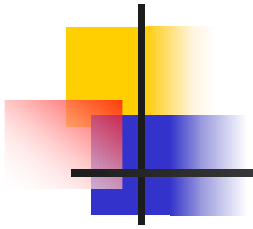
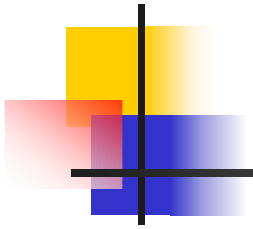


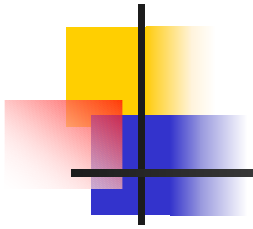
Chapter 13

Ad Hoc and Sensor Networks



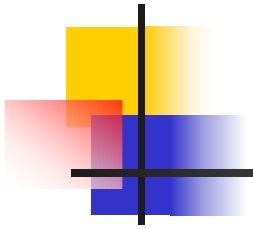
Outline

- Introduction
- Characteristics of Ad Hoc Networks
- Applications
- Routing
  - Table-driven Routing Protocols
  - Source-initiated On-demand Routing
  - Hybrid Protocols
- Wireless Sensor Networks
  - Routing in Sensor Networks
  - Fixed Wireless Sensor Networks



Introduction

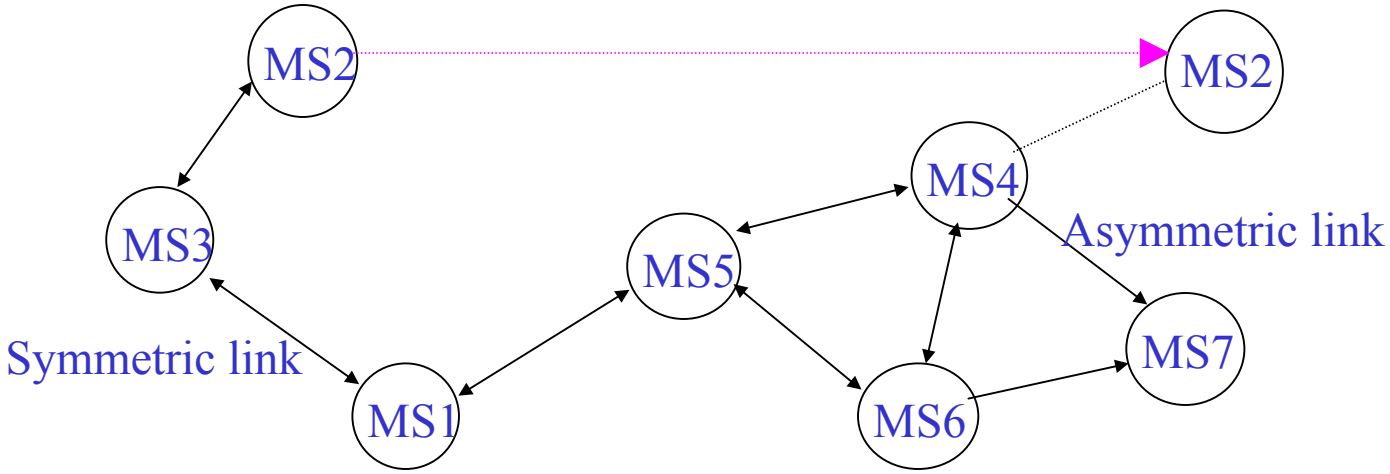
- A Mobile Ad hoc Network (MANET) is an autonomous system of nodes (MSs) connected by wireless links.
- A MANET does not necessarily need support from any existing network infrastructure like an Internet gateway or other fixed stations.
- The network's wireless topology may dynamically change in an unpredictable manner since nodes are free to move.
- Information is transmitted in a store-and forward manner using multi hop routing.

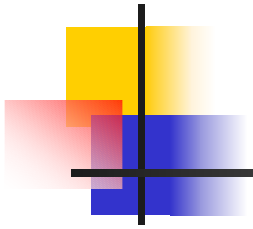


Introduction (Cont'd)

- Each node is equipped with a wireless transmitter and a receiver with an appropriate antenna.
- We assume that it is not possible to have all nodes within each other's radio range.
- When the nodes are close-by i.e., within radio range, there are no routing issues to be addressed.
- At a given point in time, wireless connectivity in the form of a random multi-hop graph exists between the nodes.

