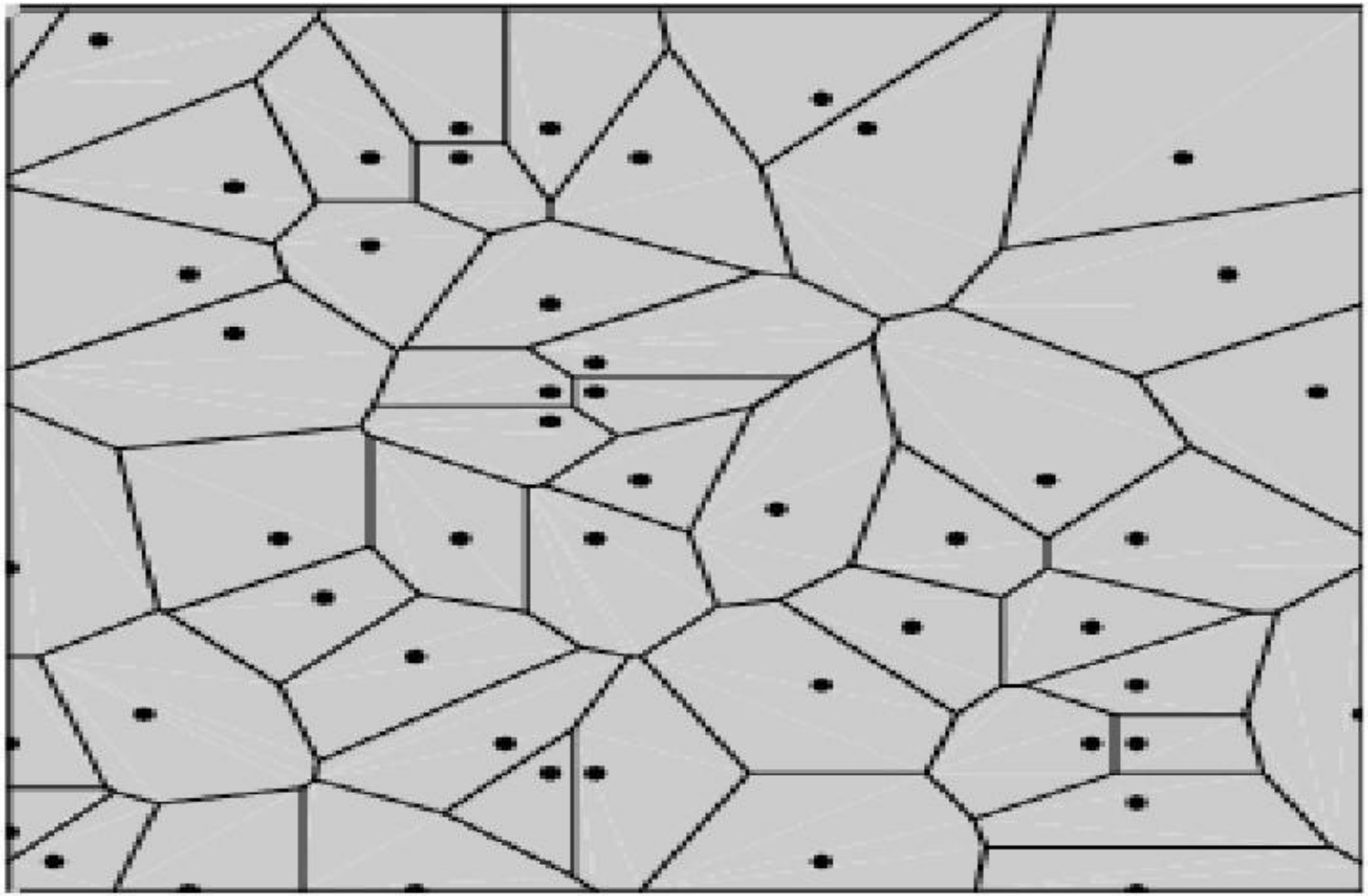
- SNs have to find themselves who their communicating neighbors are and how many of them are present

- The adjacency among SNs can be initially determined by sending bacon signals as is done in a typical ad hoc network (MANET)

- The communication range of associated wireless radio should be such that the SNs could be connected together to form a WSN

- Distribution of the SNs and their sensing range would also determine if the physical parameter in the complete deployed area can be sensed by at least one SN

Randomly Distributed Sensors: Voronoi diagram



Heterogeneous WSNs

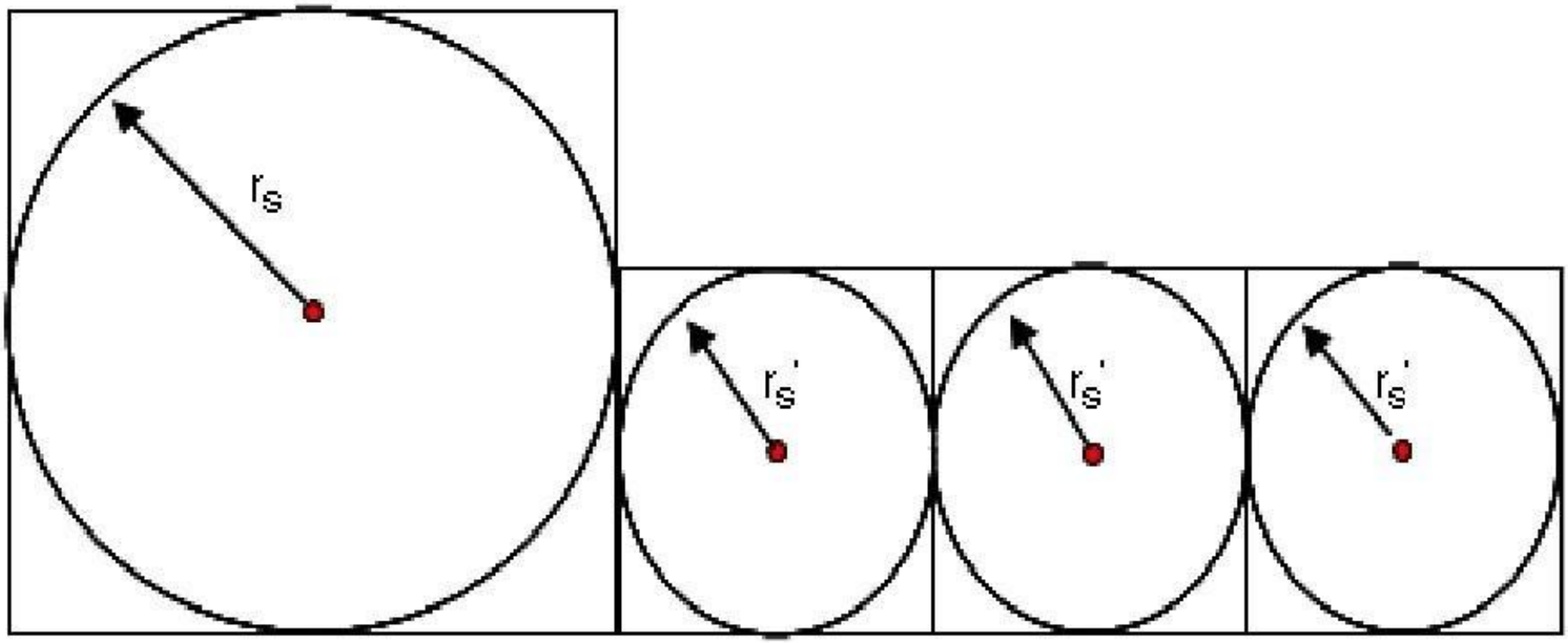
With constant sensing and transmission range for all SNs, WSNs are also known as homogeneous WSNs

This makes the design simpler and easier to manage

In some situations, when a new version of SNs are deployed to cover additional area, or some of the existing SNs are replaced by new ones for extended life or precision, then sensing and/or communication range and/or computing power may also depend on the sensor type or version

Use of sensors with different sensing and/or communication and/or computation capabilities leads to a heterogeneous WSN which is helpful for performing additional functionalities or be given much more responsibilities

Heterogeneous WSNs



Mobile Sensors

- The enhancements in the field of robotics are paving the way for industrial robots to be applied to a wider range of tasks

- However, harnessing their full efficiency also depends on how accurately they understand their environment

- Thus, as sensor networks are the primary choice for environmental sensing, combining sensor networks with mobile robots is a natural and very promising application

- Robots could play a major role of high-speed resource carriers in defense and military applications where human time and life is very precious

- Other applications include fire fighting, autonomous waste disposal

- Thus, we see that there are a number of future applications where sensors and robots could work together through some form of cooperation

Mobile Sensors

- Sensors detect events autonomously and the mobile robots could take appropriate actions based on the nature of the event
- Coordination between the mobile robots is obviously critical in achieving better resource distribution and information retrieval
- Mobile sensor Networks have been suggested to cover the area not reachable by static sensors
- Coordination between multiple robots for resource transportation has been explored for quite some time now
- Transporting various types of resources for different applications like defense, manufacturing process, and so on, has been suggested
- In these schemes, time taken to detect an event depends entirely on the trail followed by the robots
- Though the path progressively gets better with the use of an ant-like type of algorithm, the whole process has to be started anew when the position of the event changes

Mobile Sensors

- In terrains where human ingress is difficult, mobile robots can be used to imitate the human's chore

- Typical resource-carrying robots are depicted in Figure 8.12 which depicts a possible means of a robot transferring its resources to anothers

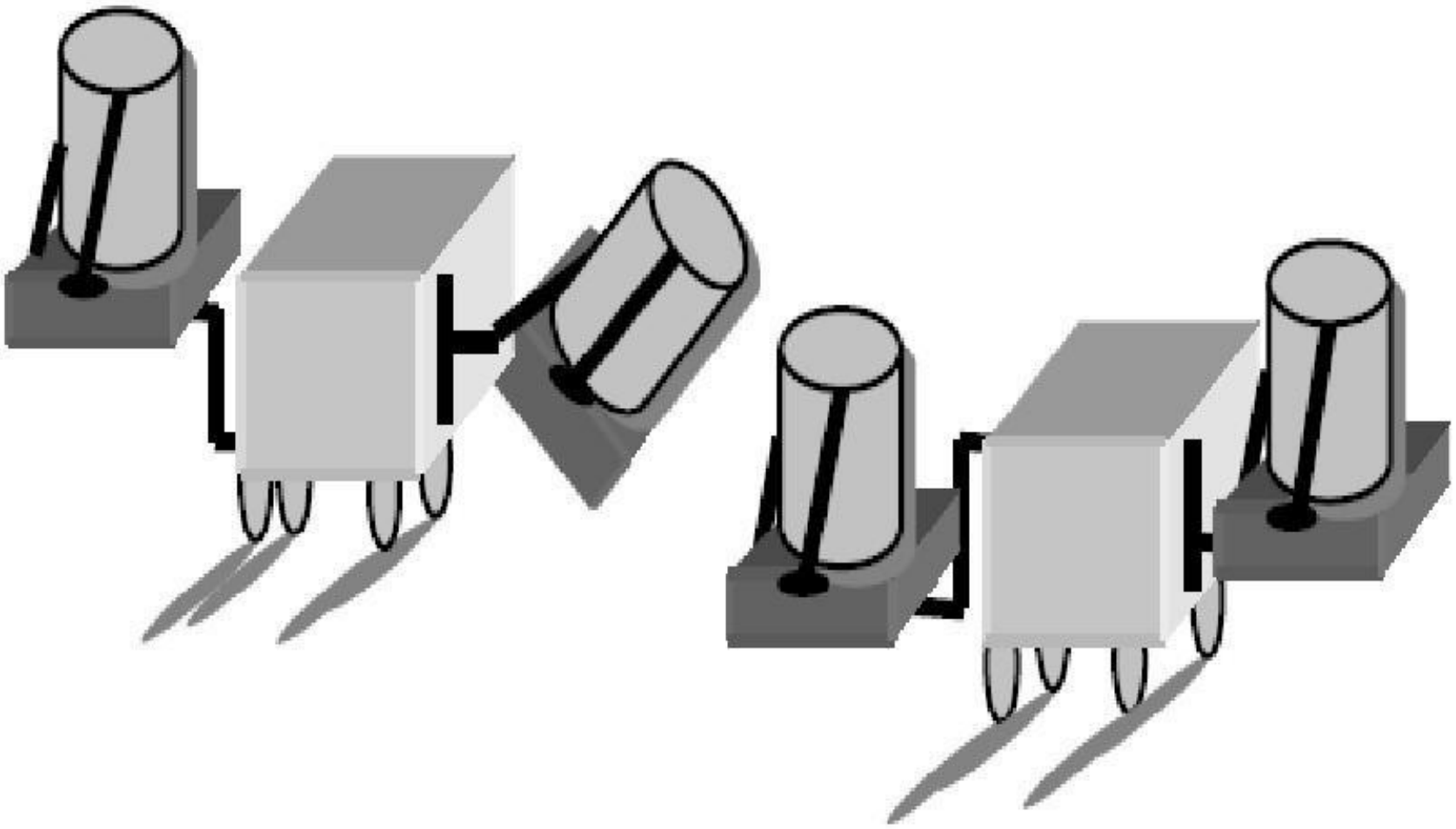
- Once depleted of their resource, they may get themselves refilled from the sink

- The resource in demand could be water or sand (to extinguish fire), oxygen supply, medicines, bullets, clothes or chemicals to neutralize hazardous wastes, and so on

- The target region that is in need of these resources is sometimes called an event location

- Whether it is a sensor or another robot within collision distance, it is considered an obstacle and the robot proceeds in a direction away from it

Mobile Sensors



Applications

- Thousands of sensors over strategic locations are used in a structure such as an automobile or an airplane, so that conditions can be constantly monitored
  both from the inside and the outside and a real-time warning can be issued whenever a major problem is forthcoming in the monitored entity

- These wired sensors are large (and expensive) to cover as much area is desirable

- Each of these need a continuous power supply and communicates their data to the end-user using a wired network

- The organization of such a network should be pre-planned to find strategic position to place these nodes and then should be installed appropriately

- The failure of a single node might bring down the whole network or leave that region completely un-monitored

Applications

- Under the civil category, envisioned applications can be classified into environment observation and forecast system, habitat monitoring equipment and human health, large structures and other commercial applications

Habitat Monitoring

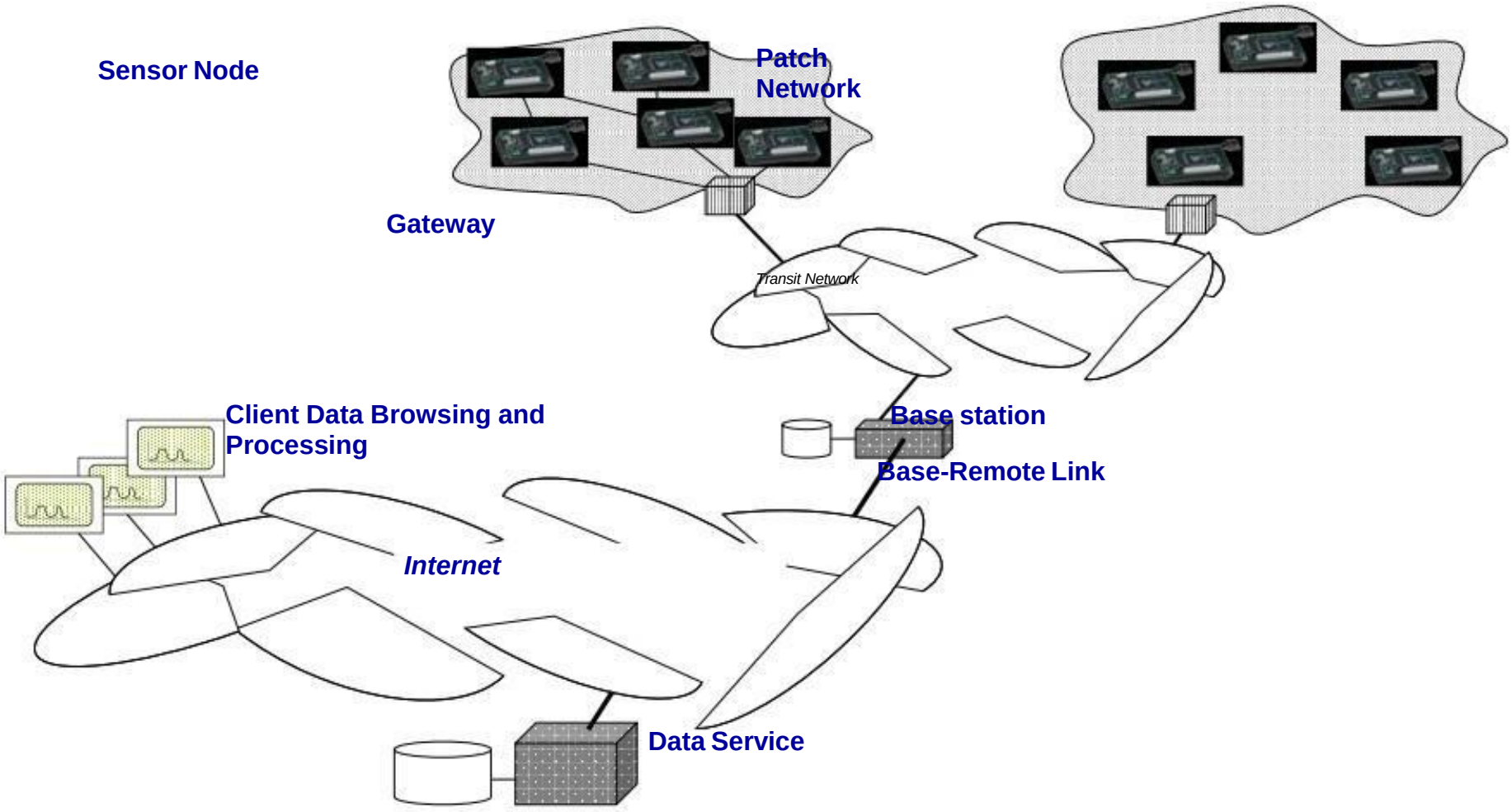
- A prototype test bed consisting of iPAQs (i.e., a type of handheld device) has been built to evaluate the performance of these target classification and localization methods

- As expected, energy efficiency is one of the design goals at every level: hardware, local processing (compressing, filtering, etc.), MAC and topology control, data aggregation, data-centric routing and storage

- Preprocessing is proposed in for habitat monitoring applications, where it is argued that the tiered network in GDI is solely used for communication

- The proposed 2-tier network architecture consists of micro nodes and macro nodes, wherein the micro nodes perform local filtering and data to significantly reduce the amount of data transmitted to macro nodes

The Grand Duck Island Monitoring Network



Environmental Monitoring Application

- Sensors to monitor landfill and the air quality

- Household solid waste and non-hazardous industrial waste such as construction debris and sewer sludge are being disposed off by using over 6000 landfills in USA and associated organic components undergo biological and chemical reaction such as fermentation, biodegradation and oxidation-reduction

- This causes harmful gases like methane, carbon dioxide, nitrogen, sulfide compounds and ammonia to be produced and migration of gases in the landfill causes physical reactions which eventually lead to ozone gases, a primary air pollutant and an irritant to our respiratory systems

- The current method of monitoring landfill employs periodic drilling of collection well, collecting gas samples in airtight bags and analyze off-site, making the process very time consuming

Environmental Monitoring Application

- The idea is to interface gas sensors with custom-made devices and wireless radio and transmit sensed data for further analysis

- Deployment of a large number of sensors allows real-time monitoring of gases being emitted by the waste material or from industrial spills

- Place a large number of sensors throughout the area of interest and appropriate type of sensors can be placed according to the type of pollutant anticipated in a given area

- A large volume of raw data from sensors, can be collected, processed and efficiently retrieval

- A generic set up of a WSN, has been covered and various associated issues have been clearly pointed out

-

Drinking Water Quality

- A sensor based monitoring system with emphasis on placement and utilization of in situ sensing technologies and doing spatial-temporal data mining for water-quality monitoring and modeling

- The main objective is to develop data-mining techniques to water-quality databases and use them for interpreting and using environmental data

- This also helps in controlling addition of chlorine to the treated water before releasing to the distribution system

- Detailed implementation of a bio-sensor for incoming wastewater treatment has been discussed

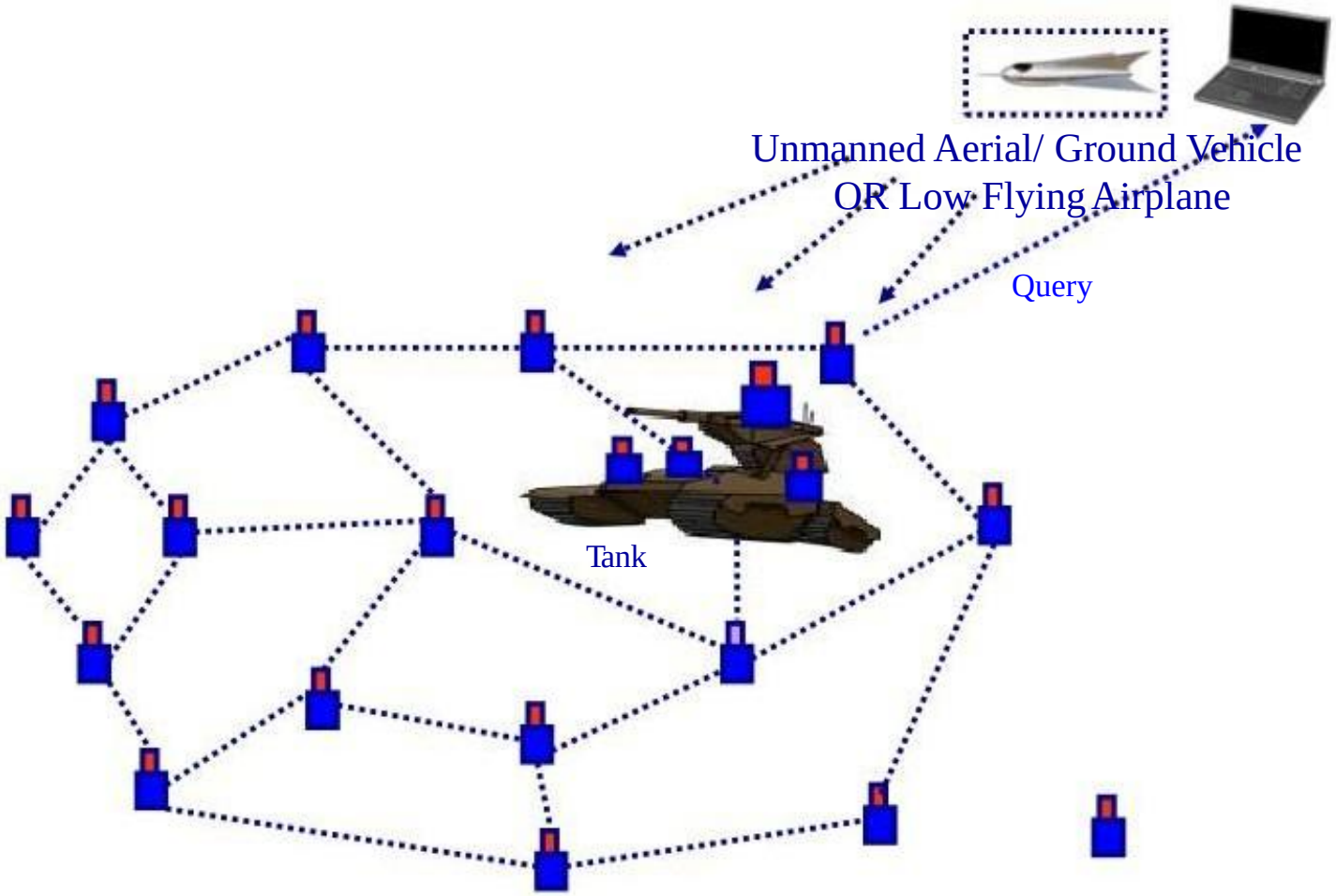
- A pilot-scale and full scale system has also been described

Conclusions and Future Directions

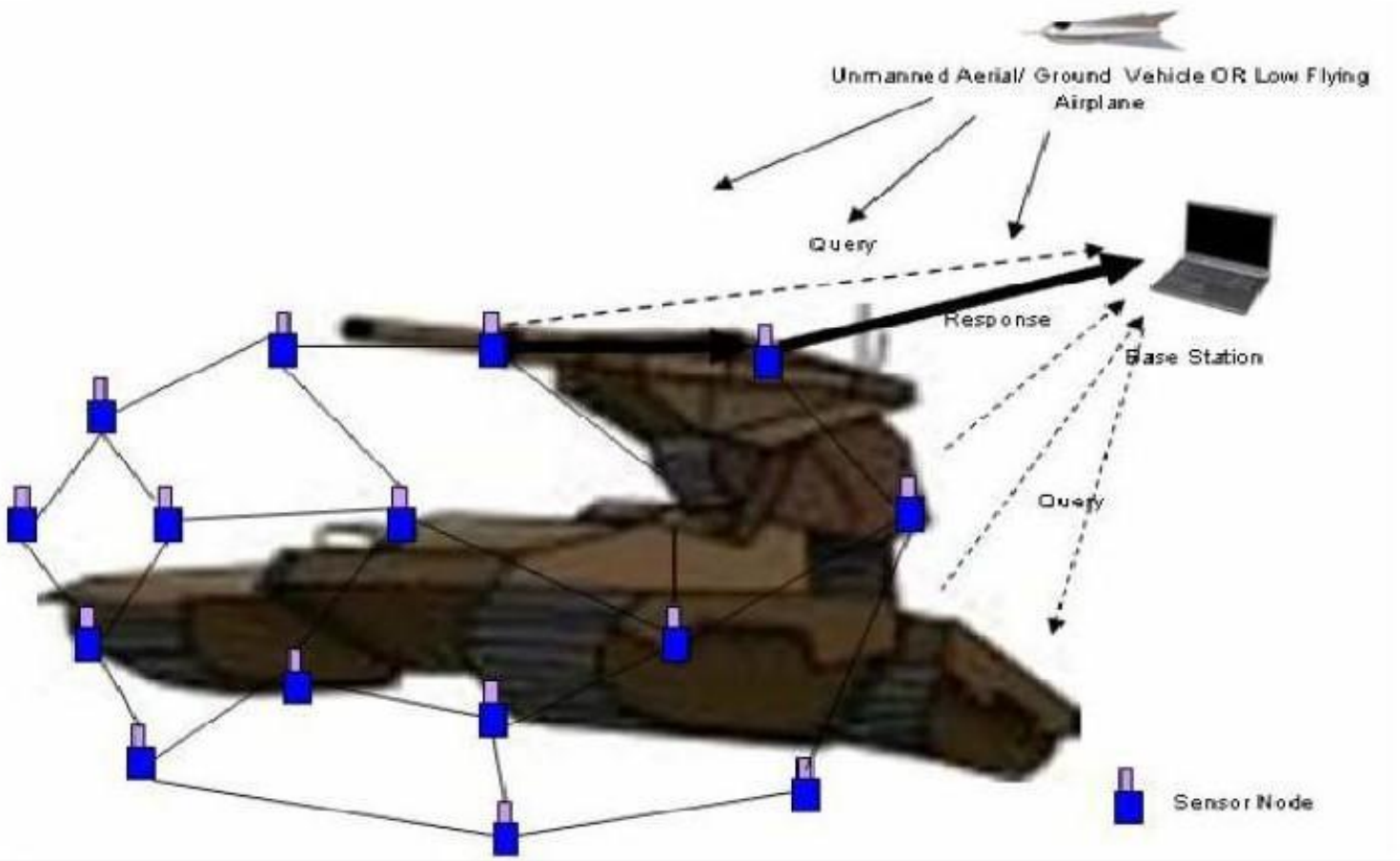
- Sensor networks are perhaps one of the fastest growing areas in the broad wireless ad hoc networking field