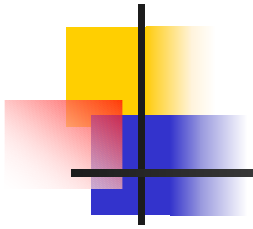
A Mobile Ad Hoc Network





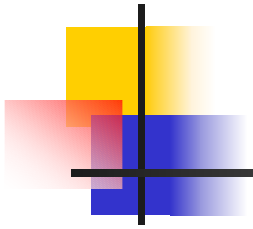
Characteristics of Ad Hoc Networks

- *Dynamic topologies:* Network topology may change dynamically as the nodes are free to move.
- *Bandwidth-constrained, variable capacity links:* Realized throughput of wireless communication is less than the radio's maximum transmission rate. Congestion occurs frequently.
- *Energy-constrained operation*: Some nodes in the ad hoc network may rely on batteries or other exhaustible means for their energy.
- *Limited physical security:* More prone to physical security threats than fixed cable networks.



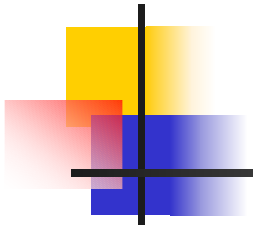
Applications

- ***Virtual navigation***: Data from a remote database is transmitted periodically in small relevant blocks using links present in the path of the automobile. This database may contain the graphical representation of streets, buildings, maps and the latest traffic information, which may be used by the driver to decide on a route.
- ***Tele-medicine***: Conference assistance from a surgeon for an emergency intervention.
- ***Tele-Geo processing***: Queries regarding location information of the users.
- ***Crisis-management***: Natural disasters, where the entire communication infrastructure is in disarray.
- ***Education via the internet***



Routing in MANETS - Goals

- Provide the maximum possible reliability - use alternative routes if an intermediate node fails.
- Choose a route with the least cost metric.
- Give the nodes the best possible response time and throughput.
- Route computation must be distributed. Centralized routing in a dynamic network is usually very expensive.
- Routing computation should not involve the maintenance of global state.
- Every node must have quick access to routes on demand.
- Each node must be only concerned about the routes to its destination.
- Broadcasts should be avoided (highly unreliable)
- It is desirable to have a backup route when the primary route has become stale.



Routing Classification

The existing routing protocols can be classified as,

- **Proactive**: when a packet needs to be forwarded, the route is already known.
- **Reactive**: Determine a route only when there is data to send.

Routing protocols may also be categorized as ,

- Table Driven protocols
- Source Initiated (on demand) protocols

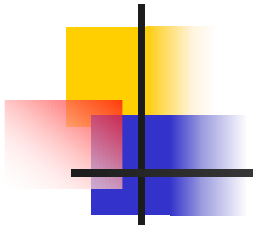
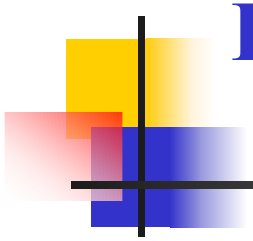


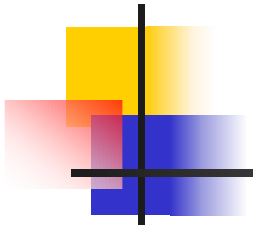
Table Driven Routing Protocols

- Each node maintains routing information to all other nodes in the network
- When the topology changes, updates are propagated throughout the network.
- Examples are:
  - *Destination Sequenced Distance Vector routing (DSDV)*
  - *Cluster-head Gateway Switch routing (CGSR)*
  - *Wireless Routing Protocol (WRP)*



Destination Sequenced Distance Vector Routing (DSDV)