- As we could see throughout this chapter, the research in sensor networks is flourishing at a rapid pace and still there are many challenges to be addressed such as:
  - Energy Conservation - Nodes are battery powered with limited resources while still having to perform basic functions such as sensing, transmission and routing
  - Sensing - Many new sensor transducers are being developed to convert physical quantity to equivalent electrical signal and many new development is anticipated
  - Communication - Sensor networks are very bandwidth-limited and how to optimize the use of the scarce resources and how can sensor nodes minimize the amount of communication
  - Computation - Here, there are many open issues in what regards signal processing algorithms and network protocols

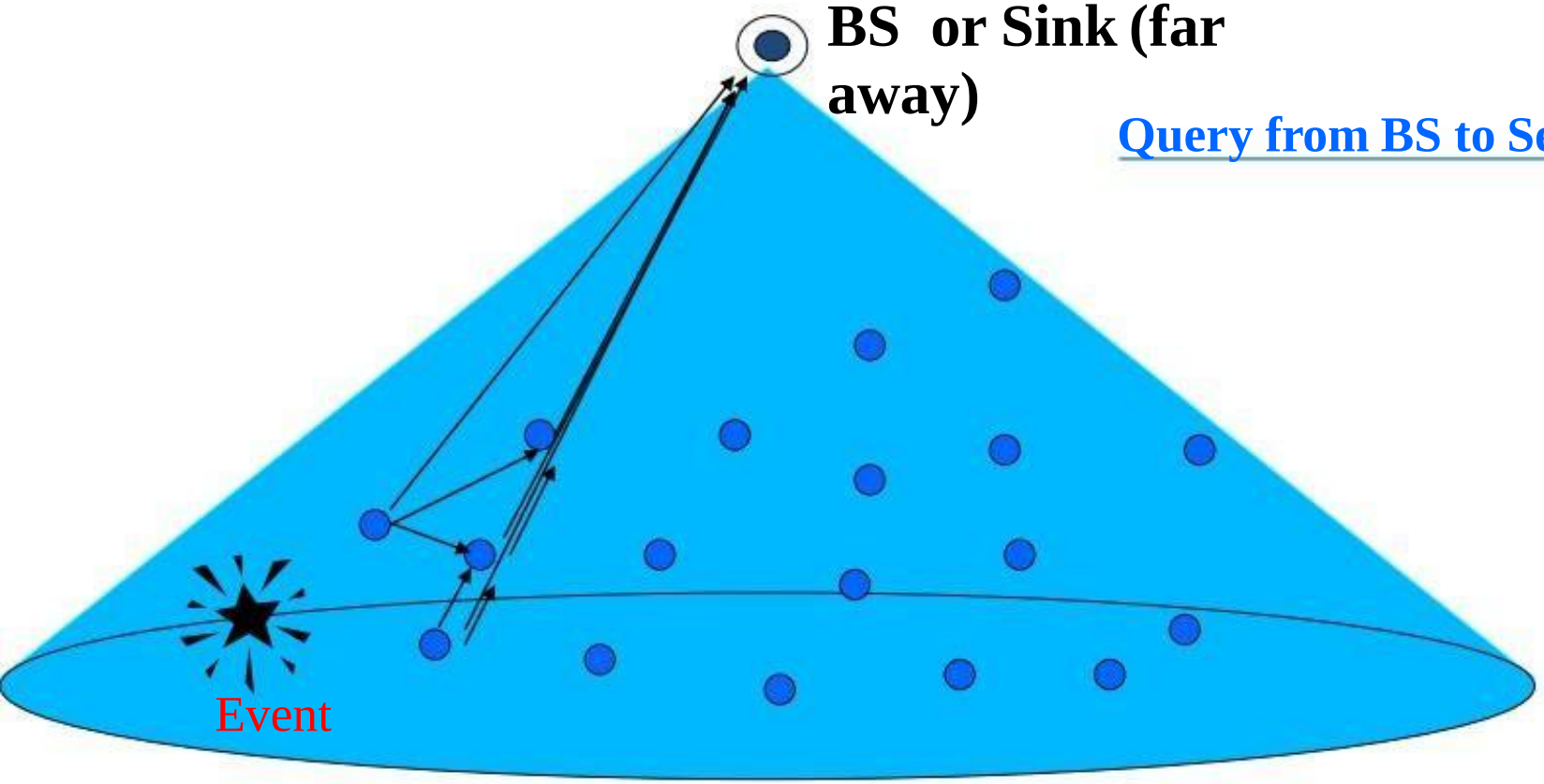
Introduction



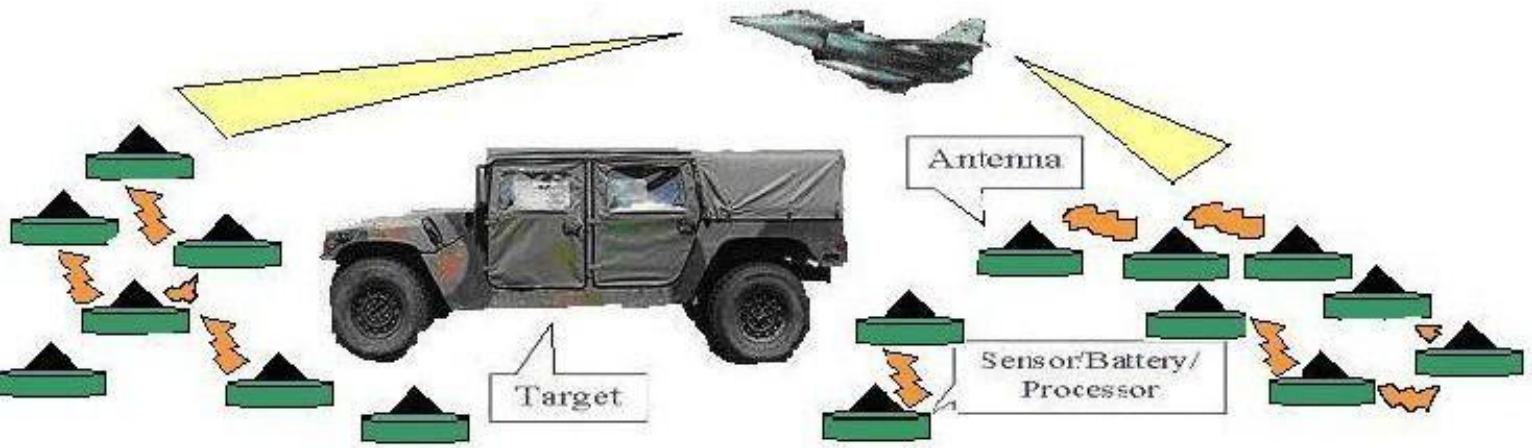
Introduction

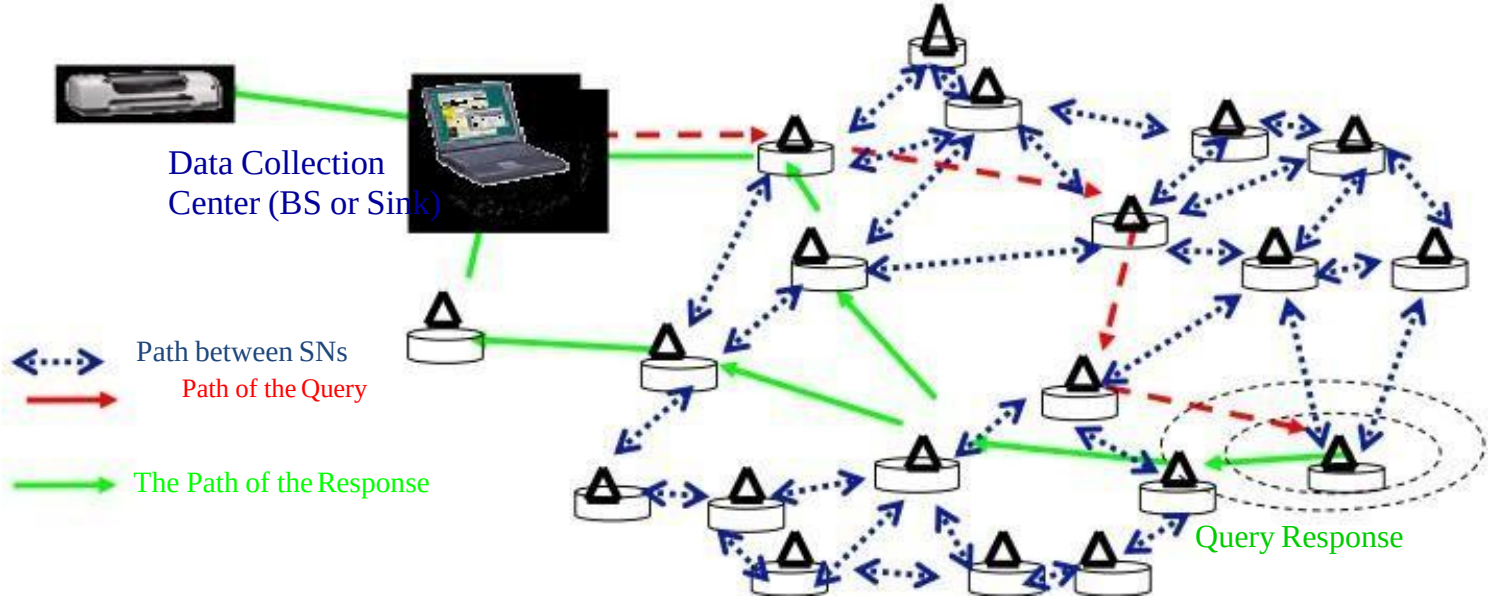


What is a Sensor Network?



Application of Wireless Sensor Networks in Defense Applications





Sensor Node (SN)

- A typical Sensor Node (SN) of the network contains several transducers to measure many different physical parameters and any one could be selected under the program control at a given time
- The sensed values need to be routed by each SN to the BS either directly or via its CH in a multihop fashion due to power limitations
- In a WSN, the overall objective can be defined by the BS and this process is usually known as injection of the query by the BS
- In real-life, a low-flying airplane, an unmanned aerial or ground vehicle or a powerful laptop can act as a BS or a sink and usually have adequate source of power
- This enables the BS to transmit a query message at a very high power level so as to reach all SNs in a given area simultaneously Such broadcasting is to enable all SNs to start working on the request and the query could also include information about some necessary characteristics of the query

Architecture of Sensor Networks

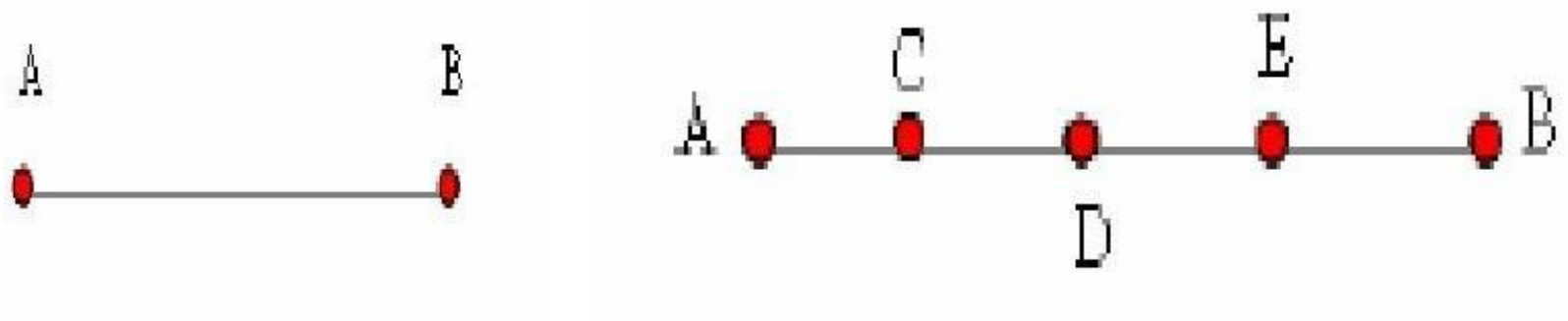
The typical hardware platform of a wireless sensor node will consist of:

- A simple embedded microcontrollers, such as the Atmel or the Texas Instruments MSP 430
- Currently used radio transceivers include the RFM TR1001 or Infineon or Chipcon devices
- Typically, ASK or FSK is used, while the Berkeley PicoNodes employ OOK modulation
- Radio concepts like ultra-wideband are in an advanced stage
- Batteries provide the required energy as an important concern is battery management and whether and how energy scavenging can be done to recharge batteries in the field
- The operating system and the run-time environment is a hotly debated issue in the literature
- On one hand, minimal memory footprint and execution overhead are required while on the other, flexible means of combining protocol building blocks are necessary, as meta information has to be used in many places in a protocol stack

Network Architecture

- WSN architecture need to cover a desired area both for sensing coverage and communication connectivity point of view
- Therefore, density of the WSN network is critical for the effective use of the WSN
- There is no well-defined measure of life-time of a WSN and some assume either the failure of a single sensor running out of battery power as life-time of the network
- Perhaps a better definition is if certain percentage of sensors stops working, may define the life-time as the network continues to operate
- The percentage failure may depend on the nature of application and as long as the area is adequately covered by the operating sensors, a WSN may be considered operational
- The SNs are yet to become inexpensive to be deploying with some degree of redundancy

Network Architecture



- There is an optimal distance between two sensors that would maximize the sensor lifetime
- So, if the density of sensors is high, then some of the sensors can be put into sleep mode to have close to optimal distance between the sensors
- Very little work has been done on protocols that suits well to the needs of WSNs
- With respect to the radio transmission, the main question is how to transmit as energy efficiently as possible, taking into account all related costs (possible retransmissions, overhead, and so on)

MAC Protocols

- WSNs are designed to operate for long time as it is rather impractical to replenish the batteries
- However, nodes are in idle state for most time when no sensing occurs
- Measurements have shown that a typical radio consumes the similar level of energy in idle mode as in receiving mode
- Therefore, it is important that nodes are able to operate in low duty cycles

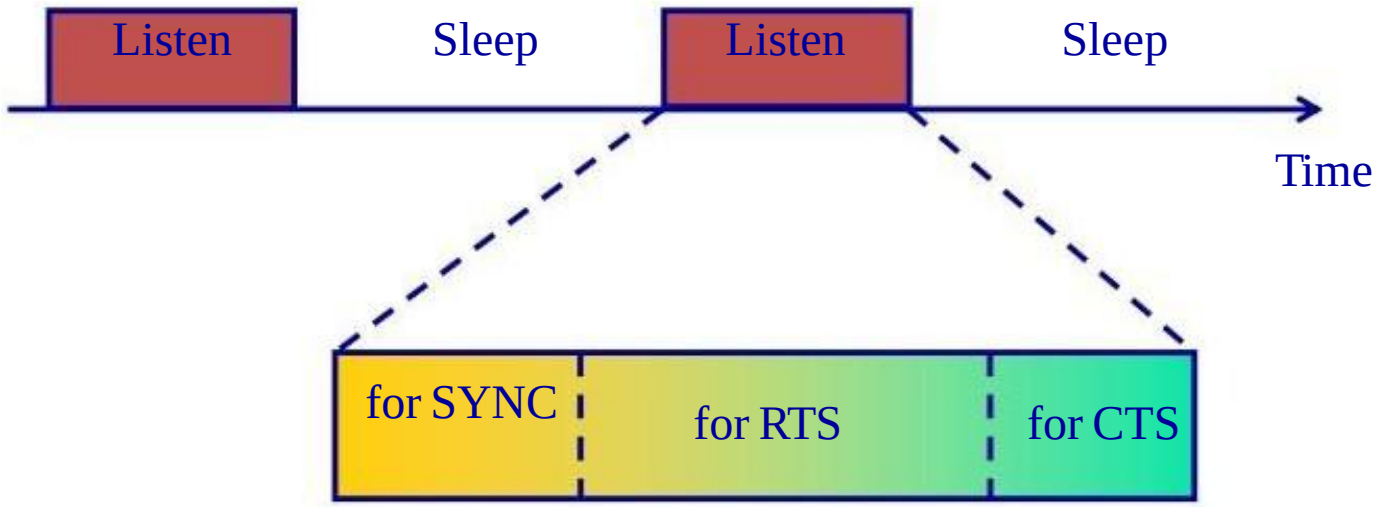
The Sensor-MAC

- The Sensor-MAC (S-MAC) protocol explores design trade-offs for energy-conservation in the MAC layer
- It reduces the radio energy consumption from the following sources: collision, control overhead, overhearing unnecessary traffic, and idle listening
- The basic scheme of S-MAC is to put all SNs into a low-duty-cycle mode -listen and sleep periodically
- When SNs are listening, they follow a contention rule to access the medium, which is similar to the IEEE 802.11 DCF

Sensor-MAC

- In S-MAC, SNs exchange and coordinate on their sleep schedules rather than randomly sleep on their own
- Before each SN starts the periodic sleep, it needs to choose a schedule and broadcast it to its neighbors
- To prevent long-term clock drift, each SN periodically broadcasts its schedule as the SYNC packet
- To reduce control overhead and simplify broadcasting, S-MAC encourages neighboring SNs to choose the same schedule, but it is not a requirement
- A SN first listens for a fixed amount of time, which is at least the period for sending a SYNC packet
- If it receives a SYNC packet from any neighbor, it will follow that schedule by setting its own schedule to be the same
- Otherwise, the SN will choose an independent schedule after the initial listening period

Sensor-MAC



- Figure depicts the low-duty-cycle operation of each SN
- The listen interval is divided into two parts for both SYNC and data packets
- There is a contention window for randomized carrier sense time before sending each SYNC or data (RTS or broadcast) packet

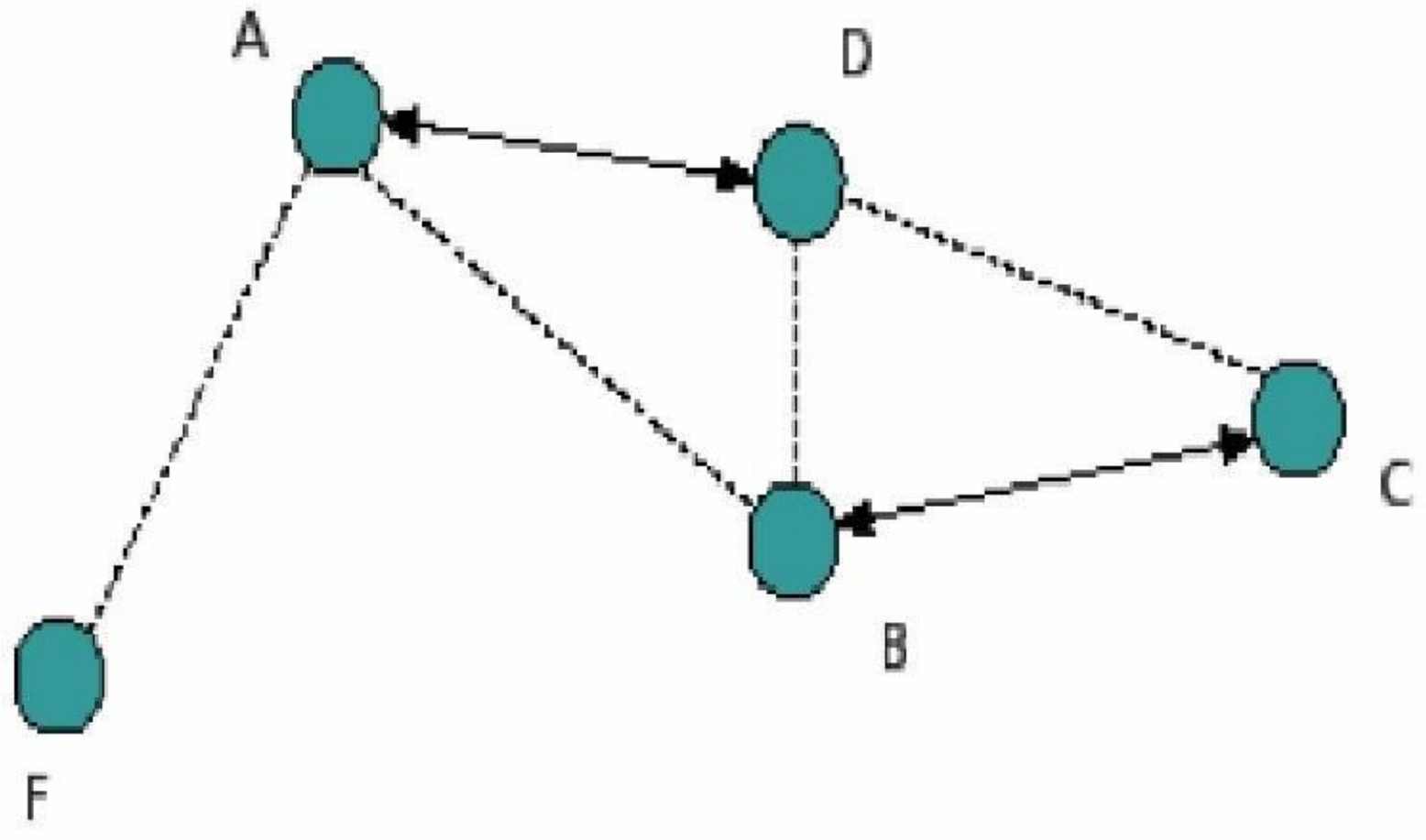
SMACS

- The SMACS is an infrastructure-building protocol that forms a flat topology (as opposed to a cluster hierarchy) for sensor networks
- SMACS is a distributed protocol which enables a collection of SNs to discover their neighbors and establish transmission/reception schedules for communicating with them without the need for any local or global master nodes
- In order to achieve this ease of formation, SMACS combines the neighbor discovery and channel assignment phases
- SMACS assigns a channel to a link immediately after the link's existence is discovered
- This way, links begin to form concurrently throughout the network
- By the time all nodes hear all their neighbors, they would have formed a connected network
- In a connected network, there exists at least one multihop path between any two distinct nodes

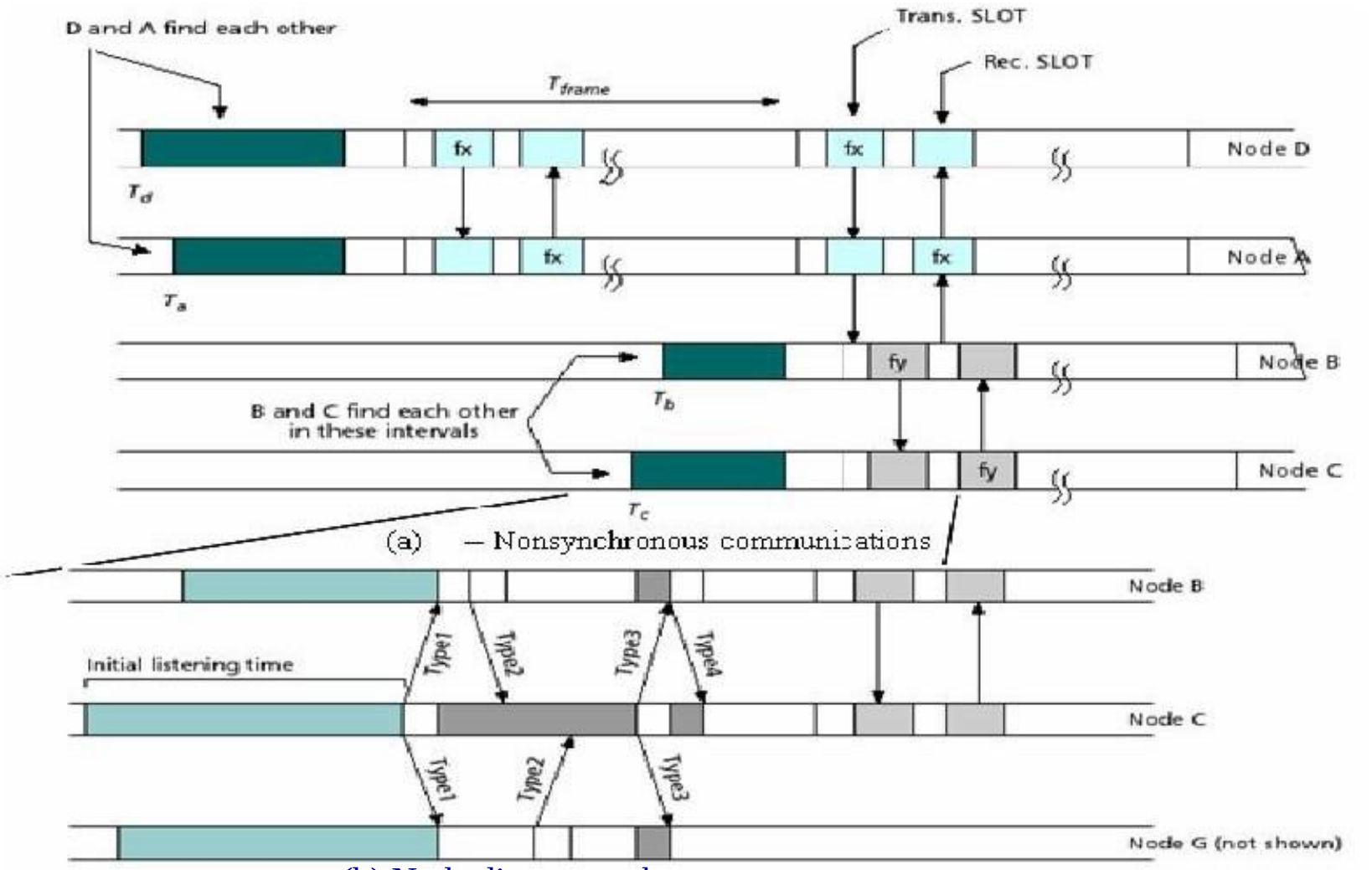
SMACS

- Since only partial information about radio connectivity in the vicinity of a SN is used to assign time intervals to links, there is a potential for time collisions with slots assigned to adjacent links whose existence is not known at the time of channel assignment
- To reduce the likelihood of collisions, each link is required to operate on a different frequency
- This frequency band is chosen at random from a large pool of possible choices when the links are formed
- This idea is described in Figure 9.6(a) for the topology of Figure 9.5
- Here, nodes A and D wake up at times T_a and T_d
- After they find each other, they agree to transmit and receive during a pair of fixed time slots
- This transmission/reception pattern is repeated periodically every T_{frame}
- Nodes B and C, in turn, wake up later at times T_b and T_c, respectively