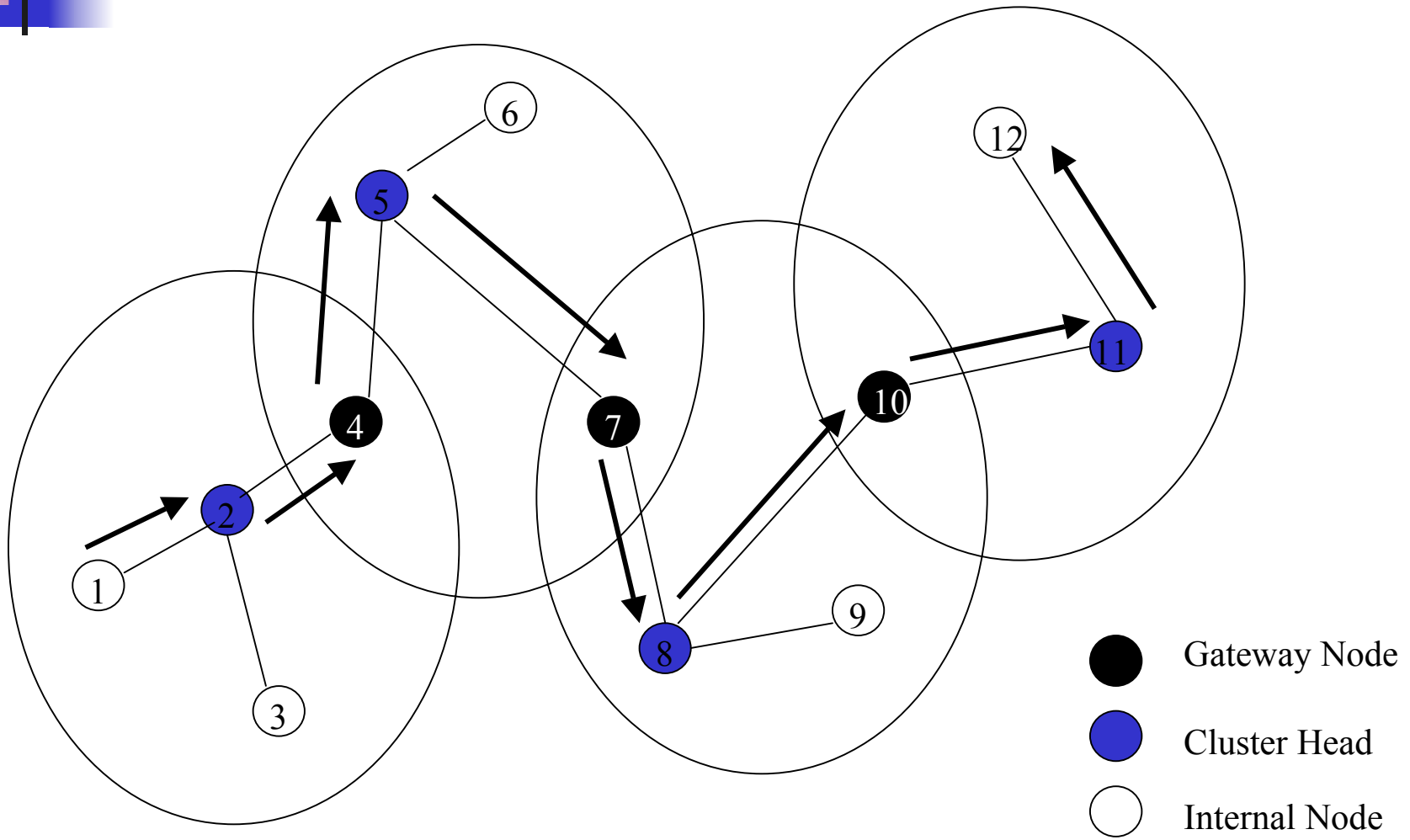
- Based on the Bellman-Ford algorithm.
- Each mobile node maintains a routing table.
- Routing table updates are periodically transmitted.
- Each entry in the table is marked by a sequence number which helps to distinguish stale routes from new ones, and thereby avoiding loops.
- To minimize the routing updates, variable sized update packets are used depending on the number of topological changes.



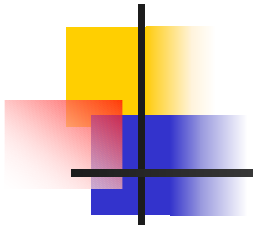
Cluster-head Gateway Switch Routing (CGSR)

- CGSR is a clustered multi-hop mobile wireless network with several heuristic routing schemes.
- A distributed cluster-head (CH) selection algorithm is used to elect a node as the cluster head.
- It modifies DSDV by using a hierarchical CH to route traffic.
- Gateway nodes serve as *bridge nodes* between two or more clusters.
- A packet sent by a node is first routed to its CH and then the packet is routed from the CH to a gateway of another cluster and then to the CH and so on, until the destination cluster head is reached.
- Frequent changes in the CH may affect the performance of the routing protocol.

CGSR (Cont'd)



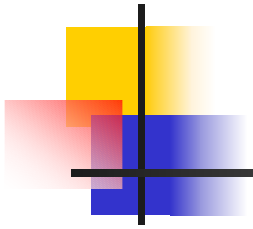
Routing in CGSR from node 1 to node 8



The Wireless Routing Protocol (WRP)

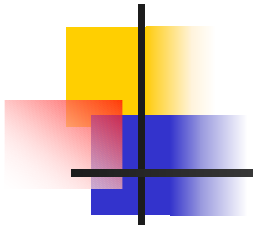
- Each node maintains 4 tables:
  - -- Distance table
  - -- Routing table
  - -- Link cost table
  - -- Message Retransmission List table (MRL)

    MRL contains the sequence number of the update message, a retransmission counter and a list of updates sent in the update message



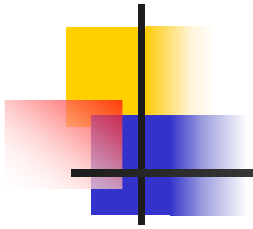
Wireless Routing Protocol (Cont'd)

- Nodes inform each other of link changes using update messages.
- Nodes send update messages after processing updates from their neighbors or after detecting a change in the link.
- If a node is not sending messages, it must send a HELLO message within a specified time to ensure connectivity.
- If the node receives a HELLO message from a new node, that node is added to the table.
- It avoids the "count to infinity" problem.



Source-Initiated On-Demand Routing

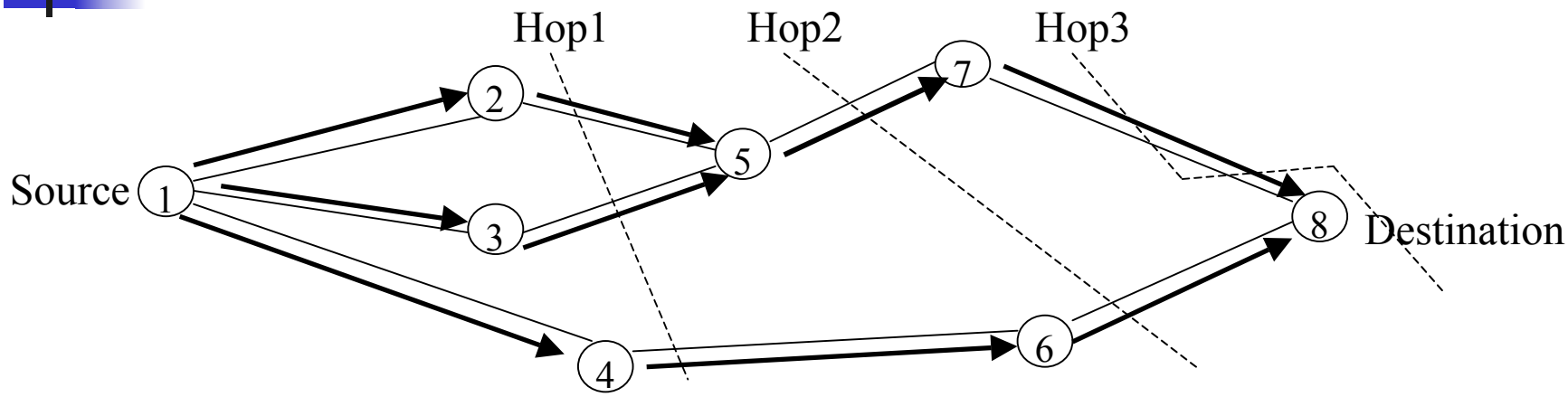
- Ad hoc On-Demand Distance Vector (AODV).
- Dynamic Source Routing (DSR)
- Temporary Ordered Routing Algorithm (TORA)
- Associativity Based Routing (ABR)
- Signal Stability Routing (SSR)



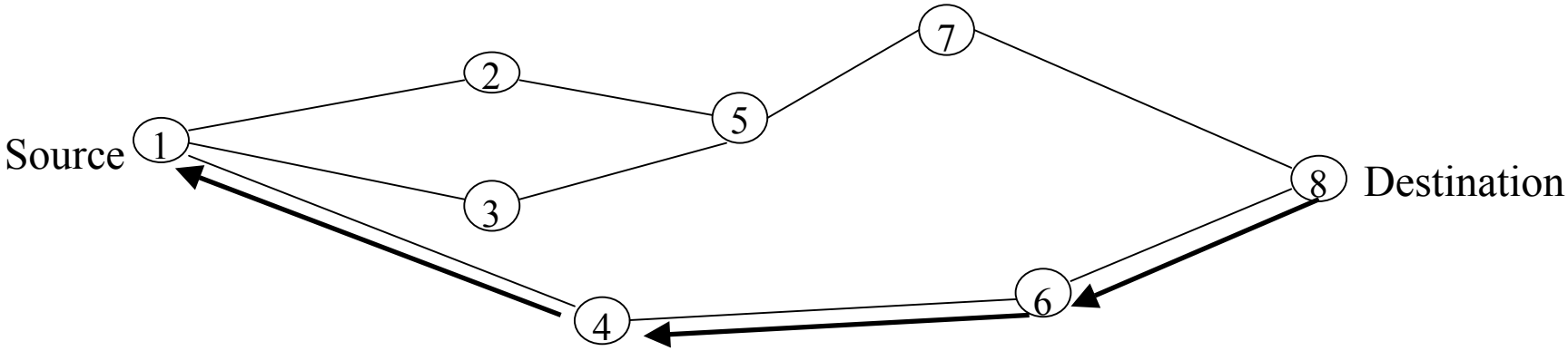
Ad Hoc On-Demand Distance Vector

- AODV is an improvement over DSDV, which minimizes the number of required broadcasts by creating routes on demand.
- Nodes that are not in a selected path do not maintain routing information or participate in routing table exchanges.
- A source node initiates a path discovery process to locate the other intermediate nodes (and the destination), by broadcasting a Route Request (RREQ) packet to its neighbors.