Network Topology



Node Discovery Phase in SMACS



(b) Node discovery phase

SMACS

- The method by which SNs find each other and the scheme by which time slots and operating frequencies are determined constitute an important part of SMACS
- To illustrate this scheme, consider nodes B, C, and D shown in Figure 9.6(b)
- These nodes are engaged in the process of finding neighbors and wake up at random times
- Upon waking up, each node listens to the channel on a fixed frequency band for some random time duration
- A node decides to transmit an invitation by the end of this initial listening time if it has not heard any invitations from other nodes
- This is what happens to node C, which broadcasts an invitation or TYPE1 message
- Nodes B and D hear this TYPE1 message and broadcasts a response, or TYPE2, message addressed to node C during a random time following reception of TYPE1

EAR (Eaves-drop-And-Register)

- Mobility can be introduced into a WSN as extensions to the stationary sensor network
- Mobile connections are very useful to a WSN and can arise in many scenarios where either energy or bandwidth is a major concern
- Where there is the constraint of limited power consumption, small, low bit rate data packets can be exchanged to relay data to and from the network whenever necessary
- At the same time, it cannot be assumed that each mobile node is aware of the global network state and/or node positions
- Similarly, a mobile node may not be able to complete its task (data collection, network instruction, information extraction) while remaining motionless
- Thus, the EAR protocol attempts to offer continuous service to these mobile nodes under both mobile and stationary constraints
- EAR is a low-power protocol that allows for operations to continue within the stationary network while intervening at desired moments for information exchange

EAR

The EAR algorithm employs the following four primary messages:

1. Broadcast Invite (BI) - This is used by the stationary node to invite other nodes to join and if multiple BIs are received, the mobile node continues to register every stationary node encountered, until its registry becomes full

2. Mobile Invite (MI) - This message is sent by the mobile node in response to the BI message from the stationary node for establishing connection

3. Mobile Response (MR) - This is sent by the stationary node in response to a MI message, and indicates the acceptance of the MI request which causes the stationary node to select slots along the TDMA frame for communication and the stationary node will enter the mobile node in its own registry

4. Mobile Disconnect (MD) - With this message, the mobile node informs the stationary node of a disconnection and for energy saving purposes, no response is needed from the stationary node

The STEM

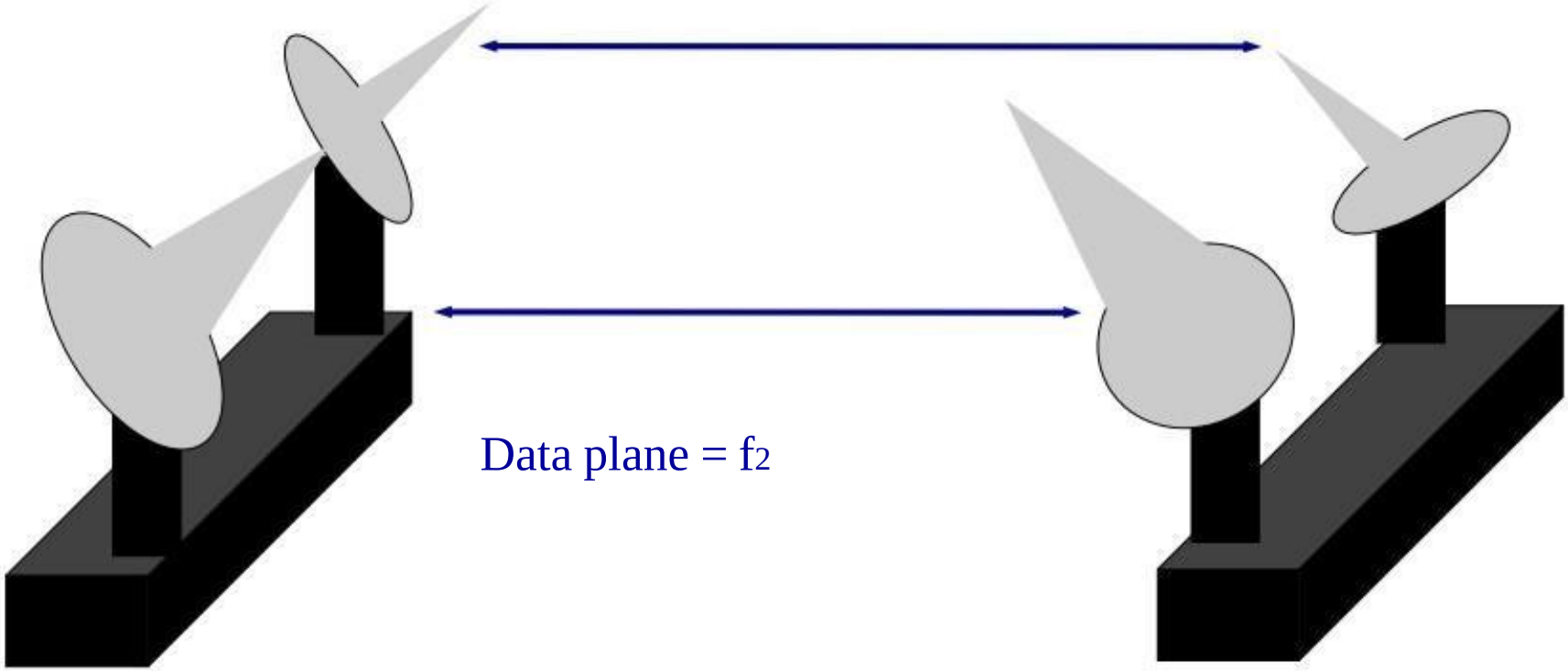
- The idea behind STEM is to turn on only a node's sensors and some preprocessing circuitry during monitoring states
- Whenever a possible event is detected, the main processor is woken up to analyze the sensed data in detail and forward it to the data sink
- However, the radio of the next hop in the path to the data sink is still turned off, if it did not detect the same event
- STEM solves this problem by having each node to periodically turn on its radio for a short time to listen if someone else wants to communicate with it
- The node that wants to communicate, i.e. , the initiator SN, sends out a beacon with the ID of the node it is trying to wake up, i.e. , the target SN
- This can be viewed as a procedure by which the initiator SN attempts to activate the link between itself and the target SN
- As soon as the target SN receives this beacon, it responds back to the initiator node and both keep their radio on at this point

The STEM

- If the packet needs to be relayed further, the target SN will become the initiator node for the next hop and the process is repeated
- Once both the nodes that make up a link have their radio on, the link is active and can be used for subsequent packets
- However, the actual data transmissions may still interfere with the wakeup protocol
- To overcome this problem, STEM proposes the wakeup protocol and the data transfer to employ different frequency bands as depicted in
  In addition, separate radios would be needed in each of these bands
- In Figure 9.7 we see that the wakeup messages are transmitted by the
- radio operating in frequency band f_1
  STEM refers to these communications as occurring in the *wakeup plane*
- Once the initiator SN has successfully notified the target SN, both SNs
- turn on their radio that operates in frequency band f_2
  The actual data packets are transmitted in this band, called the *data plane*
-

The Stem

Wakeup plane = f_1



Data plane = f_2

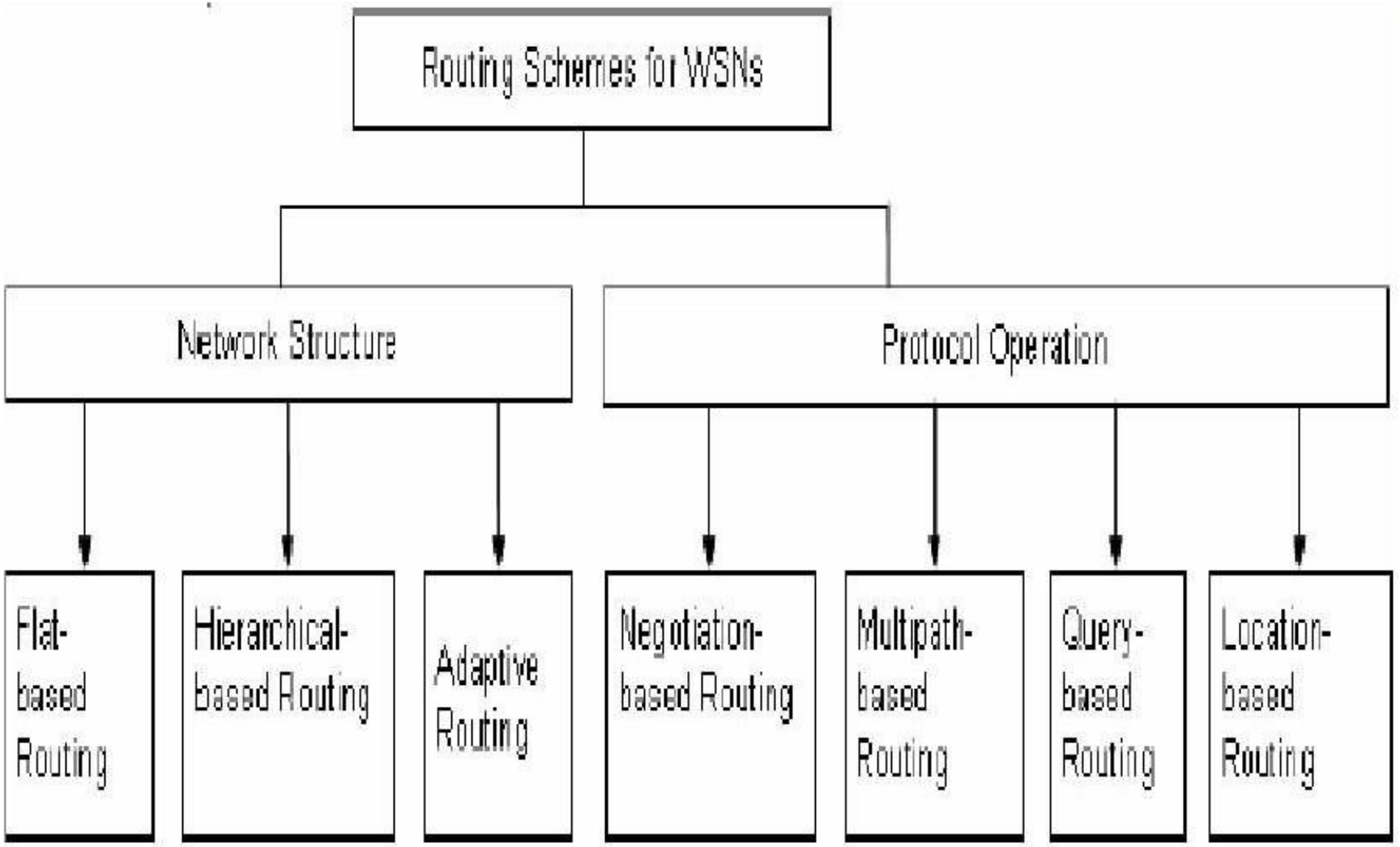
Routing Layer

- Routing in sensor networks is usually multi-hop
- The goal is to send the data from source node(s) to a known destination node
- The destination node or the sink node is known and addressed by means of its location
- A BS may be fixed or mobile, and is capable of connecting the sensor network to an existing infrastructure where the user can have access to the collected data
- The task of finding and maintaining routes in WSNs is nontrivial since energy restrictions and sudden changes in node status (e.g., failure) cause frequent unpredictable topological changes
- Thus, the main objective of routing techniques is to minimize the energy consumption in order to prolong WSN lifetime
- To achieve this objective, routing protocols proposed in the literature employ some well-known routing techniques as well as tactics special to WSNs
- To preserve energy, strategies like data aggregation and in-network processing, clustering, different node role assignment, and data-centric methods are employed

Routing Layer

- In sensor networks, conservation of energy is considered relatively more important than quality of data sent
- Therefore, energy-aware routing protocols need to satisfy this requirement
- Routing protocols for WSNs have been extensively studied in the last few years
- Routing protocols for WSNs can be broadly classified into flat-based, hierarchical-based, and adaptive, depending on the network structure
- In flat-based routing, all nodes are assigned equal role
- In hierarchical-based routing, however, nodes play different roles and certain nodes, called cluster heads (CHs), are given more responsibility
- In adaptive routing, certain system parameters are controlled in order to adapt to the current network conditions and available energy levels
- Furthermore, these protocols can be classified into multipath-based, query-based, negotiation-based, or location-based routing techniques

Routing Layer



Network Structure Based

- In this class of routing protocols, the network structure is one of the determinant factors
- In addition, the network structure can be further subdivided into flat, hierarchical and adaptive depending upon its organization

Flat Routing

- In flat routing based protocols, all nodes play the same role and we present the most prominent protocols falling in this category

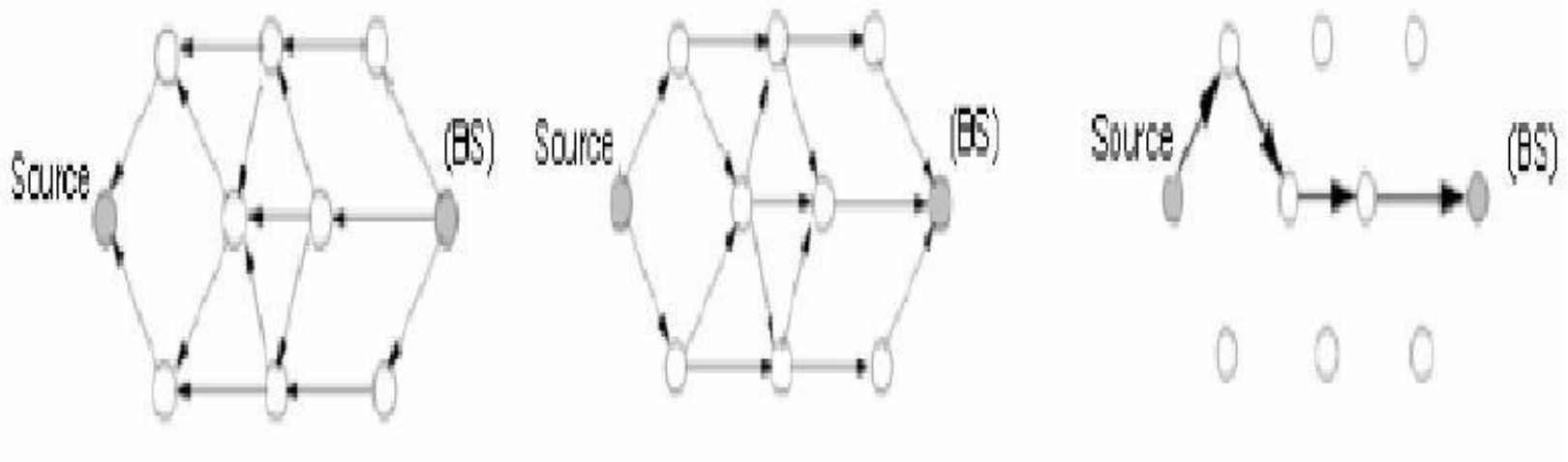
Directed Diffusion

- Directed Diffusion is a data aggregation and dissemination paradigm for sensor networks
- It is a data-centric (DC) and application-aware approach in the sense that all data generated by sensor nodes is named by attribute-value pairs
- Directed Diffusion is very useful for applications requiring dissemination and processing of queries
- The main idea of the DC paradigm is to combine the data coming from different sources en-route(in-network aggregation) by eliminating redundancy, minimizing the number of transmissions; thus saving network energy and prolonging its lifetime

Data Centric Routing and Directed Diffusion

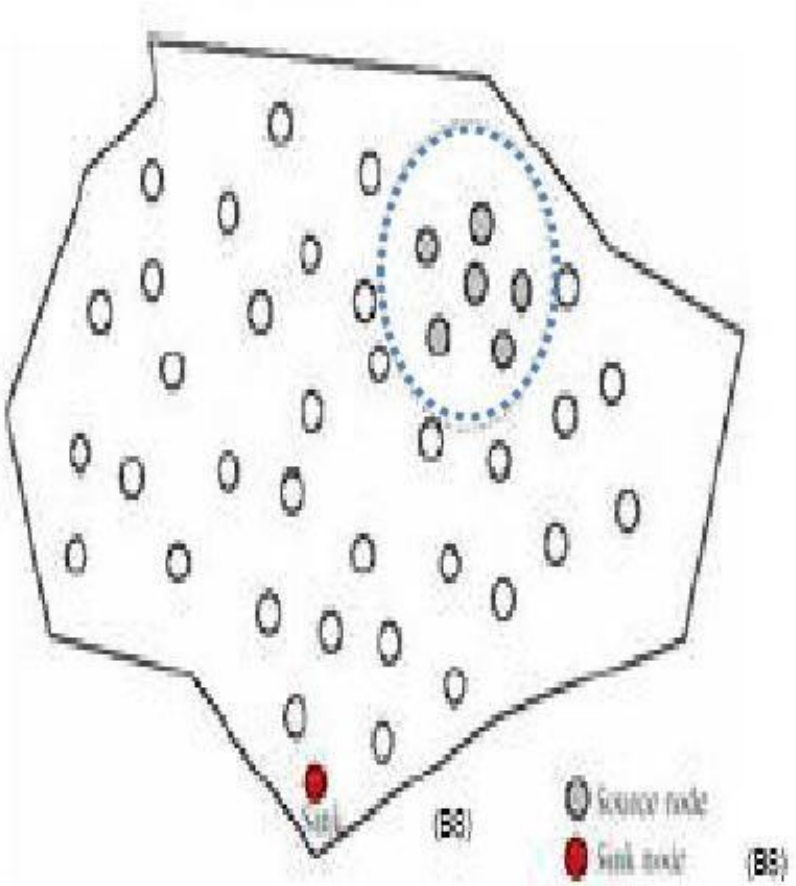
- Unlike traditional end-to-end routing, DC routing finds routes from multiple sources to a single destination (BS) that allows in-network consolidation of redundant data
- In Directed Diffusion, sensors measure events and create gradients of information in their respective neighborhoods
- The BS requests data by broadcasting interests, which describes a task to be done by the network
- Interest diffuses through the network hop-by-hop, and is broadcast by each node to its neighbors
- As the interest is propagated throughout the network, gradients are setup to draw data satisfying the query towards the requesting node
- Each SN that receives the interest setup a gradient toward the SNs from which it receives the interest
- This process continues until gradients are setup from the sources back to the

Data Centric Routing and Directed Diffusion

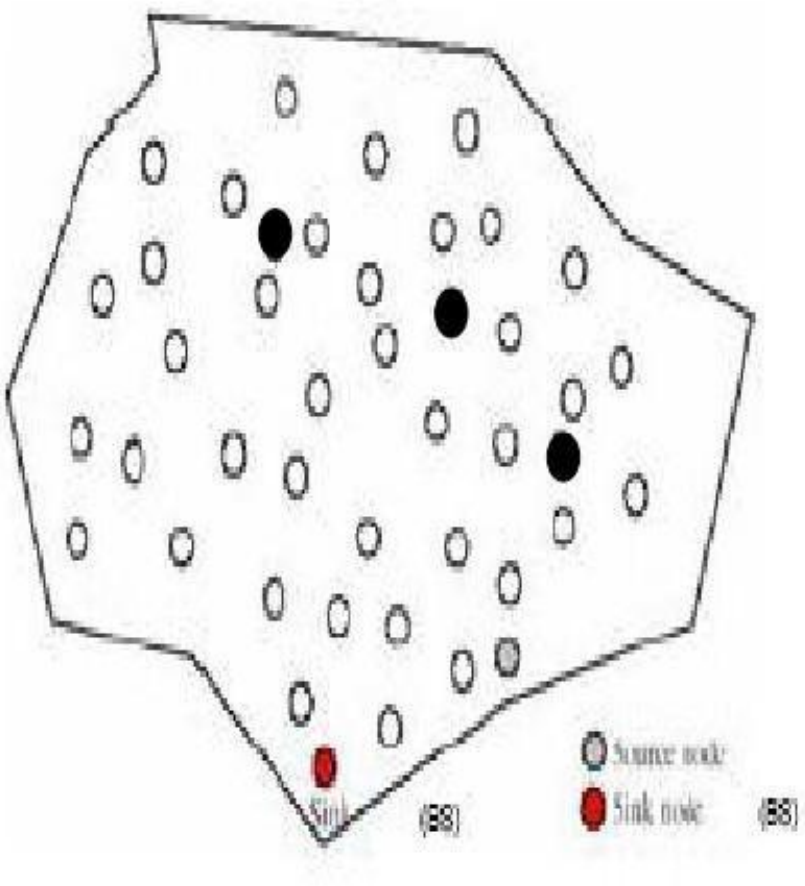


- Sensor nodes in a directed diffusion-based network are application-aware, which enables diffusion to achieve energy savings by choosing empirically good paths and by caching and processing data in the network
- An application of directed diffusion is to spontaneously propagate an important event to regions of the sensor network
- Such type of information retrieval is well suited for persistent queries where requesting nodes expect data that satisfy a query for a period of time

Network Structure Based



Event Radius (ER) model



Randum source (RS) model

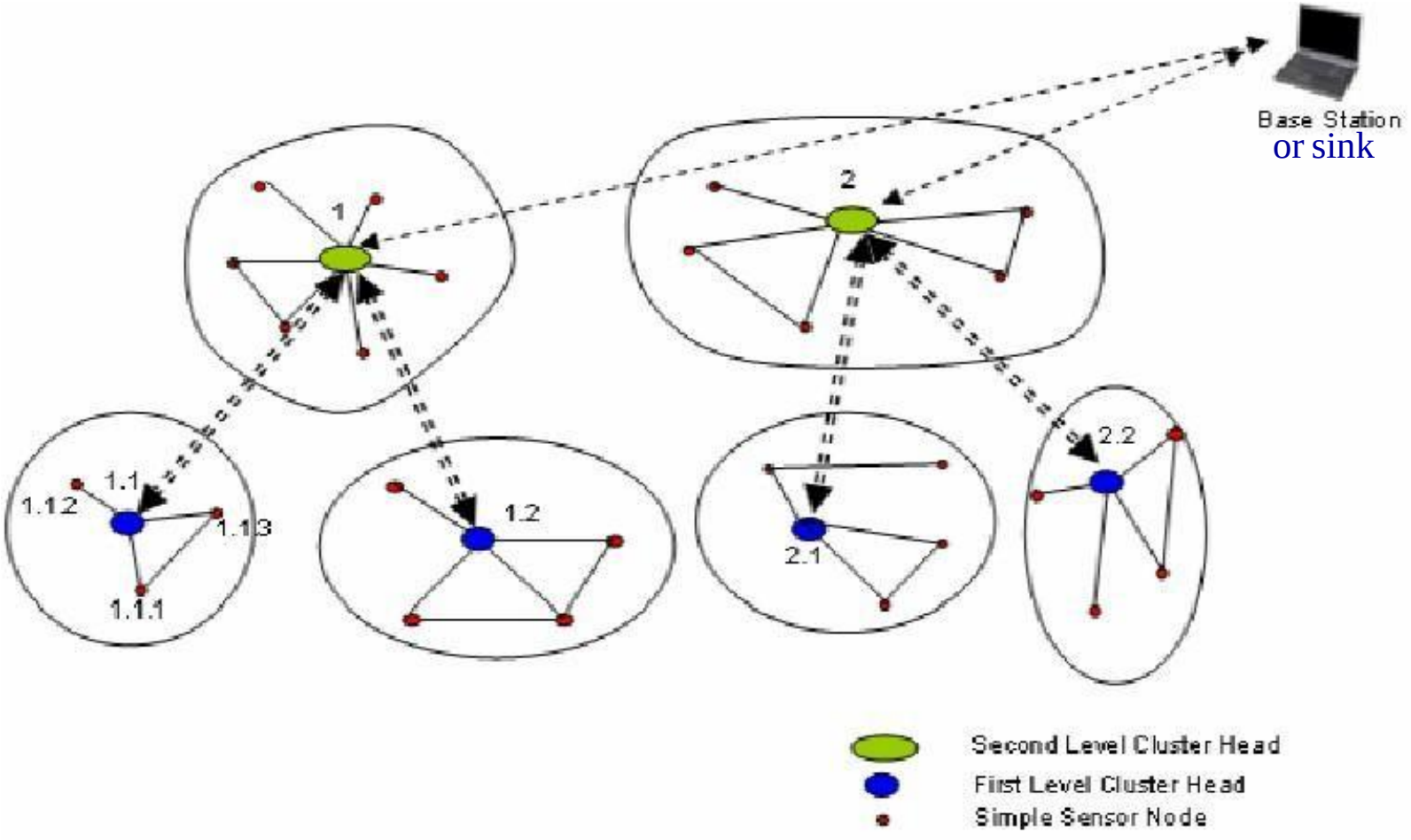
Sequential Assignment Routing (SAR)

- The routing scheme in SAR depends on three factors: energy resources, QoS on each path, and the priority level of each packet
- To avoid single route failure, a multi-path approach coupled with a localized path restoration scheme is employed
- To create multiple paths from a source node, a tree rooted at the source node to the destination nodes (i.e. , the set of BSs) isconstructed
- The paths of the tree are defined by avoiding nodes with low energy or QoS guarantees
  At the end of this process, each sensor node is a part of multi-path tree
- For each SN, two metrics are associated with each path: delay (which is an
- additive QoS metric); and energy usage for routing onthat path
  The energy is measured with respect to how many packets will traverse that path
- SAR calculates a weighted QoS metric as the product of the additive QoS metric and a weight coefficient associated with the priority level of the
- packet
  The goal of SAR is to minimize the average weighted QoS metric forthe network
-

Minimum Cost Forwarding Algorithm

- The minimum cost forwarding algorithm (MCFA) exploits the fact that the direction of routing is always known, that is, towards fixed and predetermined external BS
- Therefore, a SN need not have a unique ID nor maintain a routing table
- Instead, each node maintains the least cost estimate from itself to the BS
- Each message forwarded by the SN is broadcast to its neighbors
- When a node receives the message, it checks if it is on the least cost path between the source SN and the BS
- If so, it re-broadcasts the message to its neighbors
- This process repeats until the BS is reached
- In MCFA, each sensor node should know the least cost path estimate from itself to the BS

Hierarchical Routing



Cluster Based Routing Protocol (CBRP)

- A simple cluster based routing protocol (CBRP) divides the network nodes into a number of overlapping or disjoint two-hop-diameter clusters in a distributed manner
- The cluster members just send the data to the CH, and the CH is responsible for routing the data to the destination
- The major drawback with CBRP is that it requires a lot of hello messages to form and maintain the clusters, and thus may not be suitable for WSN
- Given that sensor nodes are stationary in most of the applications this is a considerable and unnecessary overhead