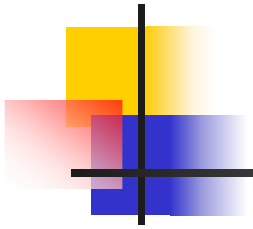
Route Discovery in AODV Protocol



(a) Propagation of Route Request (RREQ) Packet

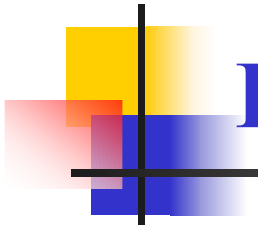


(b) Path Taken by the Route Reply (RREP) Packet



Dynamic Source Routing

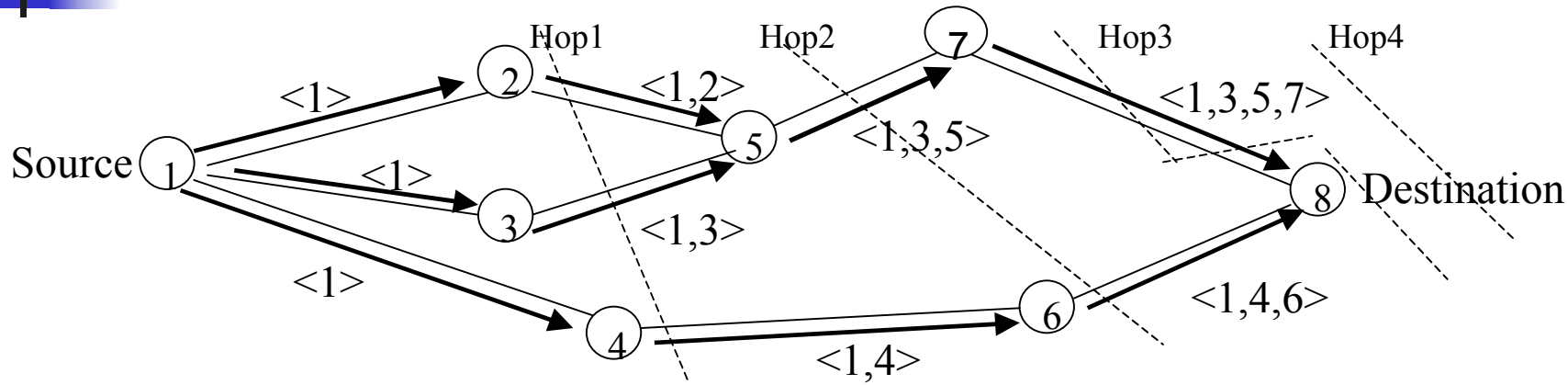
- The protocol consists of two major phases: Route Discovery, Route Maintenance.
- When a mobile node has a packet to send to some destination, it first consults its route cache to check whether it has a route to that destination.
- If it is an un-expired route, it will use this route.
- If the node does not have a route, it initiates route discovery by broadcasting a Route Request packet.
- This Route Request contains the address of the destination, along with the source address.



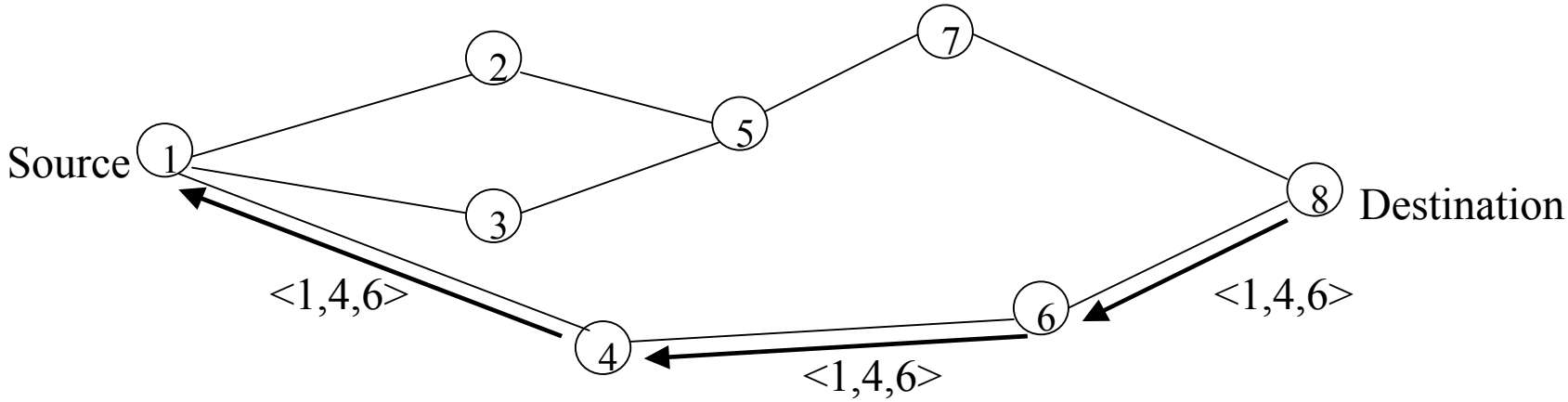
Dynamic Source Request (Cont'd)