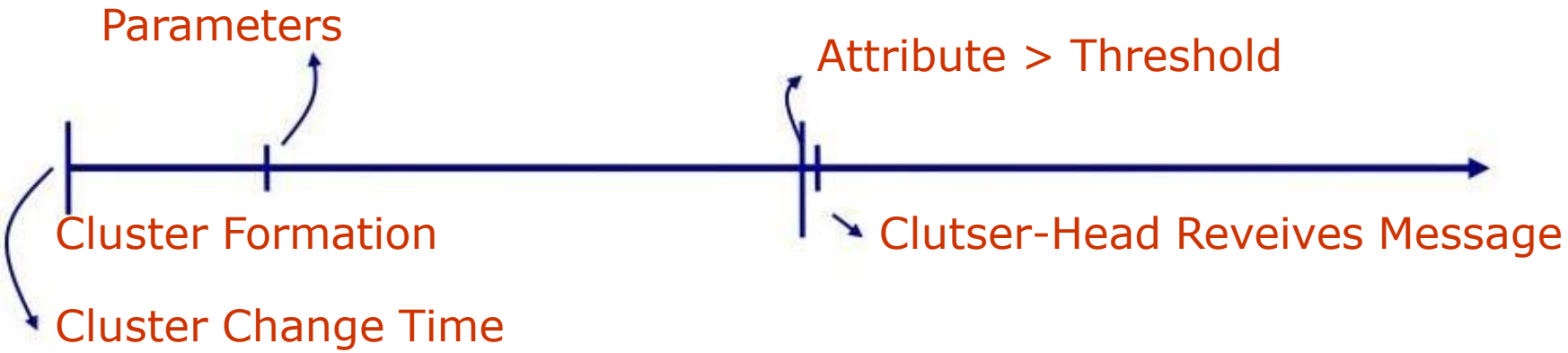
Scalable Coordination

- In hierarchical clustering method, the cluster formation appears to require considerable amount of energy as periodic advertisements are needed to form the hierarchy
- Also, any changes in the network conditions or sensor energy level result in re-clustering which may be not quite acceptable as some parameters tend to change dynamically

Small Minimum Energy Communication Network (MECN)

- The minimum energy communication network (MECN) protocol has been designed to compute an energy-efficient subnetwork for a given sensor network
- On top of MECN, a new algorithm called Small MECN (SMECN) has been proposed to construct such a subnetwork
- The subnetwork (i.e. , subgraph G') constructed by SMECN is smaller than the one constructed by MECN if the broadcast region around the broadcasting node is circular for a given power assignment
- The subgraph G' of graph G, which represents the sensor network, minimizes the energy consumption satisfying the following conditions:
  - The number of edges in G' is less than in G, while containing all nodes in G
  - The energy required to transmit data from a node to all its neighbors in subgraph G' is less than the energy required to transmit to all its neighbors in graph G
- The resulting subnetwork computed by SMECN helps in the task of sending messages on minimum-energy paths

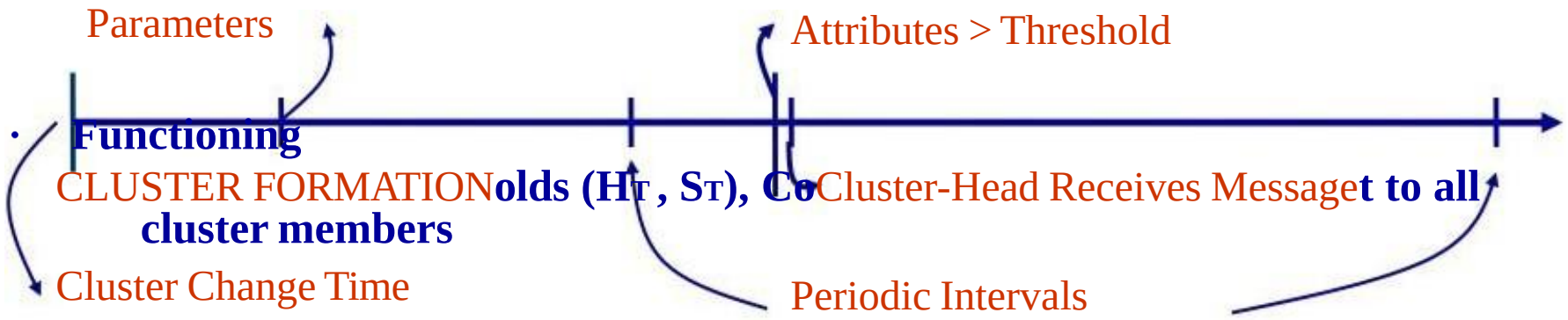
Threshold-sensitive Energy Efficient (TEEN)



- Features
  - Suited for time critical sensing applications
  - Time critical data reaches the user almost instantaneously
  - At every cluster change time, the parameters are broadcast afresh and so, the user can change them as required
  - Energy consumption can be controlled by changing the threshold values

Hybrid Protocol (APTEEN)

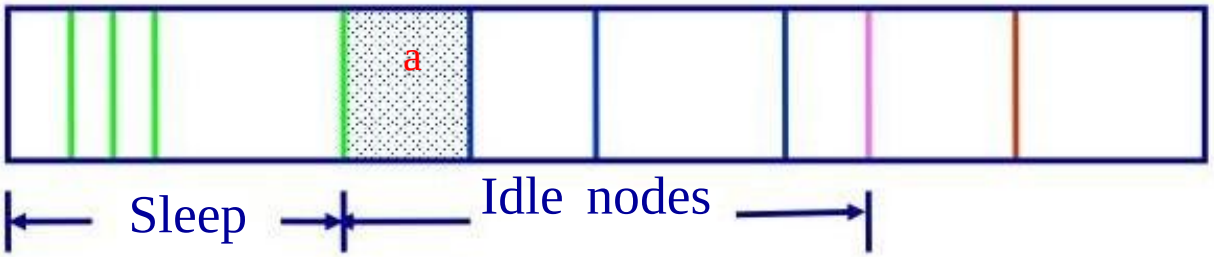
- **To take advantage of both the networks, it is preferable to have both the features in the system (UC)**



Modified TDMA for APTEEN

- **Time-critical queries and historical queries are answered by the BS**
- **Based on the assumption that adjacent nodes sense similar data, we can make only one of them handle the query**
  - **This might reduces the accuracy of data for non-critical queries**
  - **This is acceptable since it almost doubles the life of the network**

Original TDMA

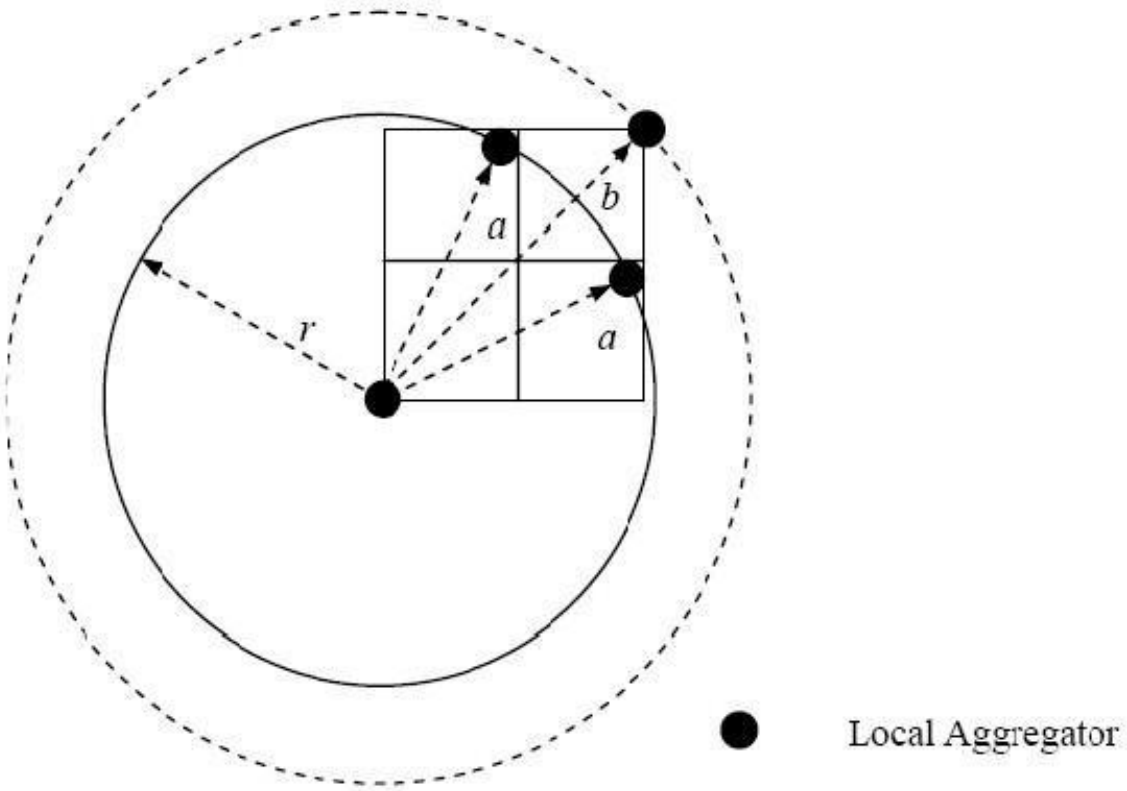


Modified TDMA

Routing in Fixed-size Clusters

- Routing in sensor networks can also take advantage of geography-awareness
- One such routing protocol is called Geography Adaptive Fidelity (GAF) where the network is firstly divided into fixed zones
- Within each zone, nodes collaborate with each other to play different roles
- For example, nodes elect one SN to stay awake for a certain period of time while the others sleep
- This particular elected SN is responsible for monitoring and reporting data to the BS on behalf of all nodes within the zone
- Here, each SN is positioned randomly in a two dimensional plane
- When a sensor transmits a packet for a total distance r, the signal is strong enough for other sensors to hear it within the Euclidean distance r from the sensor that originates the packet
- Figure 9.14 depicts an example of fixed zoning that can be applied to WSN

Routing in Fixed-size Clusters



r is the distance of packet transmission by each sensor

- A fixed cluster of each side *a* can be selected and is connected if:
- If the signal travels a distance of a = r/(5) v/n adjacent vertical or horizontal directions, two sensors can communicate directly
- For a diagonal communication to take place, the signal has to span a distance of a = r/(2 2) v/

Sensor Aggregates Routing

- A sensor aggregate includes those SNs in a network that satisfy a grouping predicate for a collaborative processing task
- The parameters of the predicate depend on the task and its resource requirements
- Here, the formation of appropriate sensor aggregate is considered in terms of resource allocation for communication and sensing
- Sensors in the network are divided into clusters according to their sensed signal strength
- After that, local cluster leaders (CH) are elected by exchanging information between neighboring sensors
- Once a sensor node has exchanged packets with all its one-hop neighbors, if it finds that its signal strength is higher than all its one-hop neighbors, it declares itself as a leader
- This leader-based tracking algorithm assumes a unique leader to know surrounding geographical region for collaboration

Hierarchical Power-Aware Routing

- A hierarchical power-aware routing scheme divides the network into groups of sensors
- The groups in a geographic proximity, are clustered together as a zone and each zone is treated as an entity
- Routing is performed by allowing each zone to decide how it routes a message hierarchically across other zones
- In this scheme, messages are routed along the path with the maximal fraction of the remaining power after the message is transmitted, and this is called the max-min path
- One of the concerns with the max-min path is that traversal through the SNs with high residual power may be expensive as compared to the path with the minimal power consumption
- Too much power consumption decreases the overall power level of the system, thereby decreasing the lifetime of the network

Sensor Protocols for Information via Negotiation (SPIN)

- Disseminates all the information of each SN to every other SN in the network
- All SNs in the network are potential BS
- A user is able to query any SN and get the required information immediately
- These protocols make use of the property that SNs in close proximity have similar data and thus transmit only the data that the other SNs do not have
- SPIN assigns a high-level name to appropriately describe their collected data, called meta-data, and perform meta-data negotiations before any data is transmitted
- This ensures that no redundant data is transmitted throughout the network
- The format of the meta-data is application-specific and is not specified in SPIN
- SPIN works in a time-driven manner wherein it distributes the information all over the network, even when a user does not request any data
- The SPIN family of protocols includes two protocols, namely, SPIN-1 and SPIN-2, which incorporate negotiation before transmitting data so as to ensure that only useful information is transferred

Flat versus Hierarchical

Hierarchical	Flat
Reservation-based scheduling	Contention-based scheduling
Collisions avoided	Collision overhead present
Reduced duty cycle due to periodic sleeping	Variable duty cycle by controlling sleep time of nodes
Data aggregation by cluster head	Node on multi-hop path aggregates incoming data from neighbors
Simple but non-optimal routing	Routing is complex but optimal
Requires global and local synchronization	Links formed in the fly, without synchronization
Overhead of cluster formation throughout the network	Routes formed only in regions that have data for transmission
Lower latency as multi-hop network formed by cluster heads is always available	Latency in waking up intermediate nodes and setting up the multi-hop path
Energy dissipation is uniform	Energy dissipation depends on traffic patterns
Energy dissipation cannot be controlled	Energy dissipation adapts to traffic pattern

Negotiation-based Routing

- Negotiation-based routing protocols use high level data descriptors in order to eliminate redundant data transmissions
- Communication decisions are also made based on the available resources
- The motivation here is that the use of flooding to disseminate data produces implosion and data overlap, leading to scenarios where nodes receive duplicate copies of the same data
- If the same data is transmitted by several sensors, considerable energy is consumed
- The main idea behind negotiation-based routing in WSNs is to suppress duplicate information and prevent redundant data from being sent to the next sensor or the BS
- This is done by conducting a series of negotiation messages before the actual data transmission begins

Query-based Routing

- In query-based routing, the destination nodes propagate a query for data (sensing task) from a node throughout the network
- A node having the data matching the query sends it back to the node which requested it
- Usually, these queries are described in natural language or in high-level query languages
- For example, a BS B1 may submit a query to node N1 inquiring: “Are there moving vehicles in battlefield region 1?”
- In query-based routing, all the nodes have tables consisting of the sensing tasks queries that they received, and send back data matching these tasks whenever they receive it
- Directed diffusion (discussed earlier in this chapter) is an example of this type of routing
- Here, the sink node sends out messages of interest to SNs
- As the interest is propagated throughout the WSN, the gradients from the source back to the sink (BS) are set up

Location-based Routing

In location-based routing, SNs are addressed by means of their locations

Here, the distance between neighboring SNs can be estimated on the basis of incoming signal strengths, and relative coordinates of neighboring SNs can be obtained by exchanging such information

Alternatively, the location of nodes may be available directly through GPS if we consider nodes are equipped with a small low power GPS receiver

In order to conserve energy, some location-based schemes demand that SNs should go to sleep if there is no activity

Clearly, the more sleeping SNs in the network the more energy can be saved

However, the active SNs should be connected, should cover the entire sensing region, and should provide basic routing and broadcasting functionalities

High-Level Application Layer Support

- The protocols we have presented so far are also found, albeit in some different form in traditional wired, cellular, or ad hoc networks
- For specific applications, a higher level of abstraction specifically tailored to WSN appears to be useful

Distributed Query Processing

- The number of messages generated in distributed query processing is several magnitudes less than in centralized scheme
- There are two approaches for processing sensor queries: warehousing and distributed
- In the warehousing approach, data is extracted in a pre-defined manner and stored in a central database
- In the distributed approach, only relevant data is extracted from the sensor network, when and where it is needed

High-Level Application Layer Support

Sensor Databases

- One can view the wireless sensor network as a comprehensive distributed database and interact with it via database queries
- This approach solves, en passant, the entire problem of service definition and interfaces to WSNs by mandating, for example, SQL queries as the interface
- The problems encountered here are in finding energy-efficiency ways of executing such queries and of defining proper query languages that can express the full richness of WSNs
- The TinyDB project carried out at the University of California at Berkeley is looking at these issues
- A model for sensor database systems known as COUGAR, defines appropriate user and internal representation of queries
- The sensor queries is also considered so that it is easier to aggregate the data and to combine two or more queries

High-Level Application Layer Support

Distributed Algorithms

- WSNs are not only concerned with merely *sensing* the environment but also with interacting with the environment
- Once actuators like valves are added to WSNs, the question of distributed algorithms becomes inevitable
- One showcase is the question of distributed consensus, where several actuators have to reach a joint decision(a functionality which is also required for distributed software update, for example)

In-Network Processing

- In-network processing, requires data to be modified as it flows through the network
- It has become one of the primary enabling technologies for WSNs as it has the potential to considerably increase the energy efficiency of the network

Security

Security for wireless sensor networks is still a wide open field

- Much work seems to be directly transferred from the MANET case, but the principal threats and possible attacks to the correct functioning of WSNs are still missing a thorough analysis (albeit they will most certainly be largely application-dependent)

- In any case, in the next chapter we present the existing security solutions in the context of not only ad hoc networks, but also wireless sensor networks

- However, we note that there is still much to do and this is a wide open field for research

Adapting to the Inherent Dynamic Nature of WSNs

Some important goals that current research in this area is aiming to achieve are as follows:

- Exploit spatial diversity and density of sensor/actuator nodes to build an adaptive node sleep schedule
- Spontaneously create and assemble network, dynamically adapt to device failure and degradation, manage mobility of sensor nodes and react to changes in task and sensor requirements
- Adaptability to drastic changes in the traffic
- Having finer control over the precision and coverage

- The Scalable Coordination Architectures for Deeply Distributed Systems (SCADDS) project, also a part of DARPA SensIT program, focuses on adaptive fidelity, dynamically adjusting the overall fidelity of sensing in response to task dynamics (turn on more sensors when a threat is perceived)

Conclusions and Future Directions

- WSNs are perhaps one of the fastest growing areas in the broad wireless ad hoc networking field

- The research in WSNs is flourishing at a rapid pace and is being considered as the revolutionary concept of this century

- But, there are many challenges that need to be addressed such as, how to miniaturize the power source, how to have a self-power generating technology to provide indefinite power source and how to provide secured communication without exceeding the resource requirements

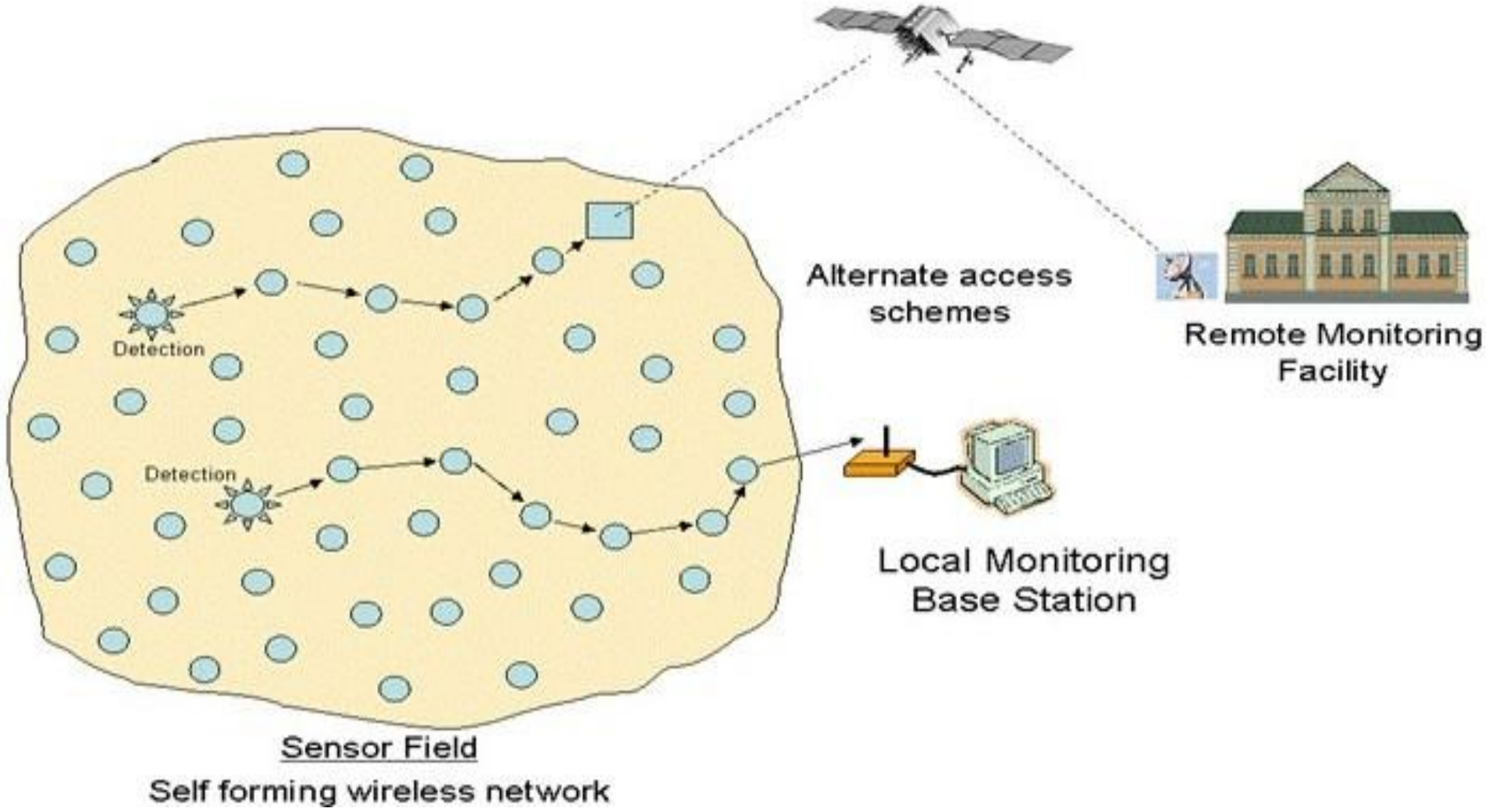
- Another area that needs serious investigation is to come up with a killer non-defense civilian application so as to enhance its usefulness and general acceptance

- The challenges are many and we have partial answers or roadmaps to some of the above questions, there is still much to be done

UNIT –IV

Security in Ad Hoc Wireless Networks

Introduction



Component and Schematic of Node

Processor.

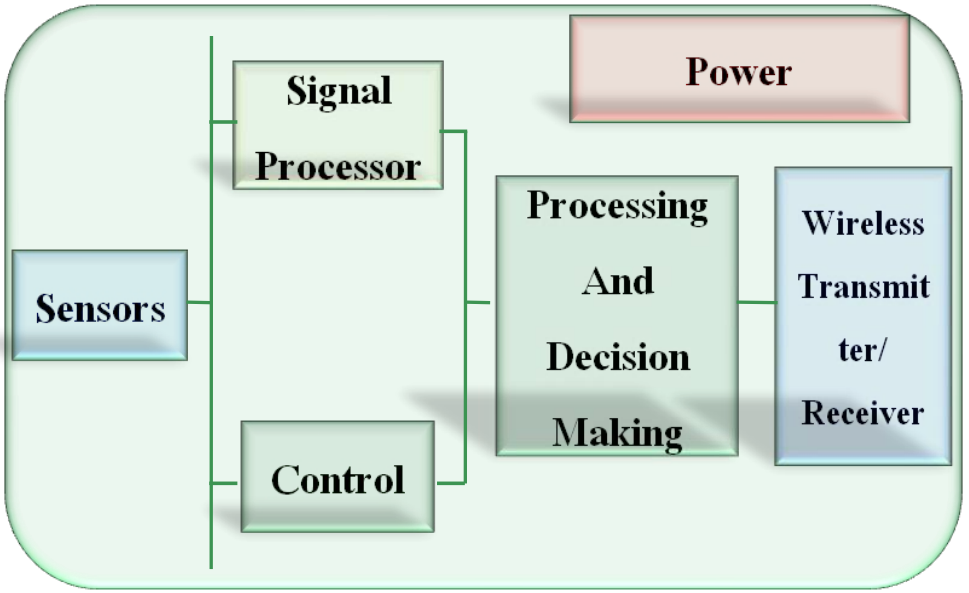
Memory.

RF Radio.

Power Source.

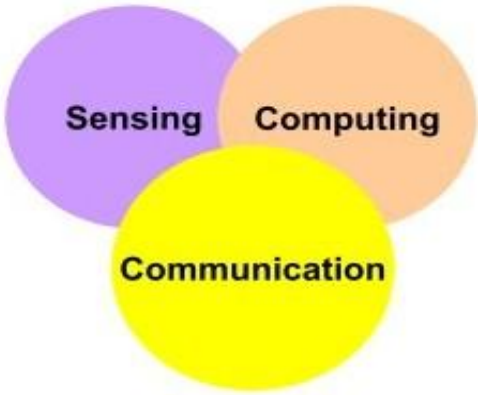
Sensor.

GPS



Introduction

Goal of Wireless Sensor Network



Collect data at regular intervals.

Then transform data into an electricalsignal.

Finally, send the signals to the sink or the base nod.

Types of Wireless Sensor Network

Temperature sensor.

Light sensor.

Sound sensor.

Vibration Sensor.

Communication pattern

Broadcast : Base station transmits message to all its immediate neighbors.

Converge cast : a group of sensors communicates to a specific sensor

Local gossip: a sensor node sends a message to its neighboring nodes within a range.

WSN Definition

A sensor network is composed of a large number of sensor nodes that are densely deployed inside or very close to the phenomenon

- random deployment
- self-organizing capabilities

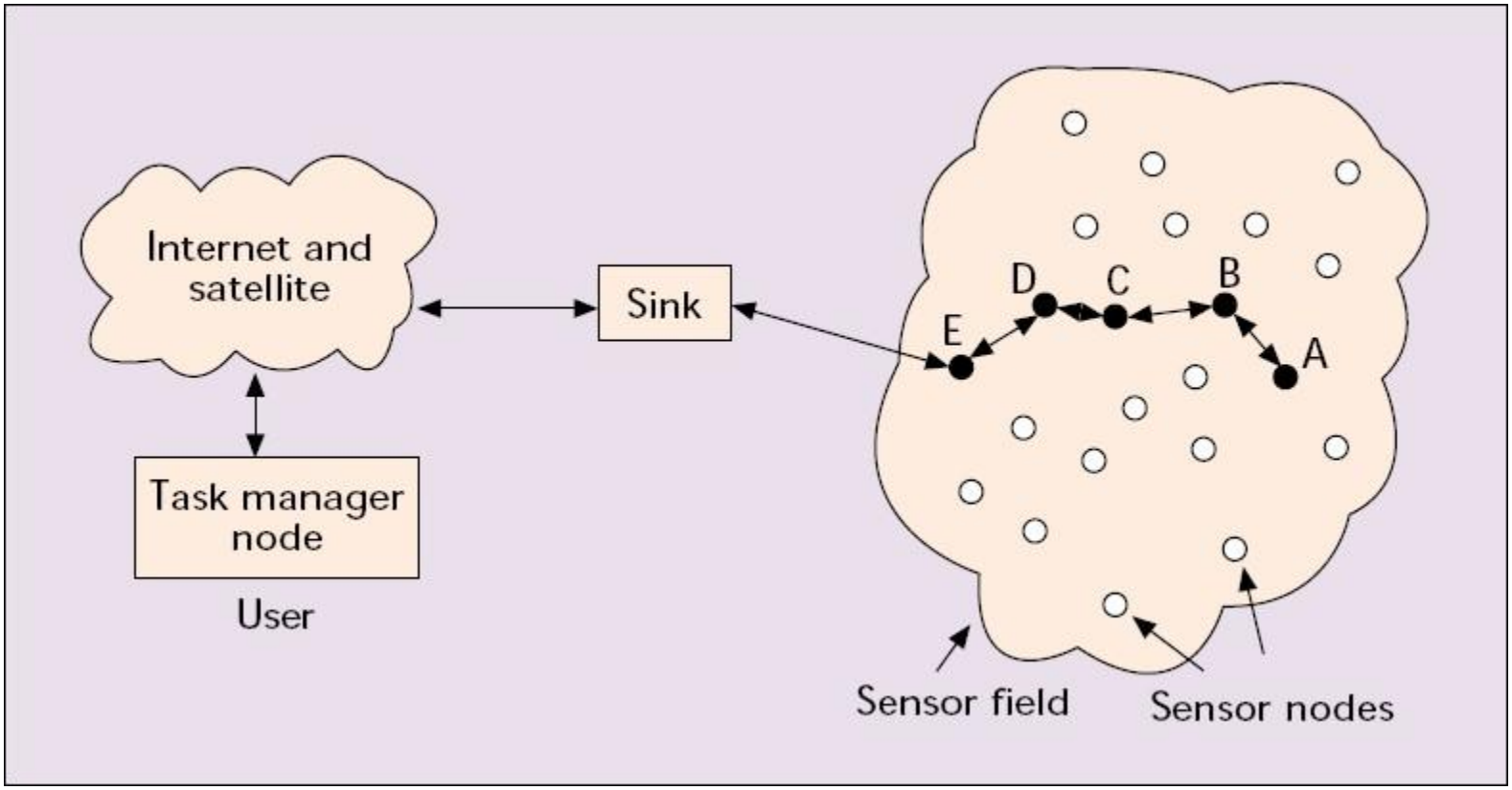
Each node of the sensor networks consist of three subsystem:

- Sensor subsystem: senses the environment
- Processing subsystem: performs local computations on the sensed data
- Communication subsystem: responsible for message exchange with neighboring sensor nodes

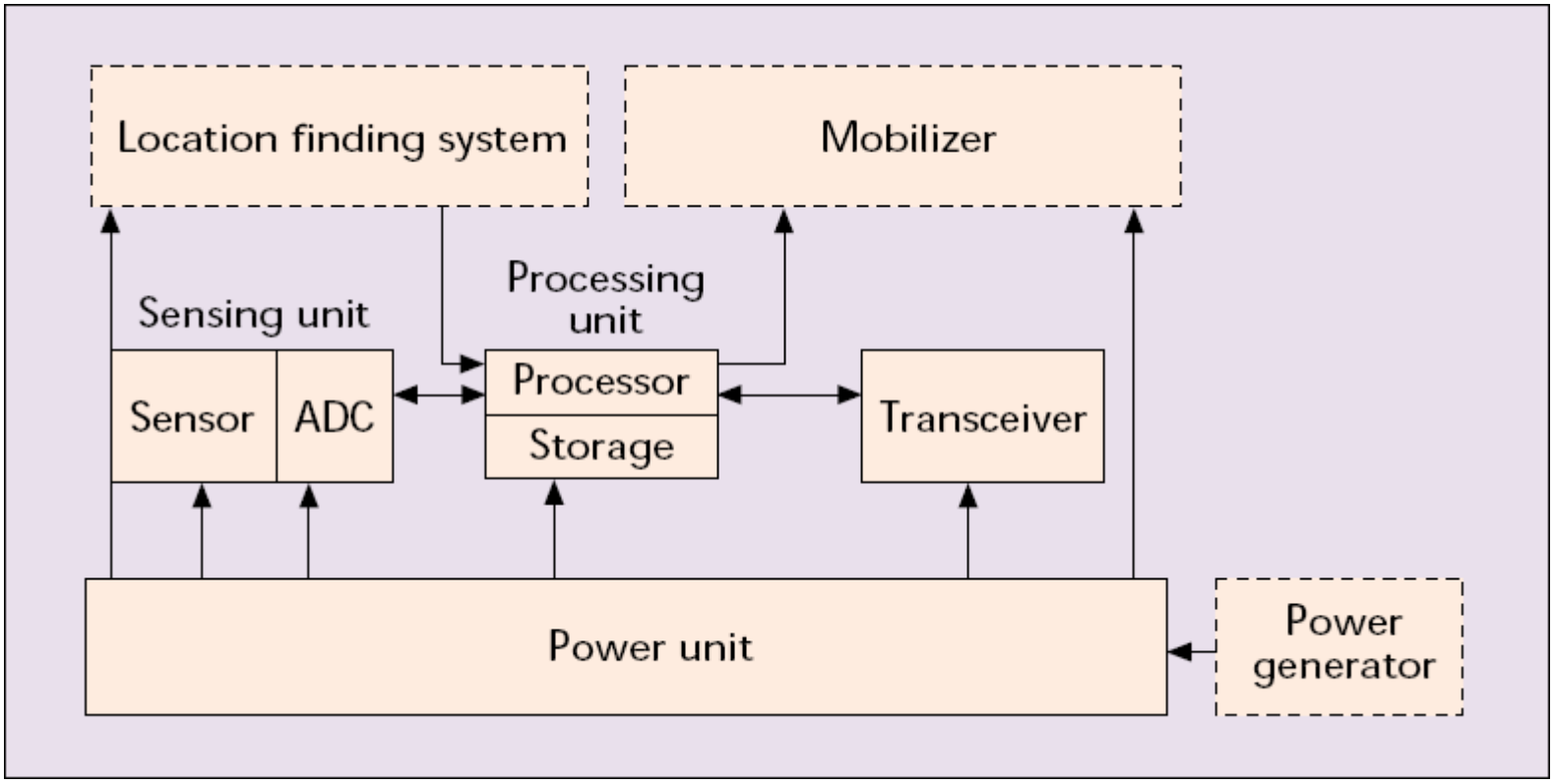
The features of sensor nodes

- Limited sensing region, processing power, energy

WSN Communication Architecture



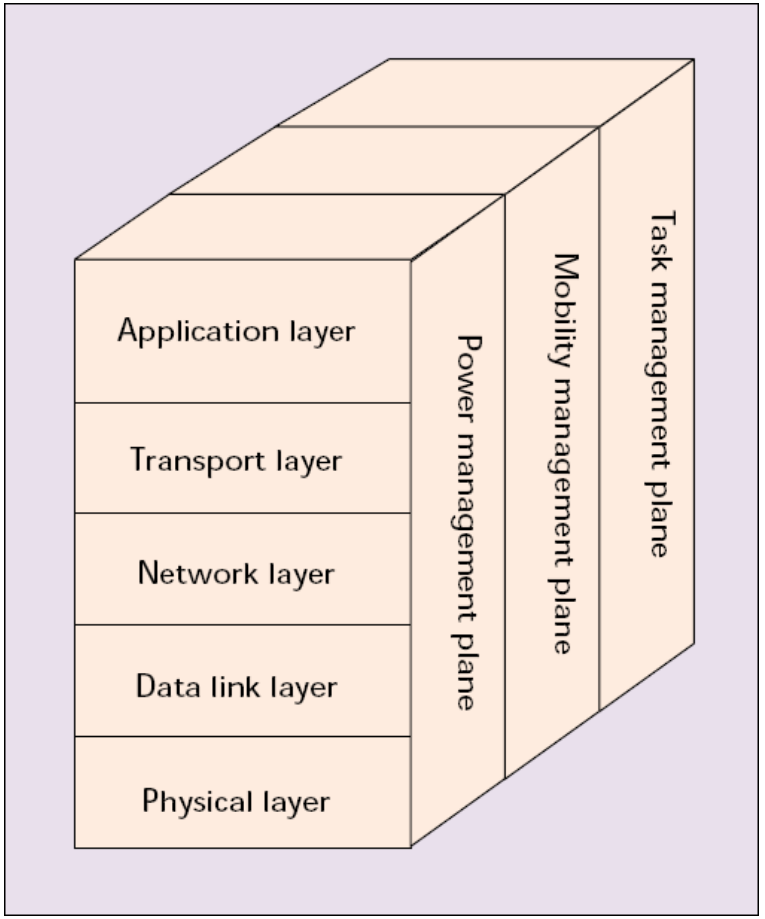
Components of Sensor Node



Protocol Stack

Protocols should be

- Power aware
- Location aware
- Application aware



WSN Characteristics

Major differences between sensor and ad-hoc network

- Number of nodes is higher
- Densely deployment
- Sensor nodes are prone to failure.
- Frequent topology changes
- Broadcast communication paradigm
- Limited processing and power capabilities.
- Possible absence of unique global ID

WSN Design Factors

Fault Tolerance

Scalability

Production Costs

Hardware Constraints

Sensor Network Topology

Environment

Transmission Media

Power Consumption

Design Factors : Fault Tolerance

Each Nodes are prone to unexpected failure (more than other network)

Fault tolerance is the ability to sustain sensor network functionalities without any interruption due to sensor node failures.

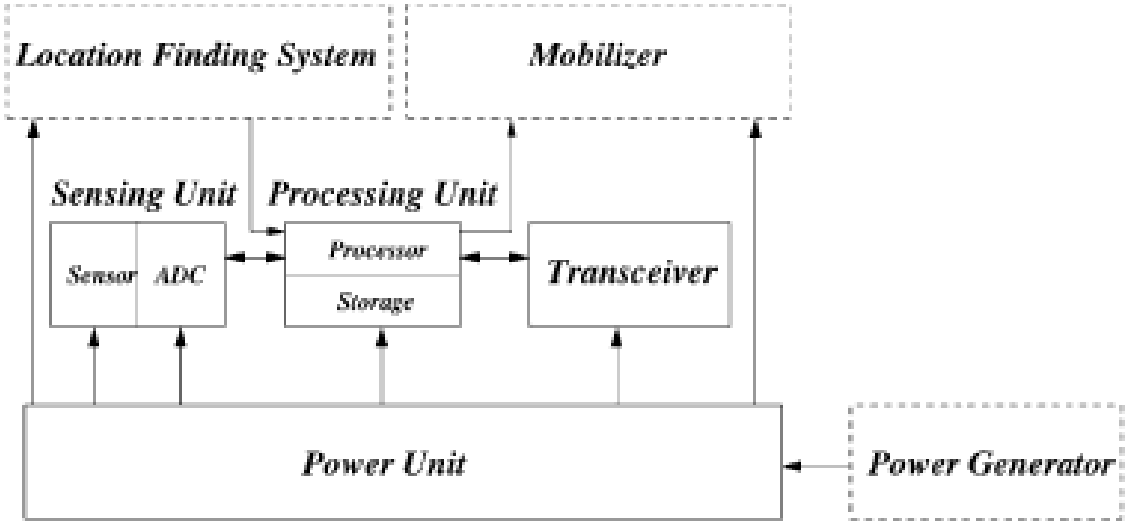
Design Factors: Production Costs

- The cost of a single node must be low given the amount of functionalities
- Much less than $1

Design Factors:Hardware Constraint

All these units combined together must

- Extremely low power
- Extremely small volume



Design Factors : Topology

Must be maintained specially in very high densities

Pre-deployment and deployment phase

Post-deployment phase

Re-deployment of additional nodes phase

Design Factors : Environment

- May be inaccessible
  - either because of hostile environment
  - or because they are embedded in a structure
- Impact of environment condition
  - Temperature
  - Humidity
  - Movement
  - Underwater
  - Underground

Design Factors: Environment

Busy intersections
Interior of a large machinery
Bottom of an ocean
Surface of an ocean during a tornado
Biologically or chemically contaminated field
Battlefield beyond the enemy lines
Home or a large building
Large warehouse
Animals
Fast moving vehicles
Drain or river moving with current

Design Factors : Transmission Media

RF

Infrared

Optical

Acoustic

Design Factors: Power Consumption

- Power conservation
  - Sensing
  - Communication
  - Data processing

Applications of WSN

Global scale

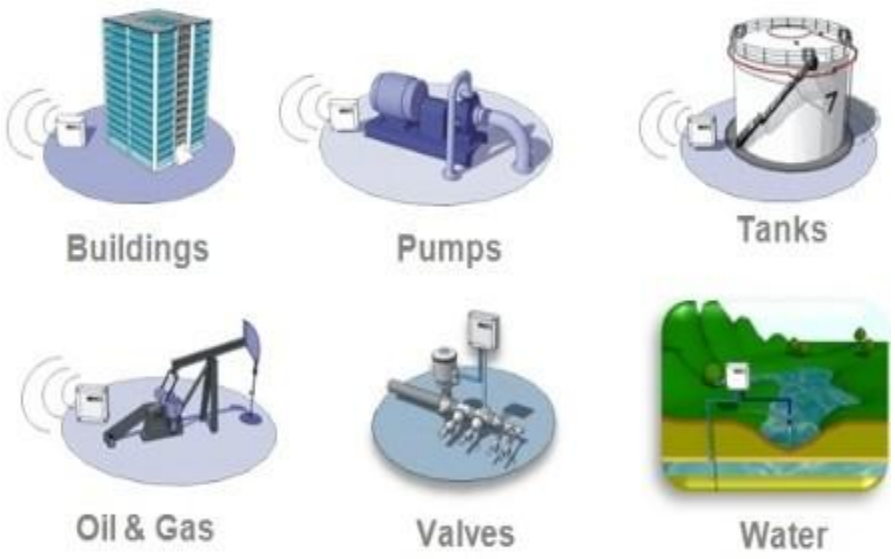
Battle field

Factories

Buildings

Homes

bodies



Applications of Sensor Networks

Using in military

Battlefield surveillance and monitoring, guidance systems of intelligent missiles, detection of attack by weapons of mass destruction such as chemical, biological, or nuclear

Using in nature

Forest fire, flood detection, habitat exploration of animals

Using in health

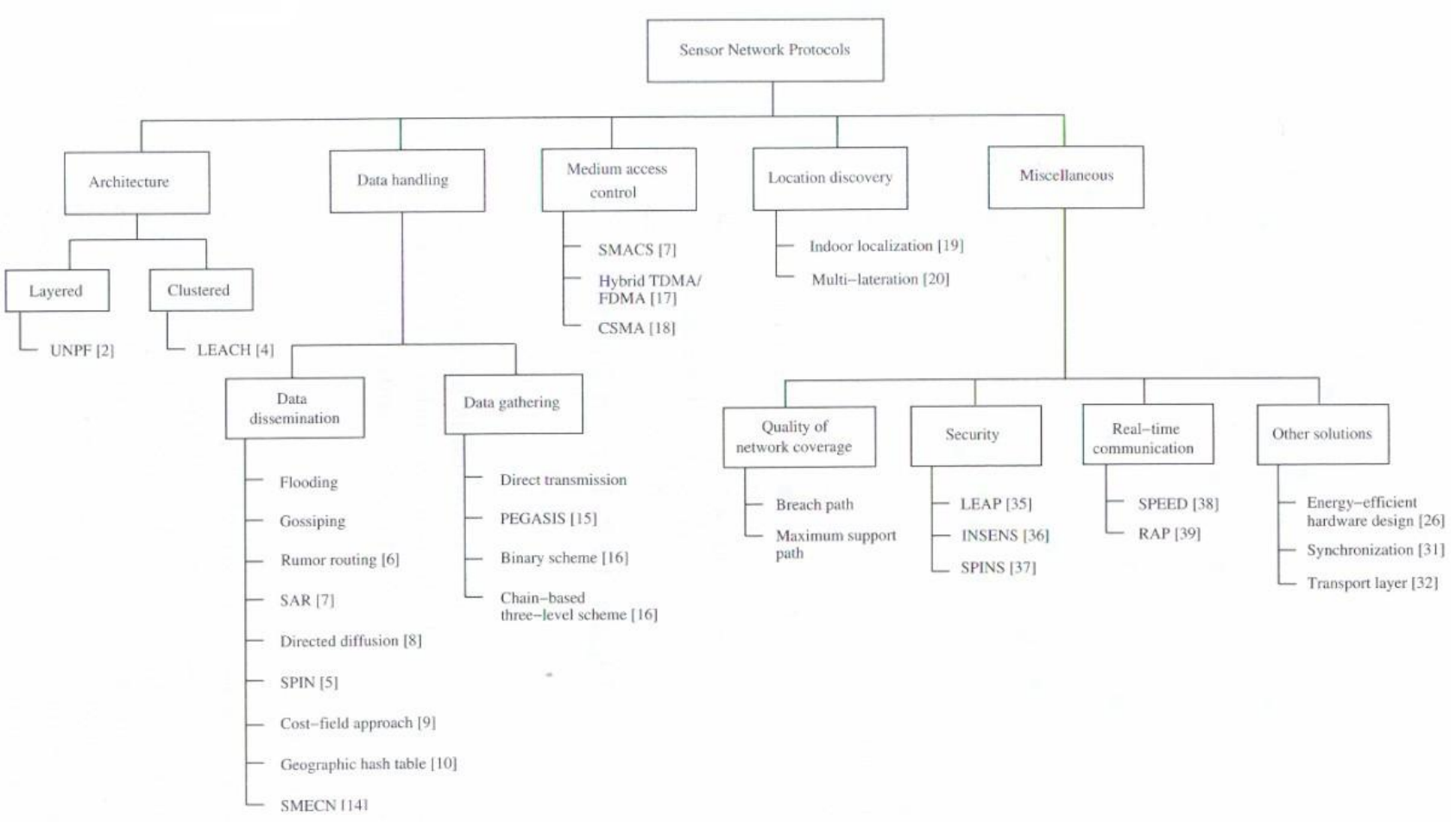
Monitor the patient's heart rate or blood pressure, and sent regularly to alert the concerned doctor, provide patients a greater freedom of movement

Comparison with Ad Hoc Wireless Networks

Different from Ad Hoc wireless networks

- The number of nodes in sensor network can be several orders of magnitude large than the number of nodes in an ad hoc network.
- Sensor nodes are more easy to failure and energy drain, and their battery sources are usually not replaceable or rechargeable.
- Sensor nodes may not have unique global identifiers (ID), so unique addressing is not always feasible in sensor networks.
- Sensor networks are data-centric, the queries in sensor networks are addressed to nodes which have data satisfying some conditions. Ad Hoc networks are address-centric, with queries addressed to particular nodes specified by their unique address.
- Data fusion/aggregation: the sensor nodes aggregate the local information before relaying. The goals are reduce bandwidth consumption, media access delay, and power consumption for communication.

Classification of sensor network protocol

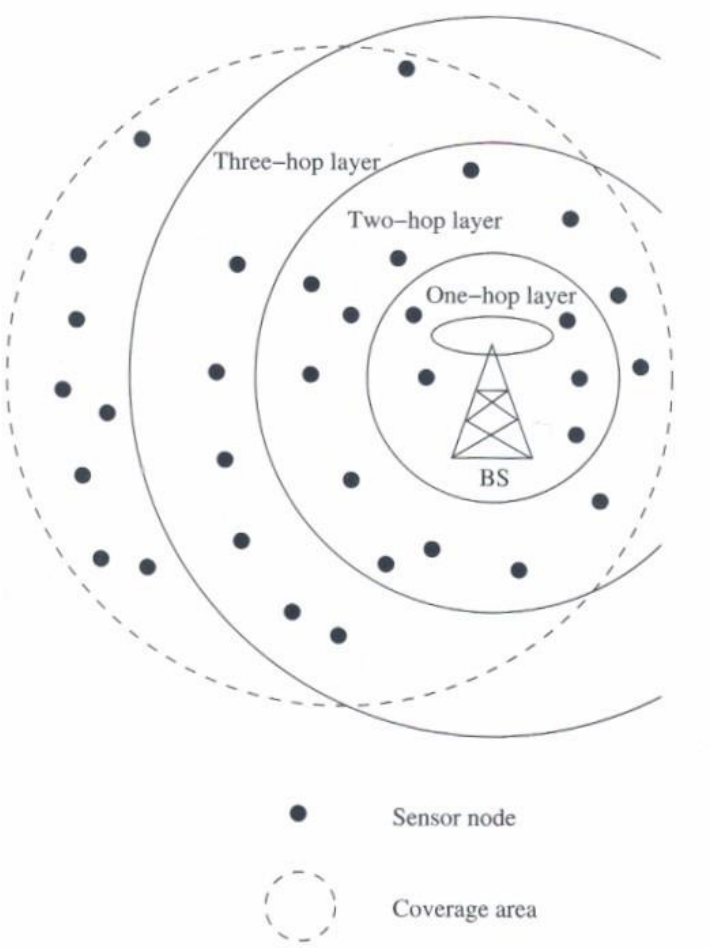


Layered Architecture

A layered architecture has a single powerful base station, and the layers of sensor nodes around it correspond to the nodes that have the same hop-count to the BS.

In the in-building scenario, the BS acts an access point to a wired network, and small nodes form a wireless backbone to provide wireless connectivity.

The advantage of a layered architecture is that each node is involved only in short-distance, low-power transmissions to nodes of the neighboring layers.



Network initialization and maintenance

The BS broadcasts its ID using a known CDMA code on the common control channel.

All node which hear this broadcast then record the BS ID. They send a beacon signal with their own IDs at their low default power levels.

Those nodes which the BS can hear form layer one

BS broadcasts a control packet with all layer one node IDs. All nodes send a beacon signal again.

The layer one nodes record the IDs which they hear (form layer two) and inform the BS of the layer two nodes IDs.

Periodic beaconing updates neighbor information and change the layer structure if nodes die out or move out of range.

Routing protocol

Downlink from the BS is by direct broadcast on the control channel. Uplink from the sensor nodes to BS is by multi-hop data forwarding.

The node to which a packet is to be forwarded is selected considering the remaining energy of the nodes. This achieves a higher network lifetime.

UNPF-R

Optimize the network performance by make the sensor nodes adaptively vary their transmission range.

Because while a very small transmission range cause network partitioning, a very large transmission range reduce the spatial reuse of frequencies.

The optimal range (R) is determined by simulated annealing

$$f(R) = \frac{\epsilon \times d}{n/N}$$

Objective function :

N : the total number of sensors

n : the number of nodes in layer on

UNPF-R

If no packet is received by the BS from any sensor node for some interval of time, the transmission range increase by Δr. Otherwise, the transmission range is either decrease by Δr with probability 0.5 x (n / N), or increase by Δr with probability [1 – 0.5 x (n / N)].

If $f(R') < f(R)$, then the transmission range R' is adopt. Otherwise, R is modified to R' with probability

$$e^{\frac{(f(R)-f(R'))\times(n/N)}{T}}$$

T : the temperature parameter

The advantage of the UNPF-R:

Minimize the energy x delay

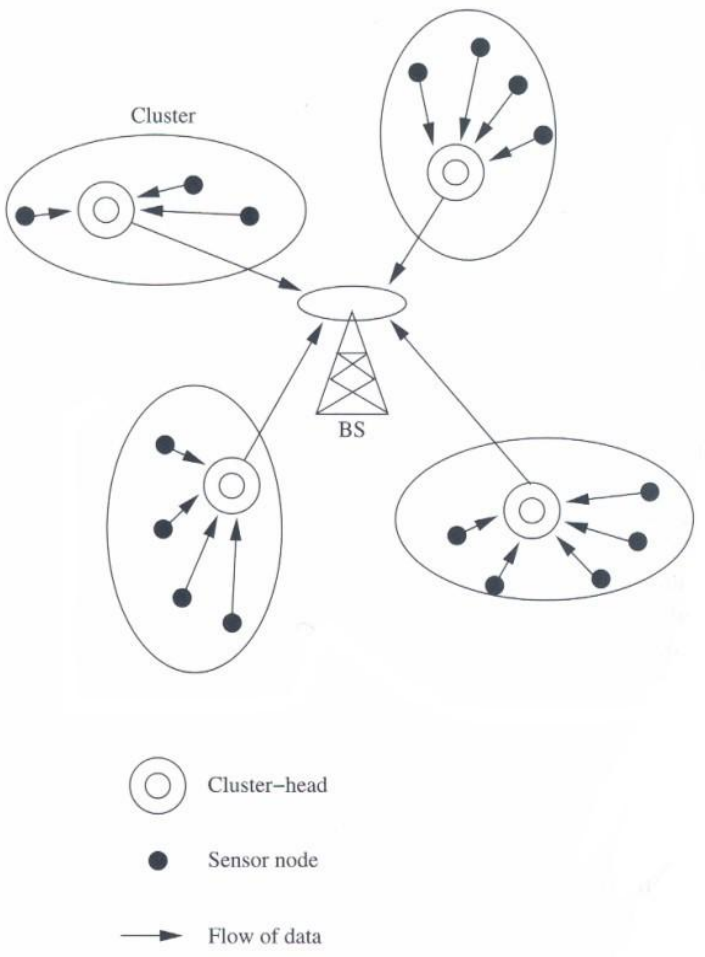
Maximize the number of nodes which can connect to the BS

Clustered Architecture

clustered architecture organizes the sensor nodes into clusters, each governed by a cluster-head. The nodes in each cluster are involved in message exchanges with their cluster-heads, and these heads send message to a BS.

Clustered architecture is useful for sensor networks because of its inherent suitability for data fusion. The data gathered by all member of the cluster can be fused at the cluster-head, and only the resulting information needs to be communicated to the BS.

The cluster formation and election of cluster-heads must be an autonomous, distributed process.



Low-Energy Adaptive Clustering Hierarchy (LEACH)

LEACH is a clustering-based protocol that minimizes energy dissipation in sensor networks. The operation of LEACH is spilt into two phases : setup and steady.Setup phase : each sensor node chooses a random number between 0 and 1. If this is lower than the threshold for node n, T(n), the sensor node becomes a cluster-head. The threshold T(n) is calculated as

$$T(n) = \begin{cases} \frac{P}{1-P[r \times mod(1/P)]} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases}$$

P : the percentage of nodes which are cluster-heads

r : the current round

G : the set of nodes that has not been cluster-heads in the past 1/P rounds

Low-Energy Adaptive Clustering Hierarchy (LEACH)

After selection, the cluster-heads advertise their selection to all nodes. All nodes choose their nearest cluster-head by signal strength (RSSI). The cluster-heads then assign a TDMA schedule for their cluster members

Steady phase : data transmission takes place based on the TDMA schedule, and the cluster-heads perform data aggregation/fusion.

After a certain period of time in the steady phase, cluster-heads are selected again through the setup phase.

Data Dissemination

Data dissemination is the process by which queries or data are routed in the sensor network. The data collected by sensor nodes has to be communicated to the node which interested in the data.

The node that generates data is call source and the information to be reported is called an event. A node which interested in an event is called sink.

Data dissemination consist of a two-step process : interest propagation and data propagation.

Interest propagation : for every event that a sink is interested in, it broadcasts its interest to is neighbor, and across the network.

Data dissemination : When an event is detected, it reported to the interested nodes (sink).

Flooding

Each node which receives a packet (queries/data) broadcasts it if the maximum hop-count of the packet is not reached and the node itself is not the destination of the packet.

Disadvantages :

Implosion : this is the situation when duplicate messages are send to the same node. This occurs when a node receives copies of the same messages from many of its neighbors.

Overlap : the same event may be sensed by more than one node due to overlapping regions of coverage. This results in their neighbors receiving duplicate reports of the same event.

Resource blindness : the flooding protocol does not consider the available energy at the nodes and results in many redundant transmissions. Hence, it reduces the network lifetime.