- Each node receiving the packet checks to see whether it has a route to the destination. If it does not, it adds its own address to the route record of the packet and forwards it.
- A route reply is generated when the request reaches either the destination itself or an intermediate node that contains in its route cache an un-expired route to that destination.
- If the node generating the route reply is the destination, it places the the route record contained in the route request into the route reply.

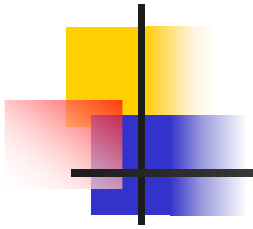
Creation of Route Record in DSR



(a) Building Record Route During Route Discovery



(b) Propagation of Route Reply with the Route Record



Temporarily Ordered Routing Algorithm (TORA)

- TORA is a highly adaptive loop-free distributed routing algorithm based on the concept of link reversal.
- TORA decouples the generation of potentially far-reaching control messages from the rate of topological changes.
- The height metric is used to model the routing state of the network.

TORA (Cont'd)

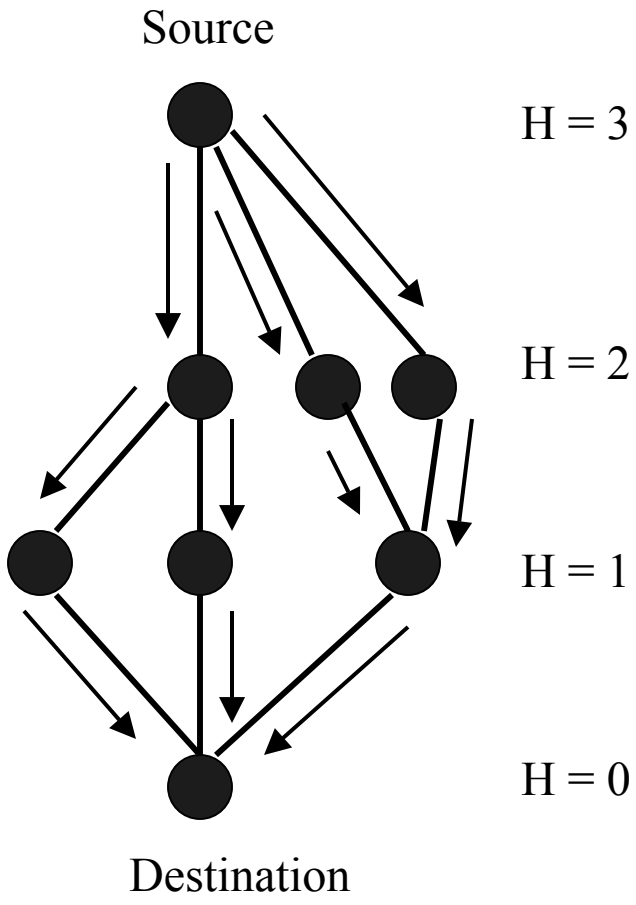
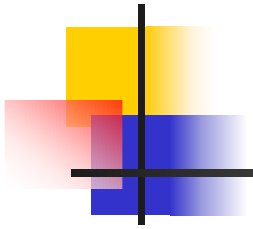


Illustration of Tora height metric



TORA (Cont'd)

- The protocol performs three basic functions: route creation, route maintenance, route erasure.
- During the route creation and maintenance phases nodes use a height metric to establish a Directed Acyclic Graph (DAG) rooted at the destination.
- Thereafter links are assigned a direction based on the relative heights

TORA (Cont'd)