Gossiping

Modified version of flooding

The nodes do not broadcast a packet, but send it to a randomly selected neighbor.

Avoid the problem of implosion

It takes a long time for message to propagate throughout the network.

It does not guarantee that all nodes of network will receive the message.

Rumor Routing

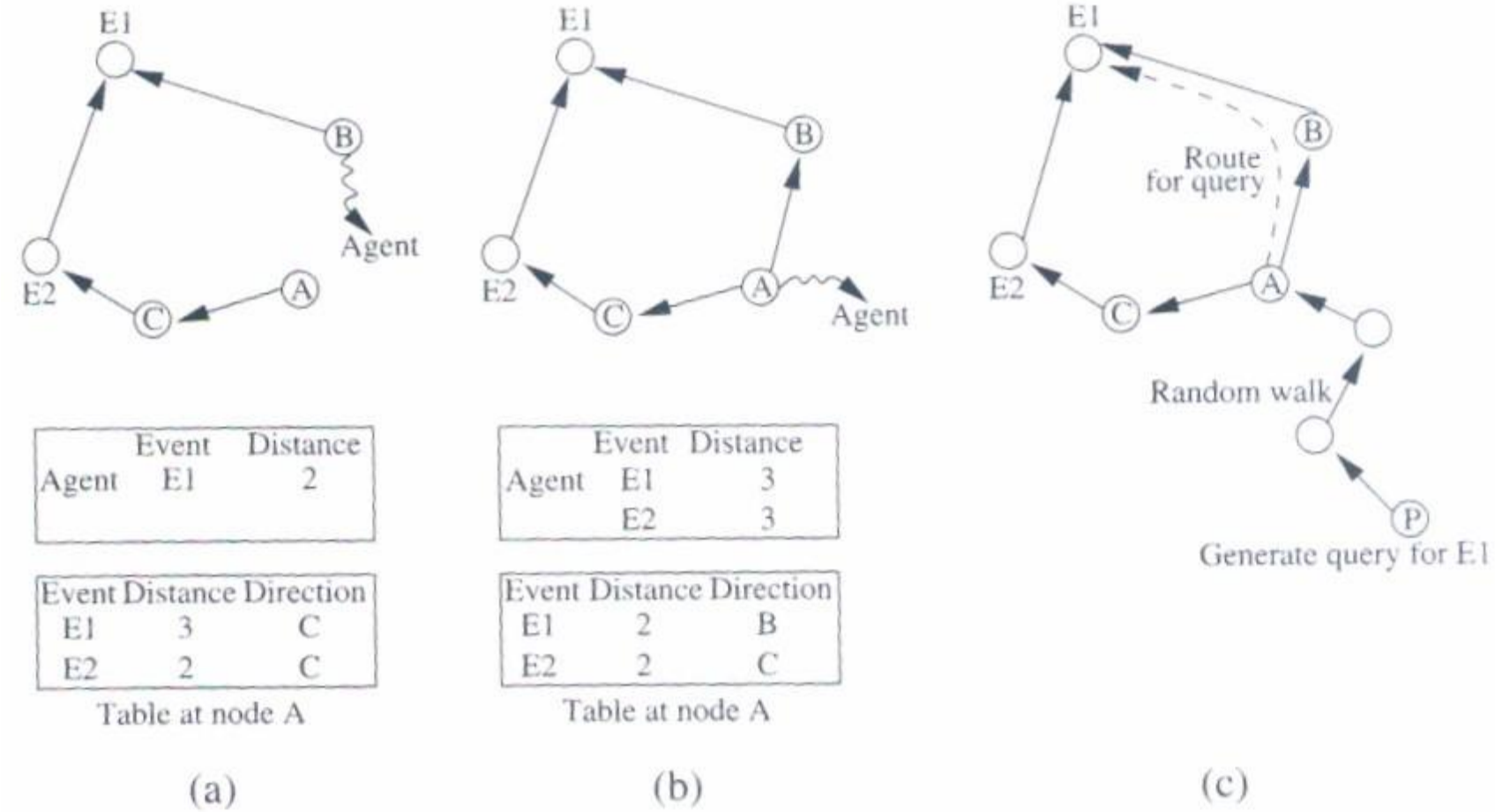
Agent-based path creation algorithm

Agent is a long-lived packet created at random by nodes, and it will die after visit k hops.

It circulated in the network to establish shortest paths to events that they encounter.

When an agent finds a node whose path to an event is longer than its own, it updates the node's routing table.

Rumor routing



After selection, the cluster-heads advertise their selection to all nodes. All nodes choose their nearest cluster-head by signal strength (RSSI). The cluster-heads then assign a TDMA schedule for their cluster members

Sequential Assignment Routing (SAR)

The sequential assignment routing (SAR) algorithm creates multiple trees, where the root of each tree is a one-hop neighbor of the sink.

To avoid nodes with low throughput or high delay.

Each sensor node records two parameters about each path though it : available energy resources on the path and an additive QoS metric such as delay

SAR minimizes the average weighted QoS metric over the lifetime of the network.

Directed Diffusion

The directed diffusion protocol is useful in scenarios where the sensor nodes themselves generate requests/queries for data sensed by other nodes.

Each sensor node names its data with one or more attributes.

Each sensor node express their interest depending on these attributes.

Each path is associated with a interest gradient, while positive gradient make the data flow along the path, negative gradient inhibit the distribution data along a particular path.

Example : two path formed with gradient 0.4 and 0.8, the source may twice as much data along the higher one

Suppose the sink wants more frequent update from the sensor which have detected an event => send a higher data-rate requirement for increasing the gradient of that path.

Directed Diffusion

Query

```
Type = vehicle              /* detect vehicle location
    interval = 1 s          /* report every 1 second
    rect = [0,0,600,800]    /* query addressed to sensors within the rectangle
    timestamp = 02:30:00 /* when the interest was originated
    expiresAt = 03:00:00    /* till when the sink retain interest in this data
```

Report

```
Type = vehicle              /* type of intrusion seen
    instance = car          /* particular instance of the type
    location = [200,250]    /* location of node
    confidence = 0.80       /* confidence of match
    timestamp = 02:45:20 /* time of detection
```

Sensor Protocols for Information via Negotiation

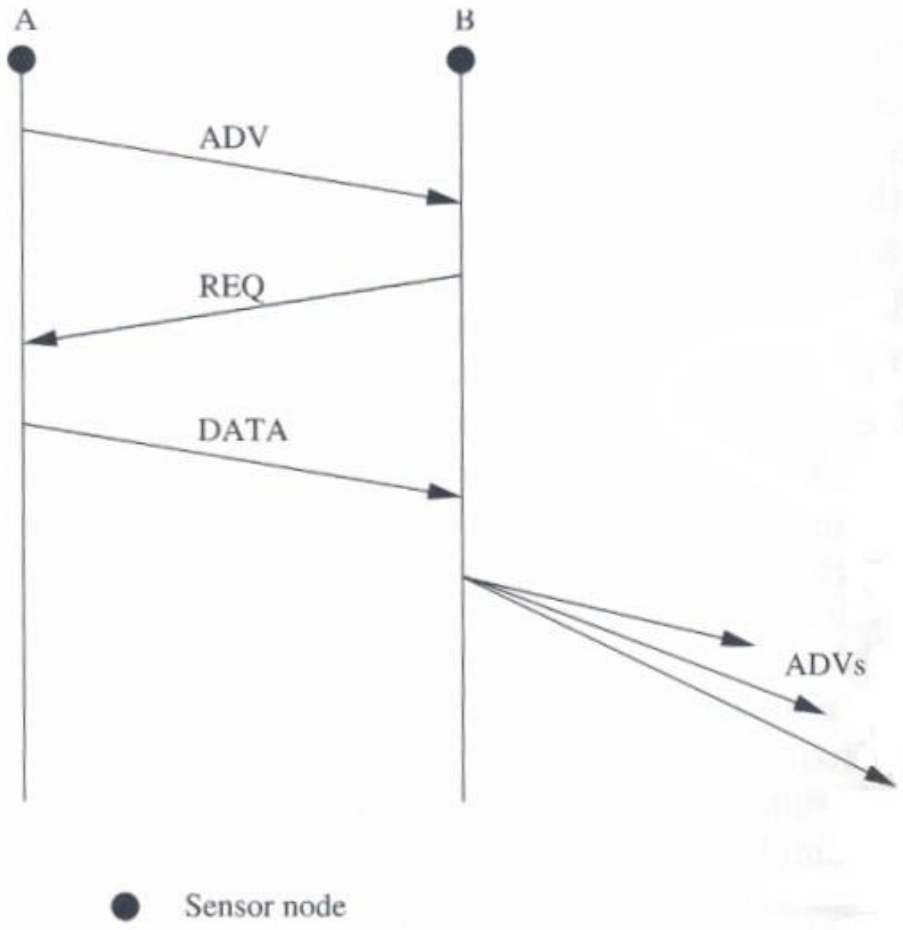
SPIN use negotiation and resource adaptation to address the disadvantage of flooding.

Reduce overlap and implosion, and prolong network lifetime.

Use meta-data instead of raw data.

SPIN has three types of messages:ADV, REQ, and DATA.

SPIN-2 using an energy threshold to reduce participation. A node may join in the ADV-REQ-DATA handshake only if it has sufficient resource above a threshold.



Cost-Field Approach

The cost-field approach considers the problem of setting up paths to a sink. The first phase being to set up the cost field, based on metrics such as delay. The second phase being data dissemination using the costs.

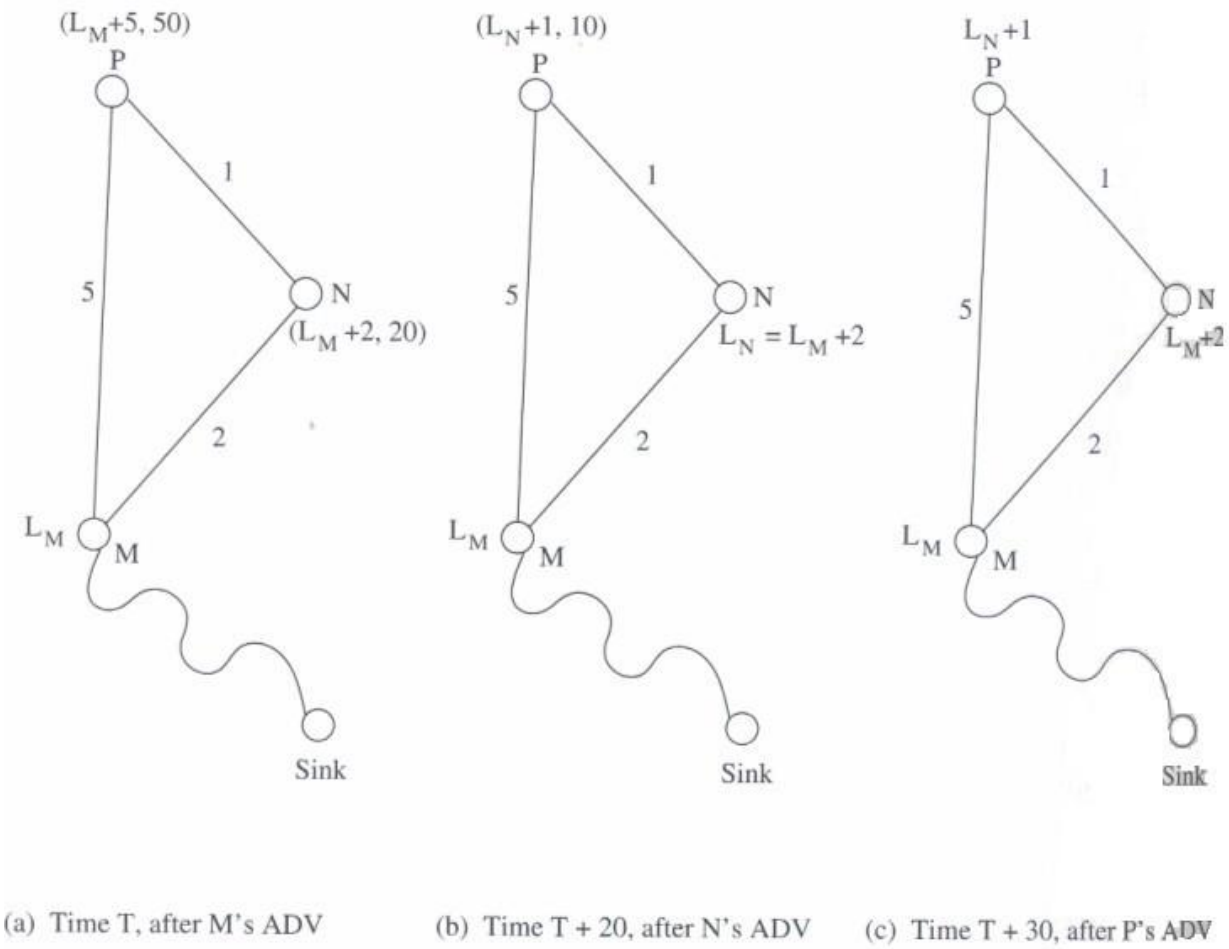
A sink broadcasts an ADV packet with its own cost as 0.

When a node N hears an ADV message from node M, it sets its own path cost to min (L_N,L_M+C_{NM}), where $L_N$is the total path cost from node N to the sink, $L_M$is the cost of node M to the sink, $C_{NM}$is the cost from N to M.

If $L_N$updated, the new cost is broadcast though anotherADV.

The back-off time make a node defer its ADV instead of immediately broadcast it. The back-off time is r x C_{MN}, where r is a parameter of algorithm.

Cost-Field Approach



(a) Time T, after M's ADV (b) Time T + 20, after N's ADV (c) Time T + 30, after P's ADV

Geographic Hash Table (GHT)

GHT hashes keys into geographic coordinates and stores a (key, value) pair at the sensor node nearest to the hash value.

Stored data is replicated to ensure redundancy in case of node failures.

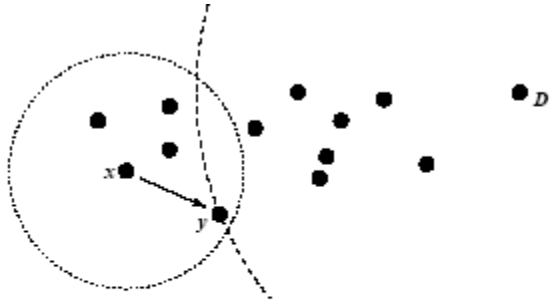


Figure 1: Greedy Forwarding Example: x forwards to y, its neighbor closest to D.

- The data is distributed among nodes such that it is scalable and the storage load is balanced.
- The routing protocol used is greedy perimeter stateless routing (GPSR), which again uses geographic information to route the data and queries.

Small Minimum Energy Communication Network

If the entire sensor network is represented by G, the subgraph G' is constructed such that the energy usage of the network is minimized.

The number of edges in G'is less than G, and the connectivity between any two nodes is not disrupted by G'.

The power required to transmit data between u and v is modeled as

$$p(u, v) = t \times d(u, v)^n$$

t : constant

n : loss exponent indicating the loss of power with distance from transmitter

d(u,v) : the distance between u and v

It would be more economical to transmit data by smaller hops

Small Minimum Energy Communication Network

Suppose the path between u (i.e. u_0) and v (i.e. u_k) is represented by $r = (u_0, u_1, \ldots u_k)$, each (u_i, u_{i+1}) is edge in G'

The total power consumed for the transmission is

$$C(r) = \sum_{i=0}^{k-1} (p(u_i, u_{i+1}) + c)$$

C : the power needed to receive the data

The path r is the minimum energy path if $C(r) \leq C(r')$ for all path's r' between u and v in G.

SMECN uses only the ME paths from G' for data transmission, so that the overall energy consumed is minimized.

Data Gathering

The objective of the data gathering problem is to transmit the sensed data from each sensor node to a BS.

The goal of algorithm which implement data gathering is

- maximize the lifetime of network
- Minimum energy should be consumed
- The transmission occur with minimum delay

The energy x delay metric is used to compare algorithm

Direct Transmission

All sensor nodes transmit their data directly to the BS.

It cost expensive when the sensor nodes are very far from the BS.

Nodes must take turns while transmitting to the BS to avoid collision, so the media access delay is also large. Hence, this scheme performs poorly with respect to the energy x delay metric.

Power-Efficient Gathering for Sensor Information Systems

PEGASIS based on the assumption that all sensor nodes know the location of every other node.

Any node has the required transmission range to reach the BS in one hop, when it is selected as a leader.

The goal of PEGASIS are as following

Minimize the distance over which each node transmit

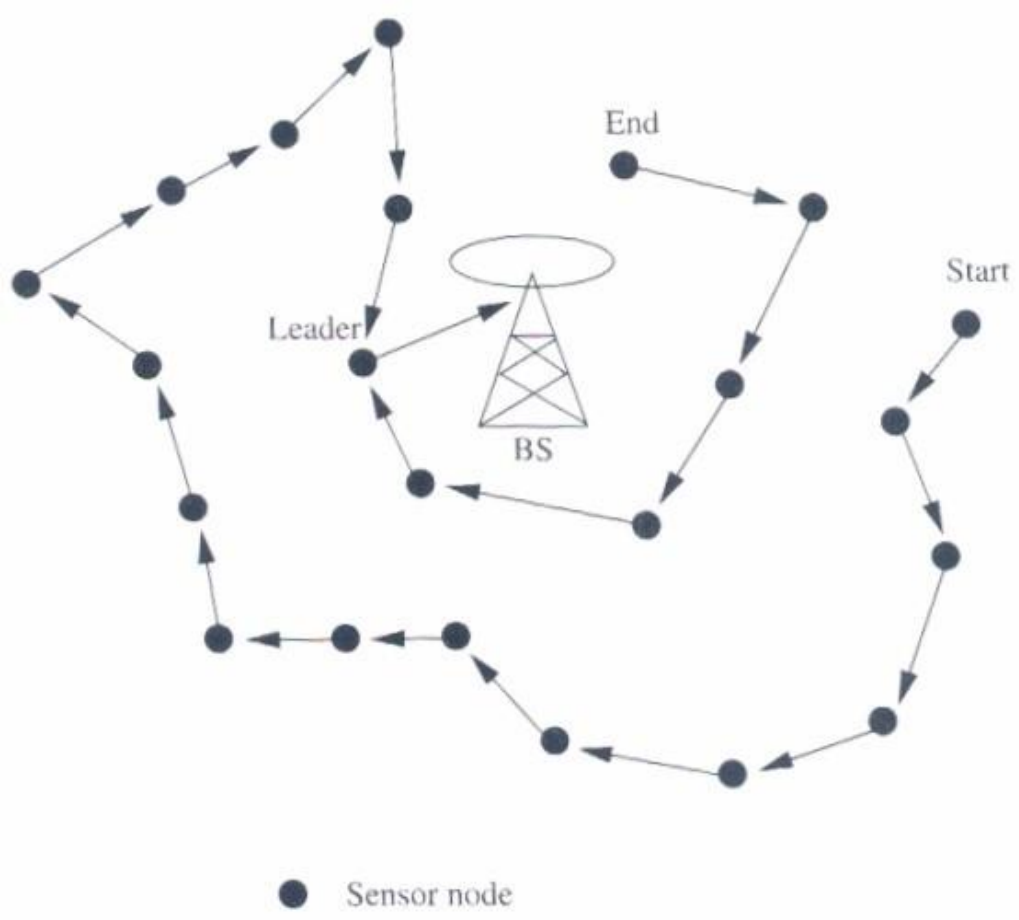
Minimize the broadcasting overhead

Minimize the number of messages that need to be sent to the BSθ Distribute the energy consumption equally across all nodes

To construct a chain of sensor nodes, starting from the node farthest from the BS. At each step, the nearest neighbor which has not been visited is added to the chain.

It is reconstructed when nodes die out.

PEGASIS



At every node, data fusion or aggregation is carried out.

A node which is designated as the leader finally transmits one message to the BS.

Leadership is transferred in sequential order.

The delay involved in messages reaching the BS is O(N)

Binary Scheme

This is a chain-based scheme like PEGASIS, which classifies nodes into different levels.

This scheme is possible when nodes communicate using CDMA, so that transmissions of each level can take place simultaneously.

The delay is O(logN)

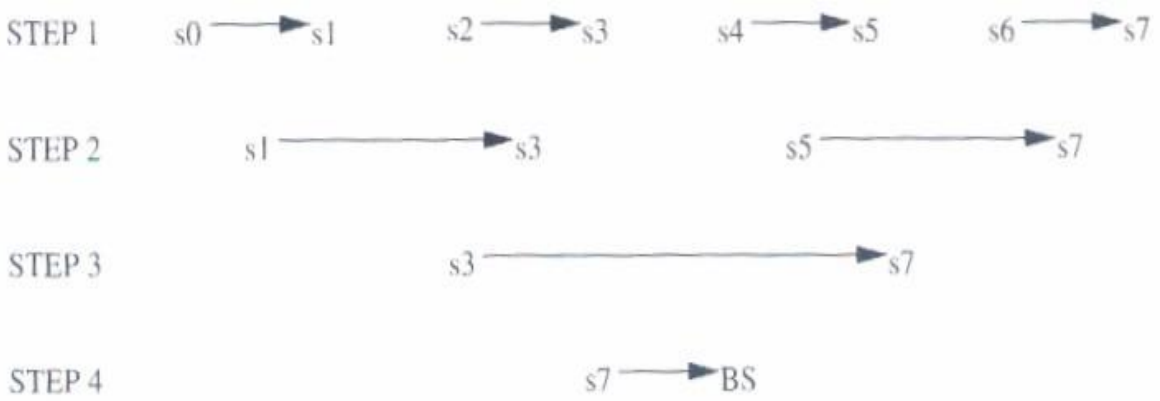


Figure 12.9. Binary scheme.

Chain-Based Three-Level Scheme

For non-CDMA sensor nodes

The chain is divided into a number of groups to space out simultaneous transmissions in order to minimize interference.

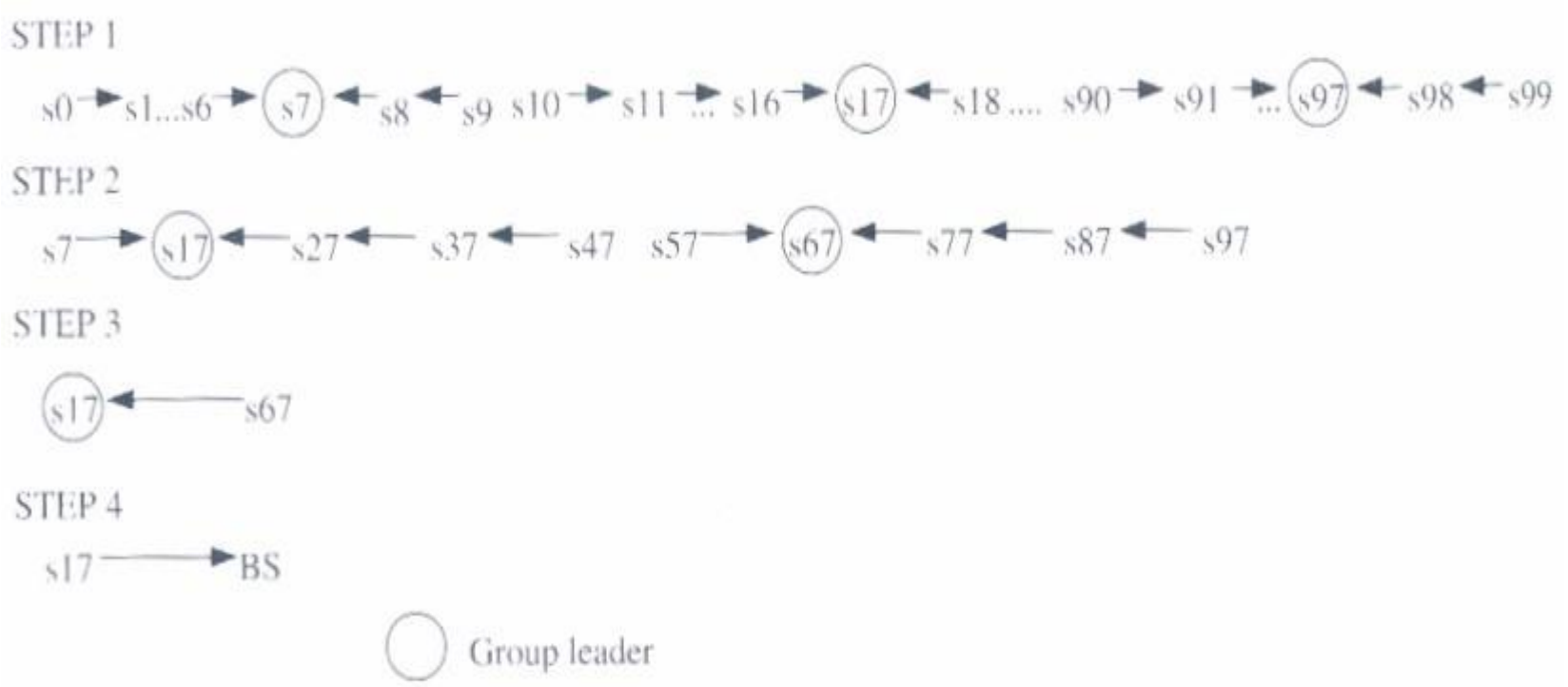
Within a group, nodes transmit data to the group leader, and the leader fusion the data, and become the member to the next level.

In the second level, all nodes are divided into two groups.

In the third level, consists of a message exchange between one node from each group of the second level.

Finally, the leader transmit a single message to the BS.

Chain-Based Three-Level Scheme



MAC Protocols for Sensor Networks

The challenges posed by sensor network MAC protocol

- No single controlling authority, so global synchronization is difficult
- Power efficiency issue
- Frequent topology changes due to mobility and failure

There are three kinds of MAC protocols used in sensor network:

- Fixed-allocation

MAC Protocols for Sensor Networks

Fixed-allocation MAC protocol

- Share the common medium through a predetermined assignment.
- It is suitable for sensor network that continuously monitor and generate deterministic data traffic
- Provide a bounded delay for each node
- However, in the case of bursty traffic, where the channel requirements of each node may vary over time, it may lead to inefficient usage of the channel.

MAC Protocols for Sensor Networks

Demand-based MAC protocol

Used in such cases, where the channel is allocated according to the demand of the node

Variable rate traffic can be efficiently transmitted

Require the additional overhead of a reservation process

Contention-based MAC protocol

Random-access-based contention for the channel when packets need to be transmitted

Suitable for bursty traffic

Collisions and no delay guarantees, are not suitable for delay-sensitive or real-time traffic

Self-Organizing MAC for Sensor Networks and Eavesdrop and Register

Self-Organizing MAC for sensor (SMACS) networks and eavesdrop and register (EAR) are two protocols which handle network initialization and mobility support, respectively.

In SMACS

- neighbor discovery and channel assignment take place simultaneously in a completely distributed manner.
- A communication link between two nodes consists of a pair of time slots, at fixed frequency.
- This scheme requires synchronization only between communicating neighbors, in order to define the slots to be used for their communication.
- Power is conserved by turning off the transceiver during idle slots.

Hybrid TDMA/FDMA

TDMA scheme minimize the time for which a node has to be kept on, but the associated time synchronization cost are very high.

A pure FDMA scheme allots the minimum required bandwidth for each connection

If the transmitter consumes more power, a TDMA scheme is favored, since it can be switch off in idle slots to save power.

If the receiver consumes greater power, a FDMA scheme is favored, because the receiver need not expend power for time synchronization.

CSMA-Base MAC Protocols

CSMA-based schemes are suitable for point-to-point randomly distributed traffic flows.

The sensing periods of CSMA are constant for energy efficiency, while the back-off is random to avoid repeated collisions.

Binary exponential back-off is used to maintain fairness in the network.

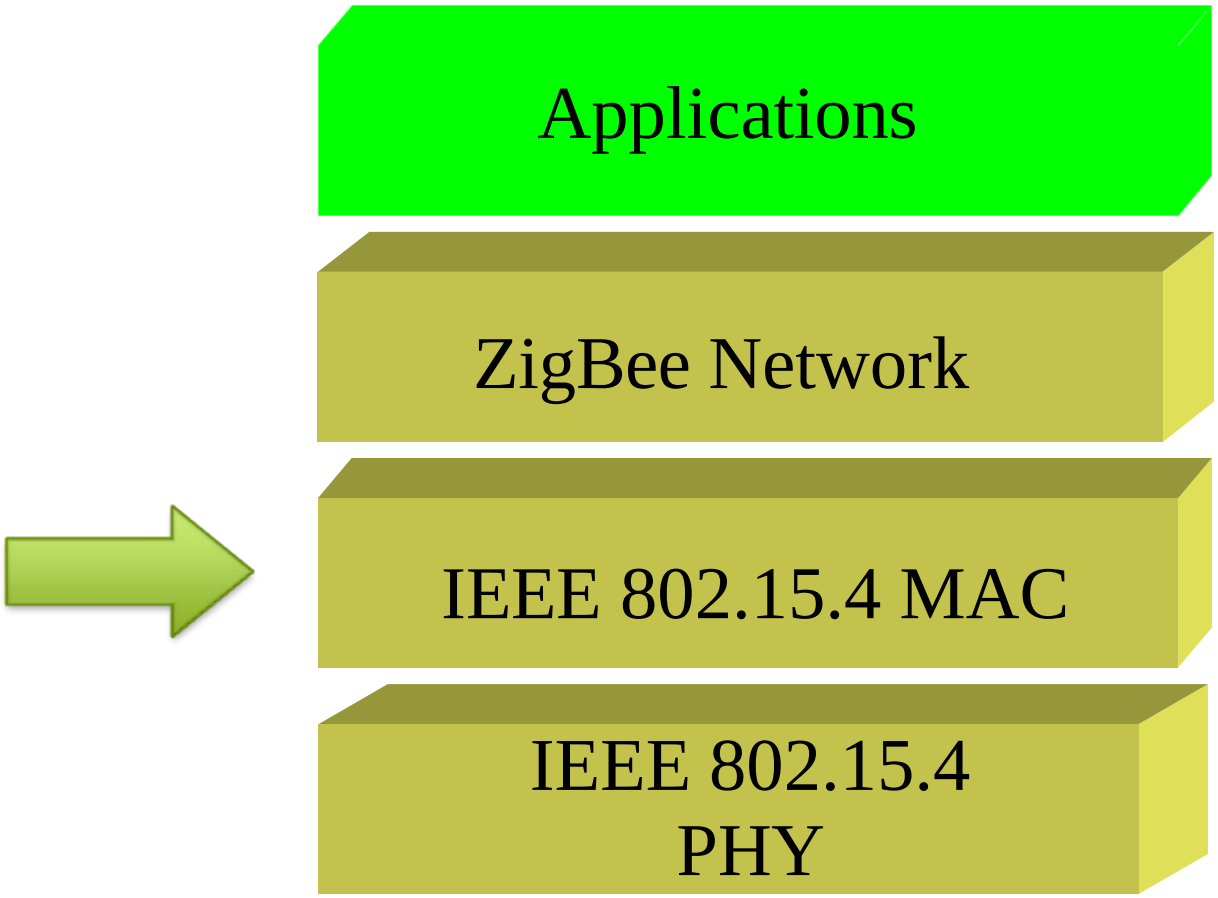
Use an adaptive transmission rate control (ARC) to balance originating traffic and route-through traffic in nodes. This ensures that nodes closer to the BS are not favored over farther nodes.

CSMA-based MAC protocol are contention-based and are designed mainly to increase energy efficiency and maintain fairness.

IEEE 802.15.4 MAC

Architecture

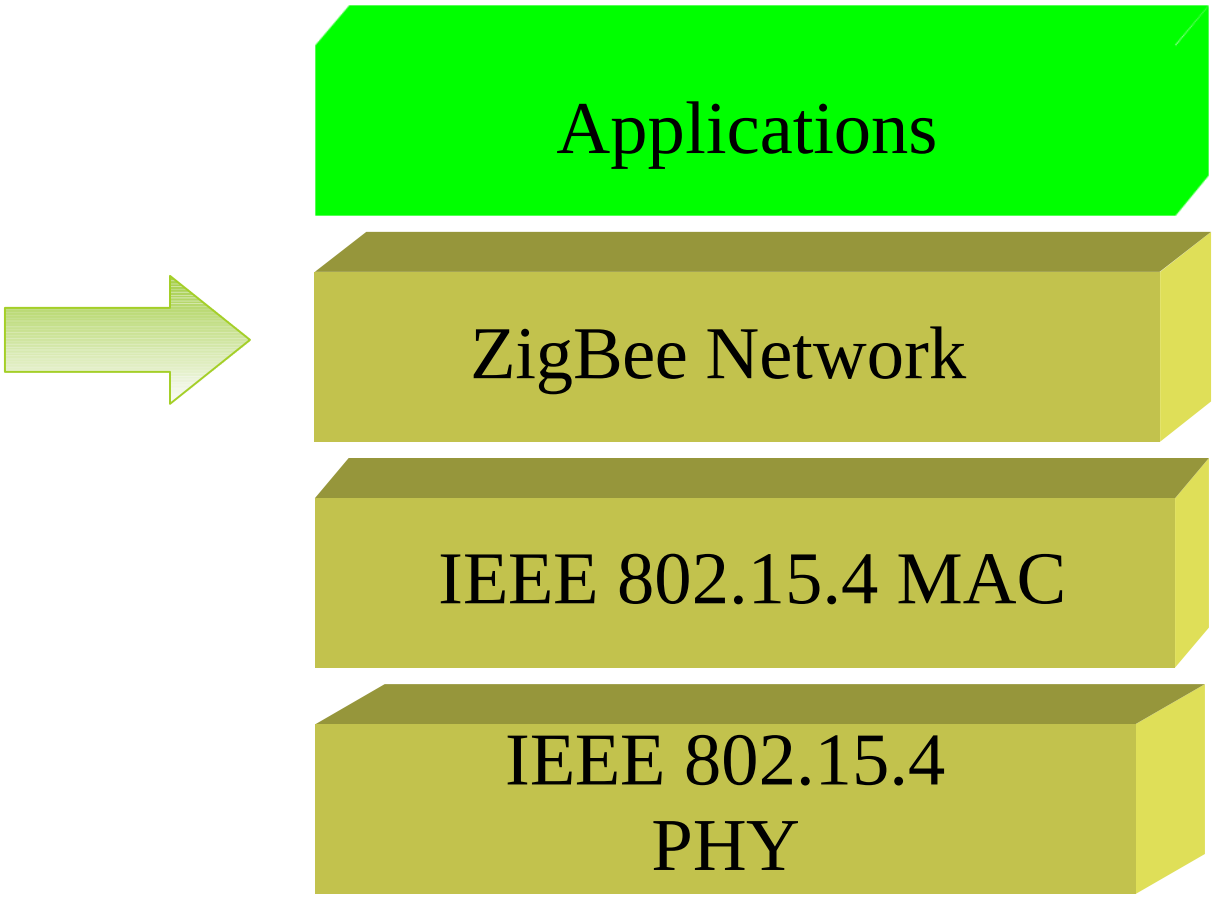
Channel acquisition
Contention Window



IEEE 802.15.4 MAC

Architecture

- Device join and leave
- Frame routing



General characteristics

Property	Range
Raw data rate	868 MHz: 20 kb/s; 915 MHz: 40 kb/s; 2.4 GHz: 250 kb/s
Range	10–20 m
Latency	Down to 15 ms
Channels	868/915 MHz: 11 channels 2.4 GHz: 16 channels
Frequency band	Two PHYs: 868 MHz/915 MHz and 2.4 GHz
Addressing	Short 8-bit or 64-bit IEEE
Channel access	CSMA-CA and slotted CSMA-CA

Approaches for low power

In order to achieve the low power and low cost goals established by IEEE 802.15.4 the following approaches are taken

Reduce the amount of data transmitted

Reduce the transceiver duty cycle and frequency of data transmissions

Reduce the frame overhead

Reduce complexity

Reduce range

Implement strict power management mechanisms (power-down and sleep modes)

Network layer

The services which network layer provides are more challenging to implement because of low power consumption requirement.

Network layer over this standard are expected to be self configuring and self maintaining to minimize total cost of user.

IEEE 802.15.4 draft standard supports multiple network topologies including star and peer to peer topology.

topology selection is application dependent. PC peripherals may require low latency connection of star topology while perimeter security which needs large coverage area may require peer to peer networking.

Star and Peer to Peer topologies

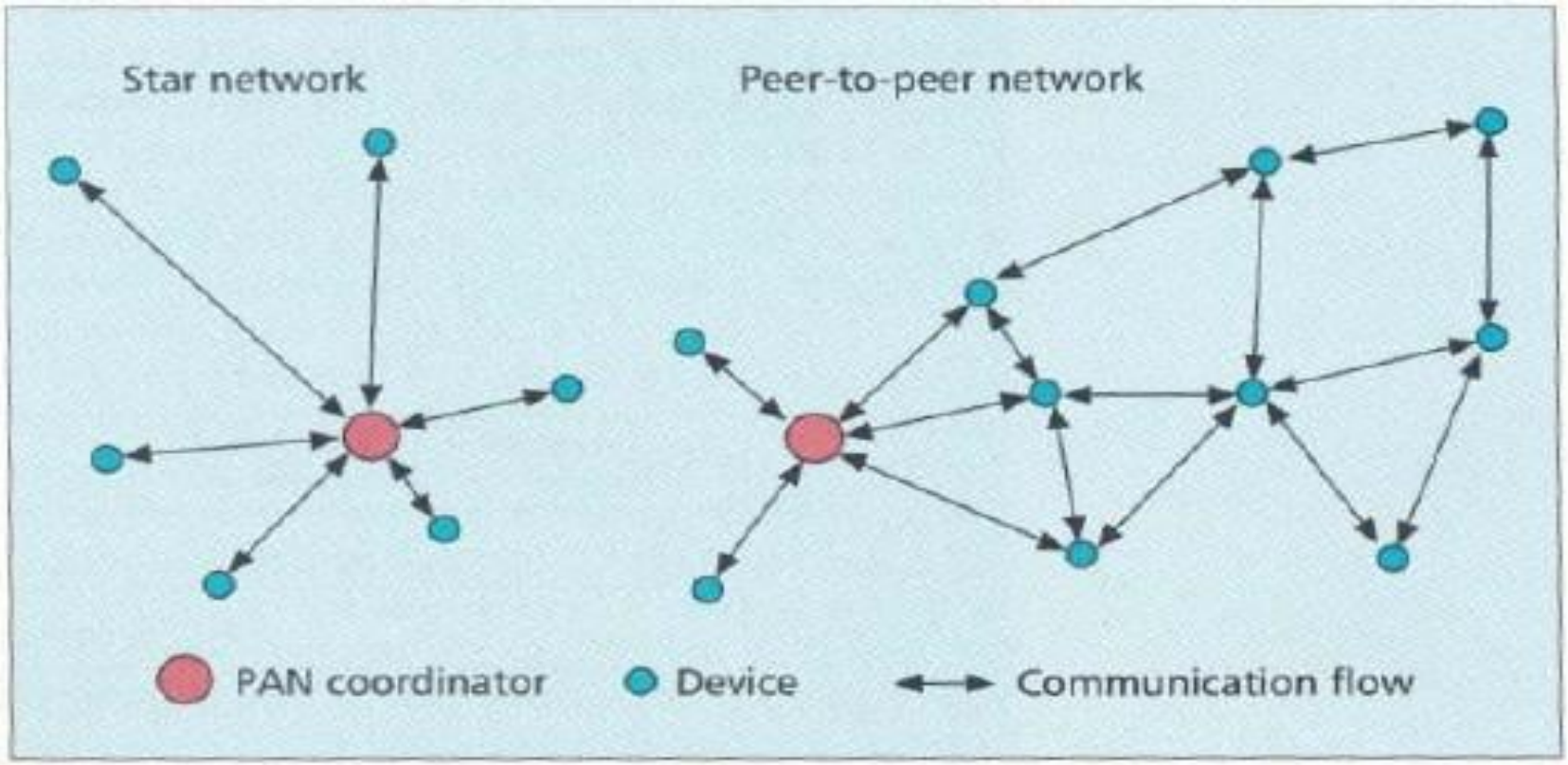


Figure 1. *Star and peer-to-peer networks.*

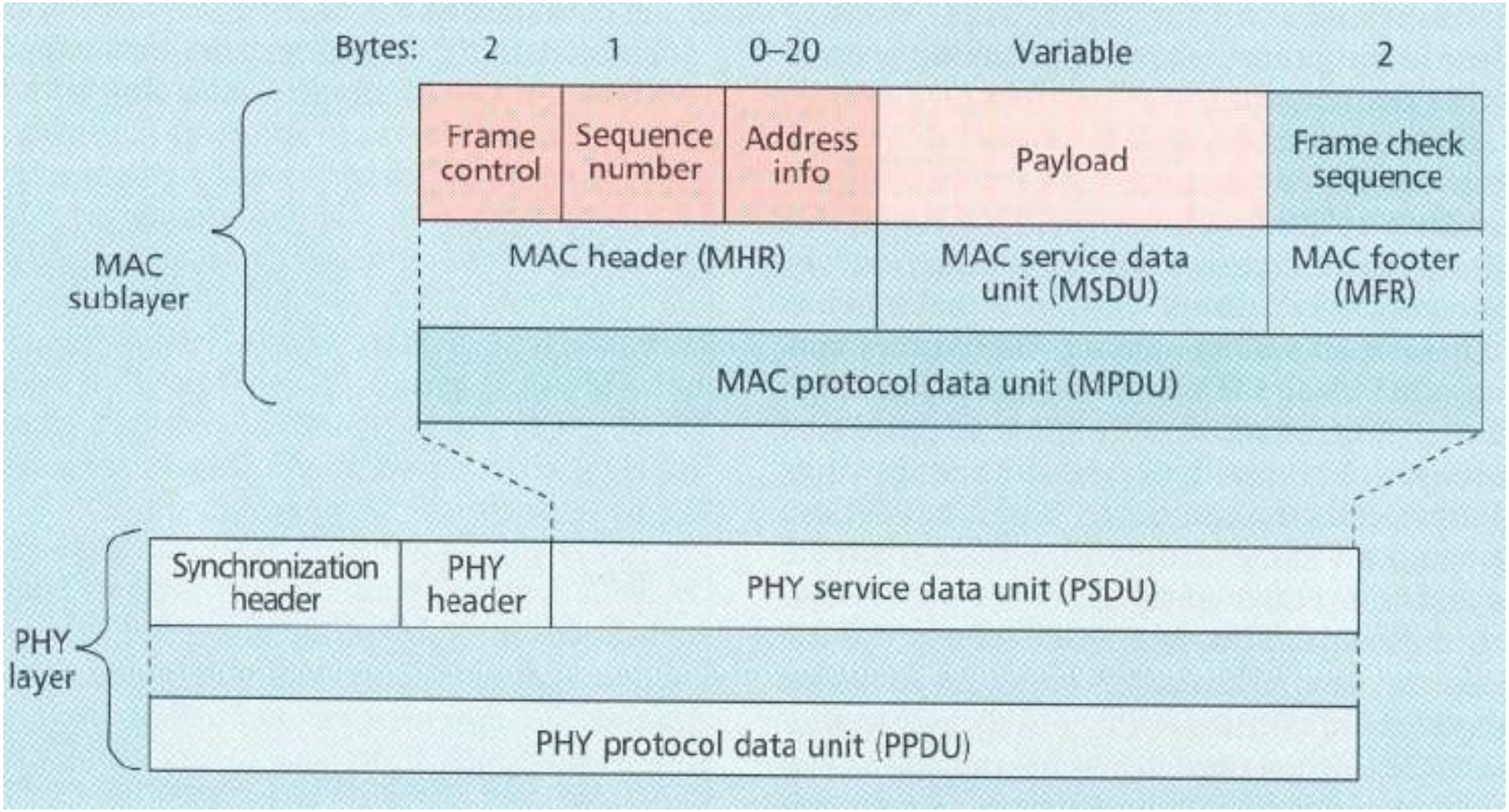
MAC

MAC provides data and management services to upper layers

The MAC management service has 26 primitives whereas 802.15.1 has about 131 primitives and 32 events,

802.15.4 MAC is of very low complexity, making it very suitable for its intended low-end applications, albeit at the cost of a smaller feature set than 802.15.1 (e.g., 802.15.4 does not support synchronous voice links).

MAC frame format



Superframe structure

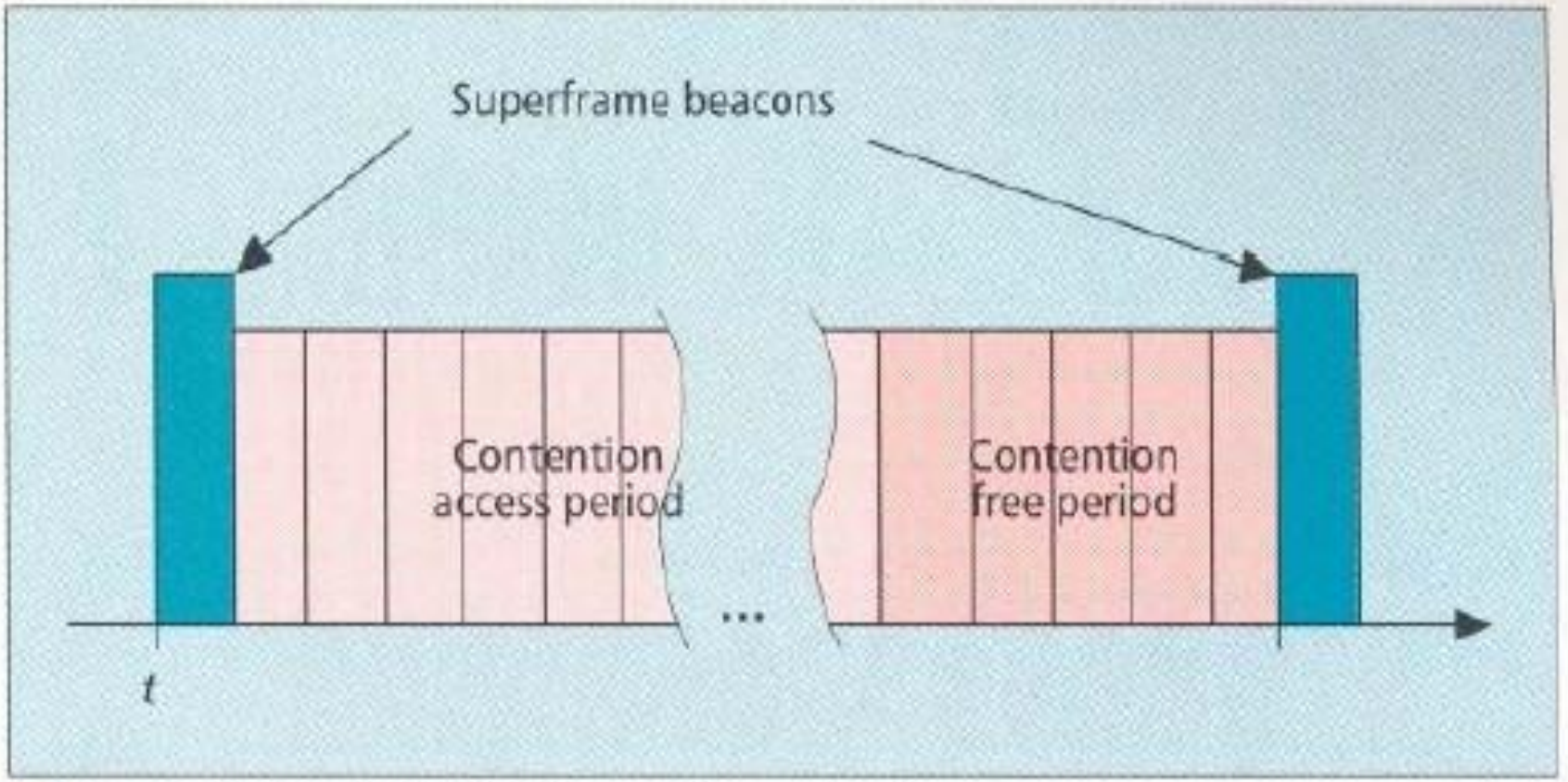


Figure 4. *The LR-WPAN superframe structure.*

Other MAC features

In a beacon-enabled network with superframes, a slotted carrier sense multiple access with collision avoidance (CSMA- CA) mechanism is used.

In others standard CSMA-CA is used I.e it first checks if another device is transmitting in the same channel if so backs off for certain time.

MAC confirms successful reception of data with an acknowledgement.

The IEEE 802.15.4 draft standard provides for three levels of security: no security of any type ,access control lists (non cryptographic security) and symmetric key security, employing AES-128.

PHY layer

This standard provides 2 PHY options with frequency band as fundamental difference.

2.4 GHz band has worldwide availability and provides a transmission rate of 250 kb/s.

The 868/915 MHz PHY specifies operation in the 868 MHz band in Europe and 915 MHz ISM band in the United States and offer data rates 20 kb/s and 40 kb/s respectively.

Different transmission rates can be exploited to achieve a variety of different goals.

Channel structure

Figure 5. *The IEEE 802.15.4 channel structure.*

Channel number	Channel center frequency (MHz)
$k = 0$	868.3
$k = 1, 2, \ldots, 10$	$906 + 2(k - 1)$
$k = 11, 12, \ldots, 26$	$2405 + 5(k - 11)$

Table 2. *IEEE 802.15.4 channel frequencies.*

Channelization

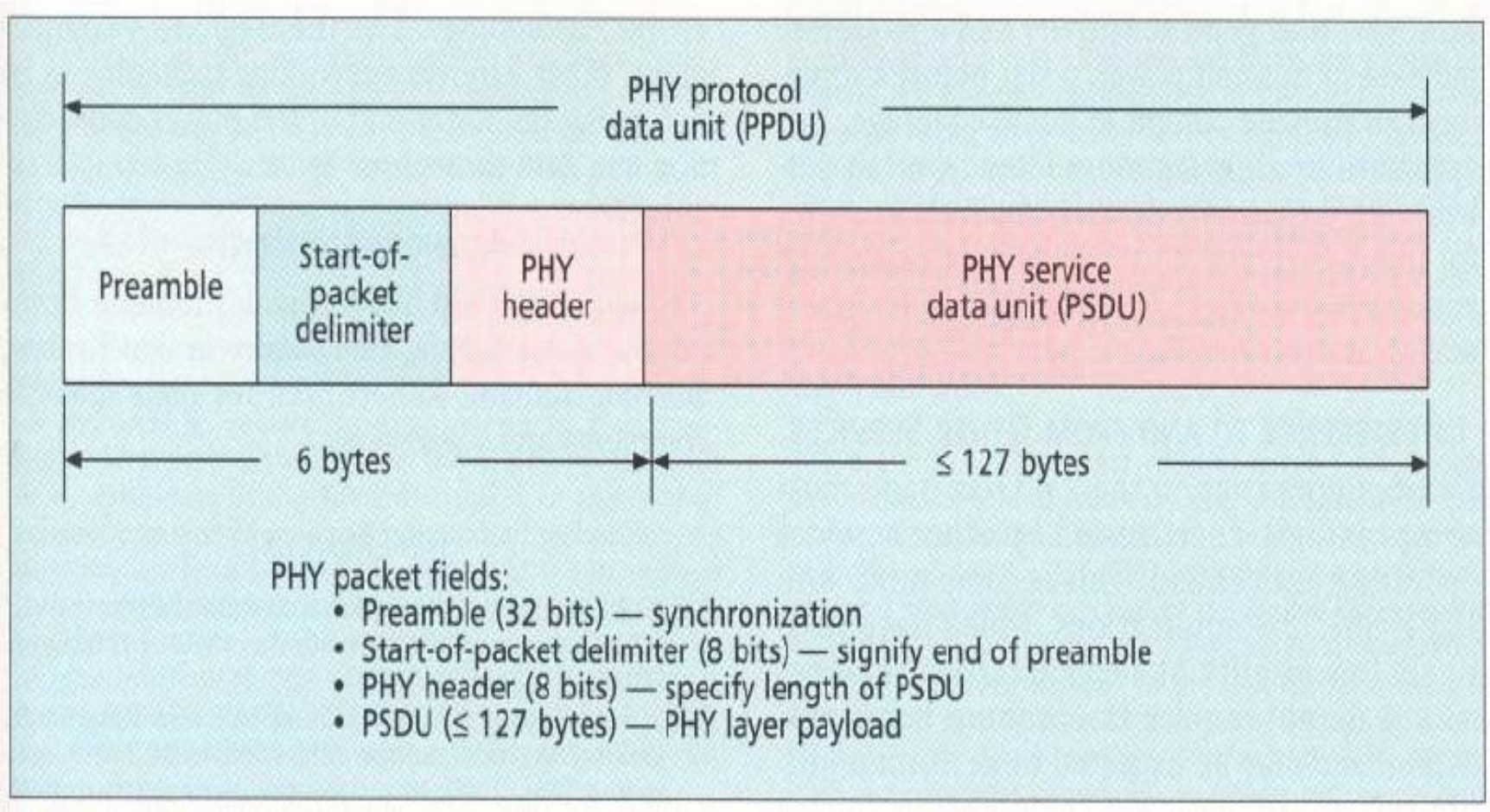
27 frequency channels are available across all the 3 bands.

This standard includes the necessary things to implement dynamic channel selection to avoid interference.

The PHY layers contain several lower-level functions, such as receiver energy detection, link quality indication, and channel switching, which enable channel assessment.

These functions are used by the network to establish its initial operating channel and to change channels in response to a prolonged outage.