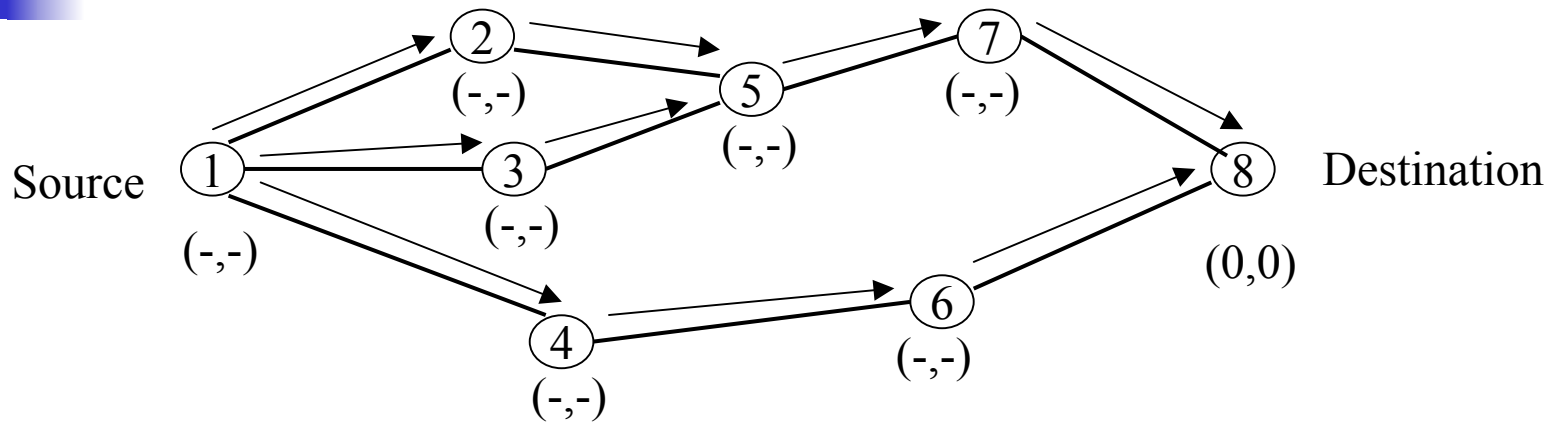
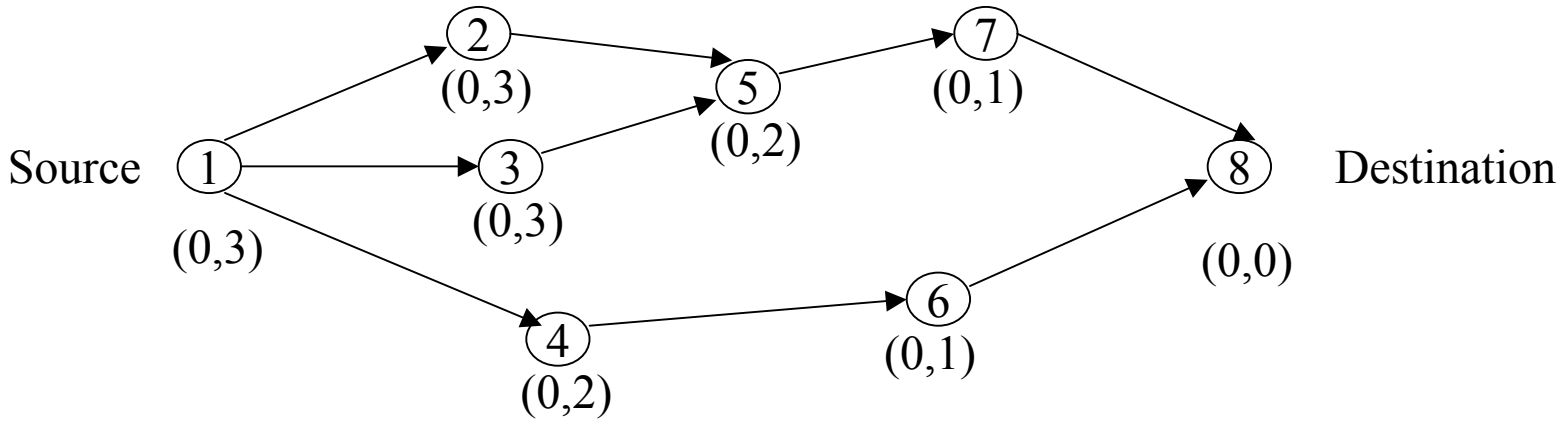
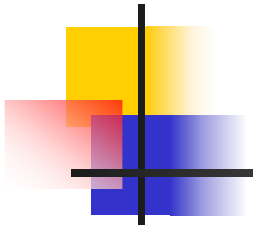


Figure 13.6(a) – Propagation of the query message

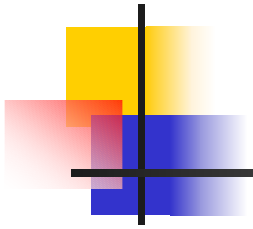


Node's height updated as a result of the update message



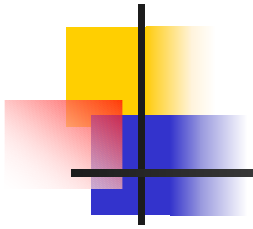
Associativity Based Routing (ABR)

- The three phases of ABR are: route discovery, route reconstruction, route deletion.
- In ABR a route is selected based on the degree of stability associated with mobile nodes.
- Association stability is defined by connection stability of one node with respect to another node over time and space.
- Each node generates a beacon to signify its existence.
- When received by neighboring nodes, the beacon causes their associativity tables to be updated.