PHY layer packet structure



Modulation

PHY	Frequency band	Data parameters			Spreading parameters	
		Bit rate (kb/s)	Symbol rate (kbaud)	Modulation	Chip rate (Mchips/s)	Modulation
868/915	868.0–868.6 MHz	20	20	BPSK	0.3	BPSK
MHz PHY	902.0–928.0 MHz	40	40	BPSK	0.6	BPSK
2.4 GHz PHY	2.4–2.4835 GHz	250	62.5	16-ary orthogonal	2.0	O-QPSK

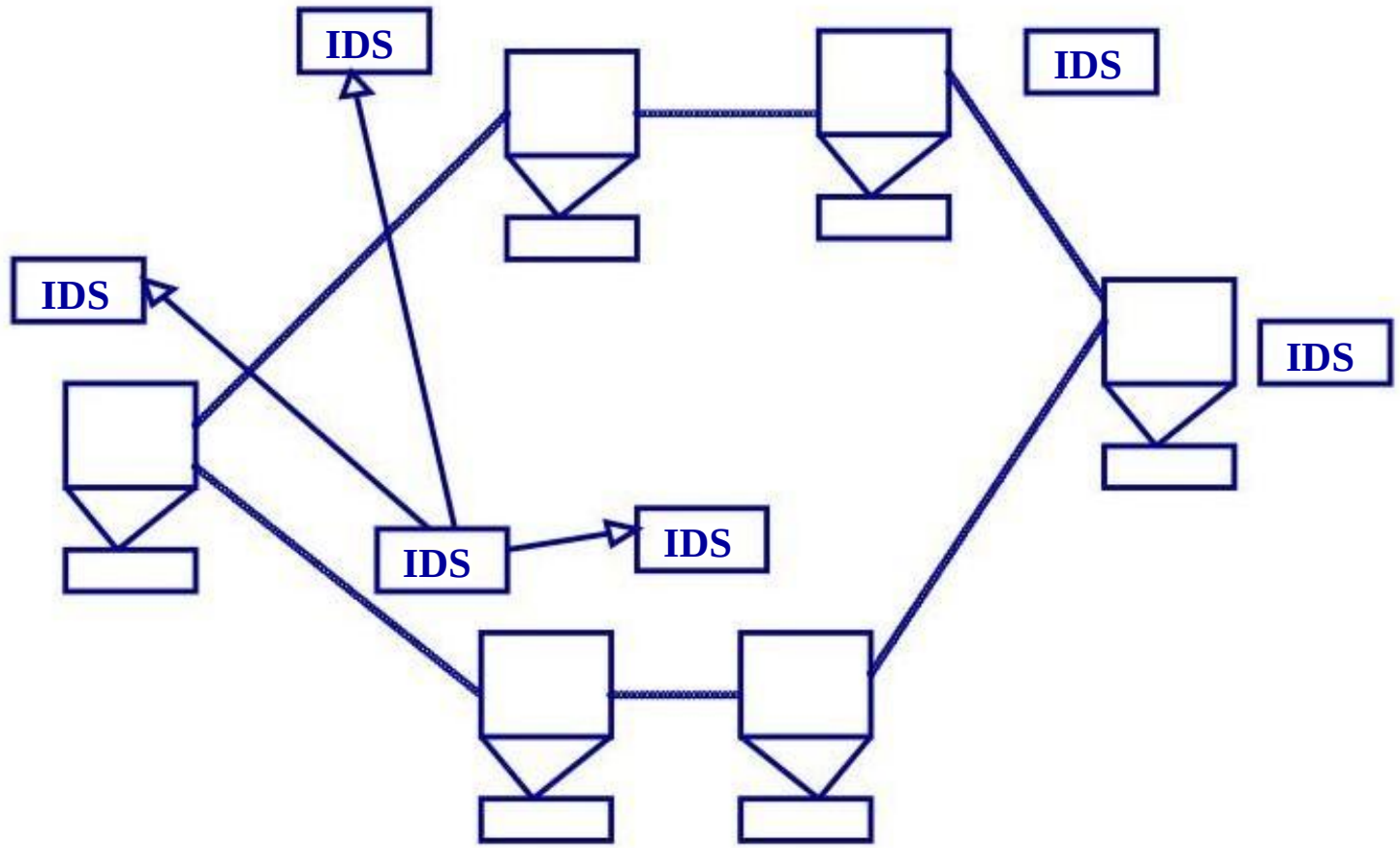
Interference

Interference is common in 2.4 GHz band because of other services operating in that band

IEEE 802.15.4 applications have low QOS requirements and may need to perform multiple retries for packet transmissions on interference.

Since IEEE 802.15.4 devices may be sleeping as much as 99.9 percent of the time they are operational, and employ low-power spread spectrum transmissions, they should be among the best of neighbors in the 2.4 GHz band.

An IDS Architecture for Wireless Ad hoc Networks



Summing up Wireless & Mobile Technology……

No limit. It ‘s beyond the sky?

Software Development Infrastructure for Sensor Networks

- Operating systems (*TinyOS*)
  - Resource (device) management
  - Basic primitives
  - Protocols (MAC, routing) {covered in many previous lectures}
- Programming languages and runtime environments
  - Low level (C, nesC)
  - Very high level abstractions (*Regiment*)
- Services needed
  - Synchronization of clocks (*RBS*)
  - Propagation of new code to all nodes (*Trickle*)
  - Localization {not today}

Maintenance overheads

Radio transmission scheduling (e.g. TDMA)

+

Route discovery & maintenance

+

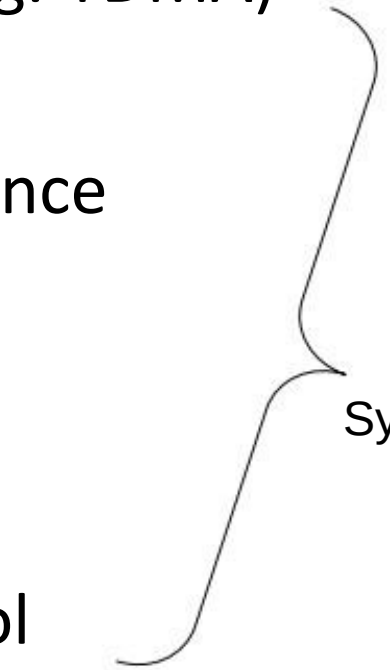
Clock synchronization

+

Code propagation protocol

+

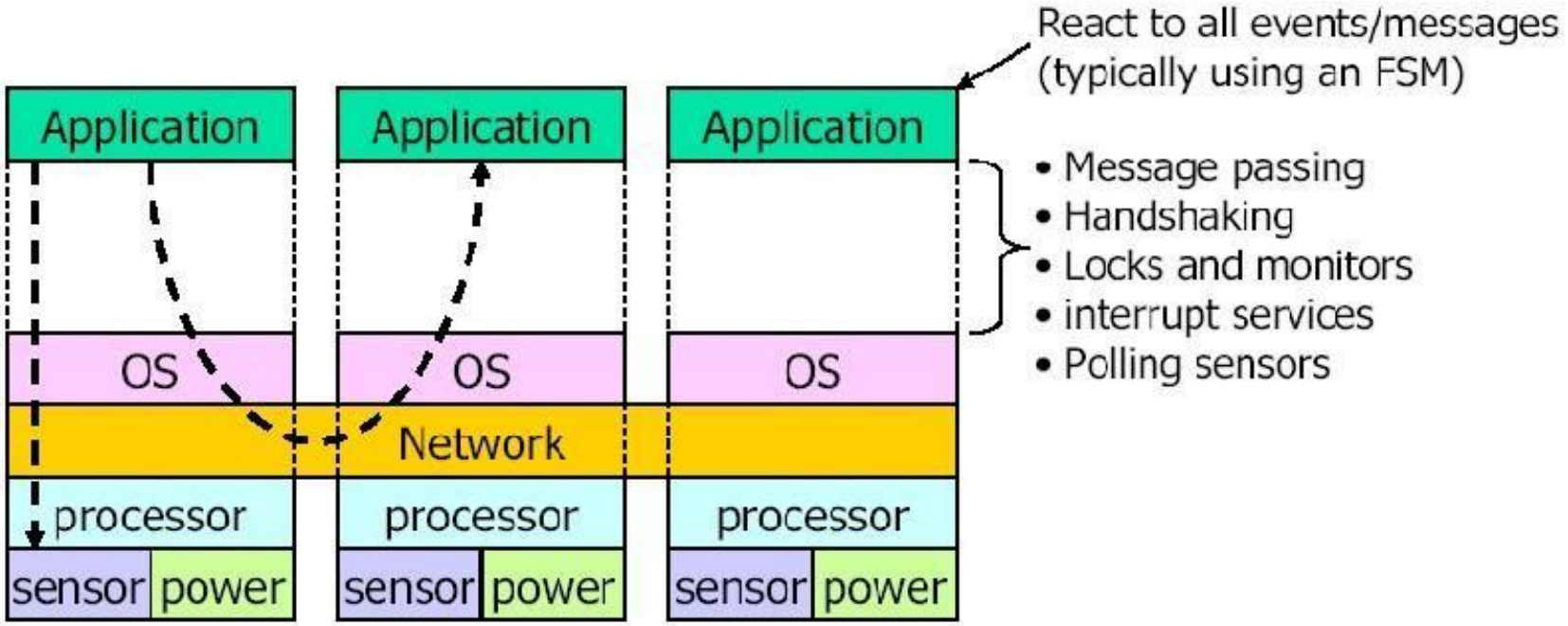
Sensor data delivery



Challenges in programming sensors

- WSN usually has severe power, memory, and bandwidth limitations
- WSN must respond to multiple, concurrent stimuli
  - At the speed of changes in monitored phenomena
- WSN are large-scale distributed systems

Traditional embedded systems



- Event-driven execution and real-time scheduling
- General-purpose layers are often bloated ! microkernel
- Strict layering often adds overhead ! expose hardware controls

UNIT -V

Operating System-Tiny OS

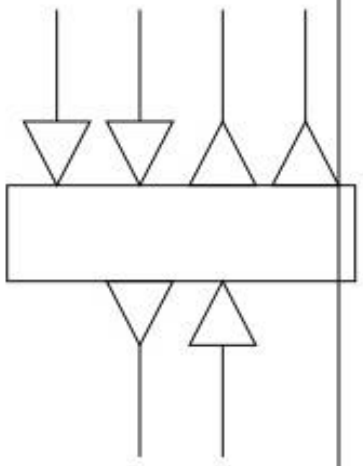
Operating System-Tiny OS

- Started out as a research project at Berkeley
- Now probably the de facto platform

- Overarching goal: conserving resources
- No file system
- No dynamic memory allocation
- No memory protection
- Very simple task model
- Minimal device and networking abstractions
- Application and OS are coupled—composed into one image

Tiny OS components

- Components: reusable building blocks
- Each component is specified by a set of interfaces
  - Provide "hooks" for wiring components together
- A component *C* can provide an interface
  - *C* must implement all commands available through
  - Commands are methods exposed to an upper layer
    - An upper layer can call a command
- A component *C* can use an interface
  - *C* must implement all events that can be signaled by
  - These are methods available to a lower layer

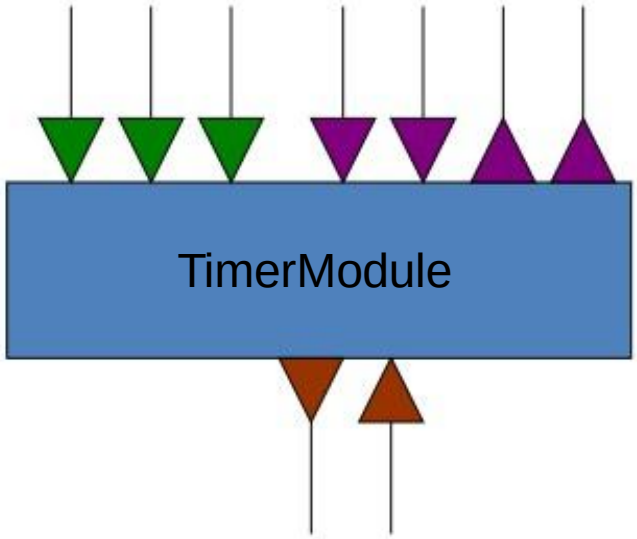


Component specification

```
module TimerModule {
  provides {
    interface StdControl;
    interface Timer01;
  }
  uses interface Clock as Clk;
}
…
```

```
interface StdControl {
  command result_t init();
  command result_t start();
  command result_t stop();
}
```

```
interface Timer01 {
  command result_t start(char type, uint32_t interv
  command result_t stop();
  event result_t timer0Fire();
  event result_t timer1Fire();
}
```




```
interface Clock {
  command result_t setRate(char interval, charsca
  event result_t fire();
}
```

Module vs. configurations

- Two types of components
  - -Module: implements the component specification (interfaces) with application code
  - -Configuration: implements the component specification by wiring existing components

Module implementation

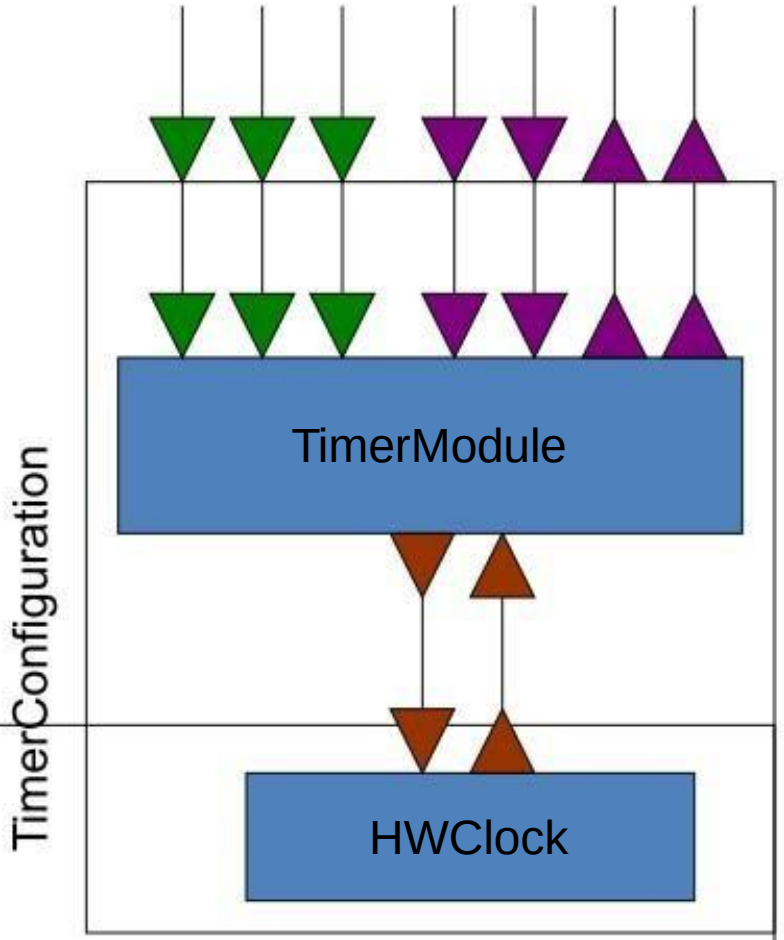
```
module TimerModule {
  provides { interface StdControl; interface Timer01; } uses interface Clock as C
}
implementation {
  bool eventFlag;
  command result_t StdControl.init() {
    eventFlag = 0;
    return call Clk.setRate(128, 4); // 4 ticks per sec
  }
  event result_t Clk.fire() {
    eventFlag = !eventFlag;
    if (eventFlag) signal Timer01.timer0Fire();
    else signal Timer01.timer1Fire();
    return SUCCESS;
  }
  …
}
```

Internal state

Just like method calls
(unlike raising exceptions in Java, e.g.)

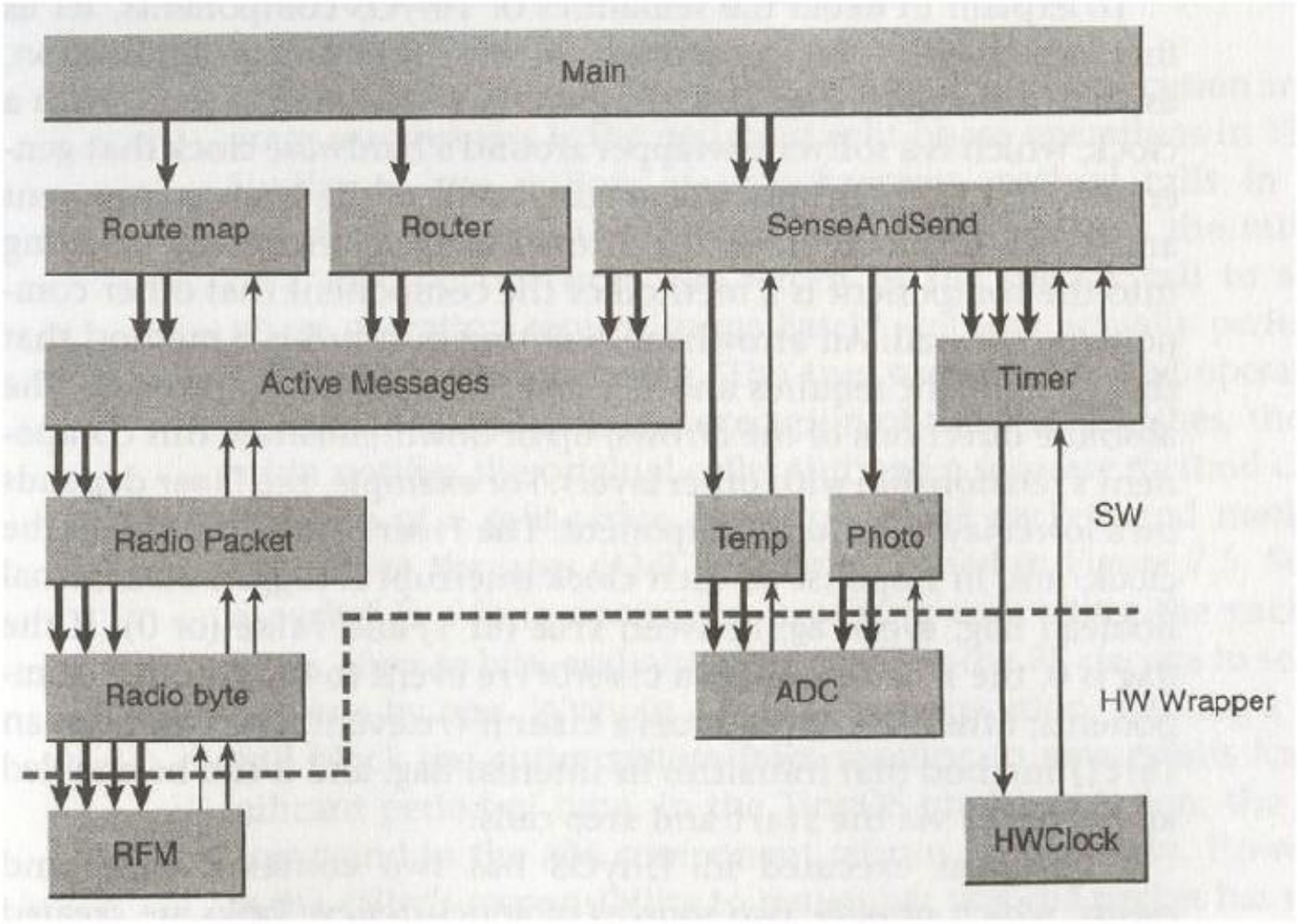
Configuration implementation

```
configuration TimerConfiguration {
  provides {
    interface StdControl;
    interface Timer01;
  }
}
implementation {
  components TimerModule, HWClock;
  StdControl = TimerModule.StdControl;
  Timer01 = TimerModule.Timer01;
  TimerModule.Clock ! HWClock.Clock;
}
```



- = (equate wire)
  - At least one must be external
- ! (link wire)
  - Both internal; goes from user to provider

FieldMonitor example



Concurrency model

Two types of execution contexts

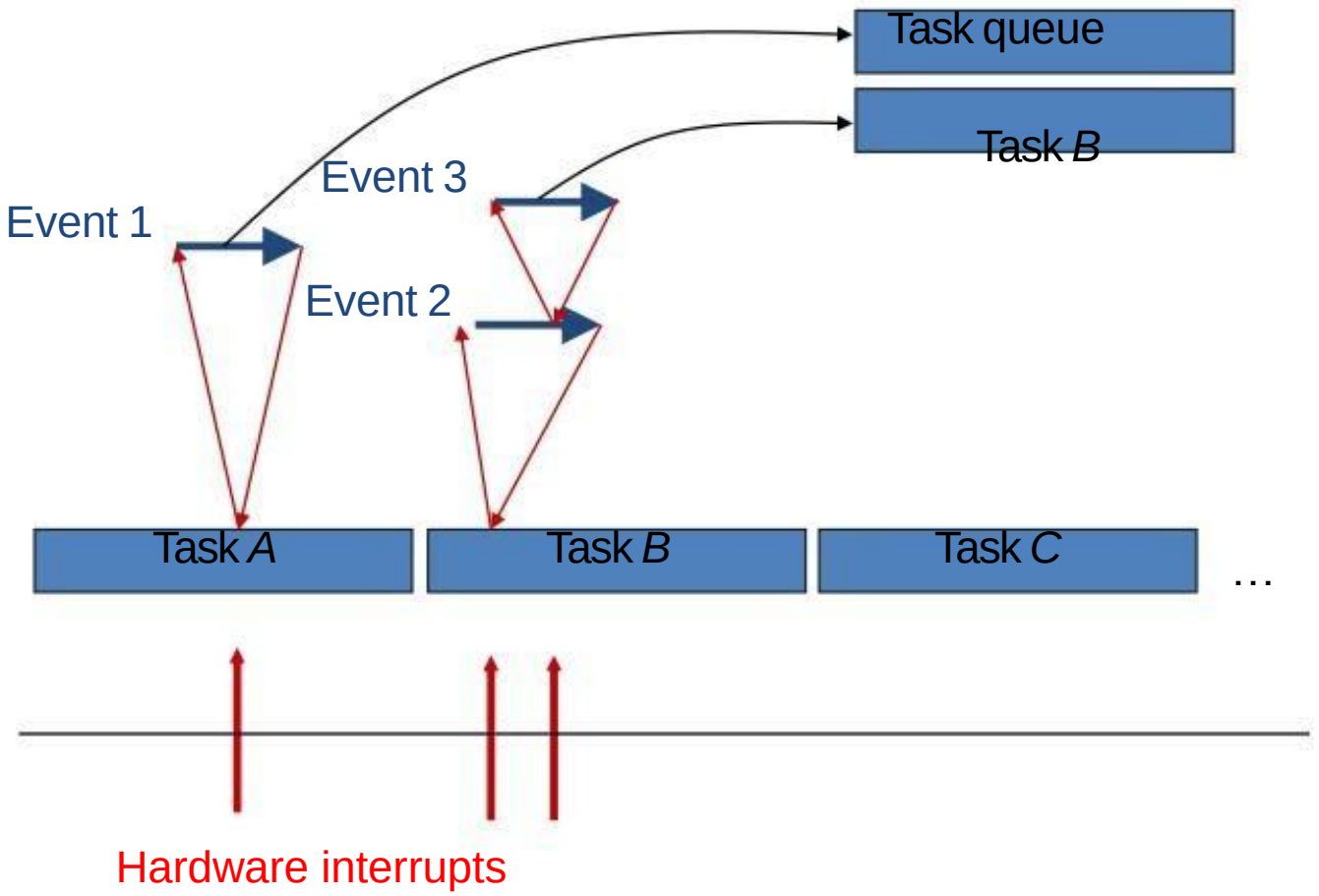
- Tasks
  - Longer running jobs
  - Time flexible
  - (Currently) simple FIFO scheduling
  - Atomic w.r.t. other tasks, i.e., single-threaded
  - But can be preempted by events
- Events (an overloaded term)
  - More precisely, hardware interrupt handlers
  - Time critical
  - Shorten duration as much as possible
    - By issuing tasks for later execution
  - LIFO semantics; can preempt tasks and earlier events

Tasks

```
implementation {
  task void TaskName() {
    …
  }
  …
  … {
    …
    post TaskName();
    …
  }
}
```

- A task is always posted for later execution; control returns to poster immediately
- Scheduler supports a bounded queue of pending tasks
  - Node sleeps when the queue is empty
- For simplicity, tasks don't take args and don't return values
- Typical use
  - Event necessitates further processing
    - Wrap it up in a task
  - Event handler simply posts the task and can return immediately

Execution example



A more complex example

```
module SenseAndSend {
  provides interface StdControl;
  uses { interface ADC; interface Timer01; interface Send;
}
implementation {
  bool busy;
  norace unit16_t sensorReading;
  …
  command result_t StdControl.init() { busy = FALSE; }
  event result_t Timer01.Timer0Fire() {
    bool localBusy;
    atomic { localBusy = busy; busy = TRUE; }
    if (!localBusy) { call ADC.getData(); return SUCCESS;}
    else { return FAILED; }
  }
  task void sendData() {
    …
    adcPacket.data = sensorReading;
    …
    call Send.send(&adcPacket, sizeof(adcPacket.data));
    return SUCCESS;
  }
  event result_t ADC.dataReady(uint16_t data) {
    sensorReading = data;
    post sendData();
    atomic { busy = FALSE; }
    return SUCCESS;
  }
  …
}
```

Timer01.Timer0Fire() triggers data acquisition (through ADC) and transmission to base station (through Send)

Split-phase operation

```
event result_t Timer01.Timer0Fire() {
  bool localBusy;
  atomic { localBusy = busy; busy = TRUE; }
  if (!localBusy) { call ADC.getData(); return SUCCESS; }
  else { return FAILED; }
}
event result_t ADC.dataReady(uint16_t data) {
sensorReading = data;
  post sendData();
  atomic { busy = FALSE; }
  return SUCCESS;
}
```

- Data acquisition doesn't take place immediately (*why?*)
- How does a traditional OS accomplish this?
  - OS puts thread to sleep when it blocks
    - *Why isn't this approach good enough here?*

Posting task in interrupt handler

```
task void sendData() {
  …
  adcPacket.data = sensorReading;
  …
  call Send.send(&adcPacket, sizeof(adcPacket.data));
  return SUCCESS;
}
event result_t ADC.dataReady(uint16_t data) {
  sensorReading = data;
  post sendData();
  atomic { busy = FALSE; }
  return SUCCESS;
}
```

- *Why?*

  - Make asynchronous code as short as possible

Race conditions

- Because of preemption, race conditions may arise on shared data
  - nesC compiler can detect them, but with false positives
- In case of false positive, declare shared variable with norace keyword
- In case of real race conditions, use atomic to make code blocks non-preemptible

```
bool busy;
norace uint16_t sensorReading;
…
event result_t Timer01.Timer0Fire() {
  bool localBusy;
  atomic { localBusy = busy; busy = TRUE; }
  if (!localBusy) { call ADC.getData(); return SUCCES
  else { return FAILED; }
}
task void sendData() {
  …
  adcPacket.data = sensorReading;
  …
  call Send.send(&adcPacket, sizeof(adcPacket.data
  return SUCCESS;
}
event result_t ADC.dataReady(uint16_t data) {
  sensorReading = data;
  post sendData();
  atomic { busy = FALSE; }
  return SUCCESS;
}
```

Discussion

- Provides framework for concurrency and modularity
- Interleaves flows, events, energy management
- Never poll, never block
- Trade off flexibility for more optimization opportunities

Still a node-level platform