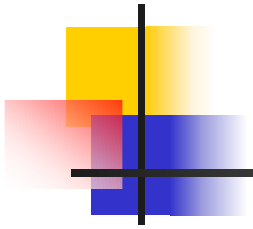
ABR (Cont'd)

- The route discovery is accomplished by a Broadcast Query- Reply (BQ-REPLY) cycle.
- When a discovered route is no longer desired, the source node initiates a Route Delete broadcast so that all the nodes along the route update their routing tables.



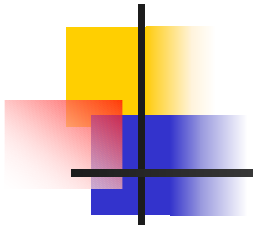
Signal Stability Routing (SSR)

- SSR selects a route based on the signal strength between nodes and a node's location stability.
- This route selection criteria has the effect of choosing routes that have a better link connectivity.



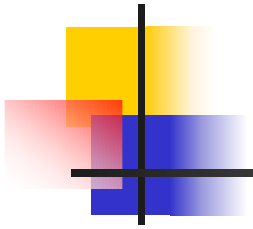
Hybrid Protocols

- **Zone Routing Protocol** (ZRP): a node proactively maintains routes to destinations within a local neighborhood. The construction of a routing zone requires a node to first know who its neighbor, which is implemented through a MAC layer Neighbor Discovery Protocol.
- **Fisheye State Routing** (FSR): There are multi-level fisheye scopes to reduce routing update overhead in large networks. It helps to make a routing protocol scalable by gathering data on the topology, which may be needed soon.
- **Landmark Routing** (LANMAR): Uses a landmark to keep track of a logical subnet. The LANMAR routing table includes only those nodes within the scope and the landmark nodes themselves.
- **Location-Aided Routing** (LAR): It exploits location information to limit the scope of routing. LAR limits the search based on the expected location of the destination node and thereby restricts and controls the flood of Route Request packets.



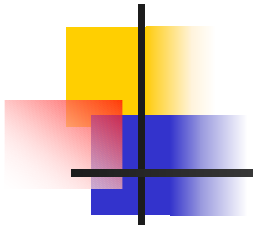
Hybrid Protocols (Cont'd)

- **Distance Routing Effect Algorithm for Mobility** (DREAM) : It is based on the distance effect and a node's mobility rate. Each node can optimize the frequency at which it sends updates to the networks and correspondingly reduce the bandwidth and energy used.
- **Relative Distance Micro-discovery Ad Hoc Routing** (RDMAR): This is based on the calculated relative distance between two terminals. The query flood is localized to a limited region centered at the source node.
- **Power Aware Routing**: power-aware metrics are used for determining routes. It reduces the cost, ensures that the mean time to node failure is increased, without any further delay in packet delivery.



Wireless Sensor Networks

- Wireless sensor networks are a collection of hundreds or thousands of tiny disposable and low power sensor nodes communicating together to achieve an assigned task.
- A sensor node is a device that converts a sensed attribute into a data form that is comprehensible by the user. Each node includes a sensing module, a communication module, memory and a small battery.
- They are “data centric” networks, i.e., the interest is in “*what* is the data?” rather than “*where* is the data?”. In wireless sensors, failure of one sensor does not affect the network operation as there are other nodes collecting similar data in the same area.



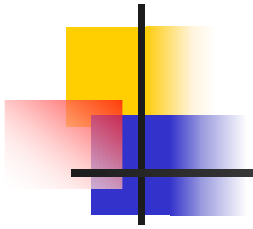
Classification of Sensor Networks

- **Proactive Networks**

  The nodes in the network periodically switch on their sensors and transmitters, sense the environment and transmit the data of interest.

- **Reactive Networks**

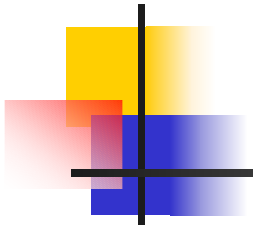
  In this scheme the nodes react immediately to sudden and drastic changes in the value of the sensed attribute.



Wireless Sensor Networks - Queries

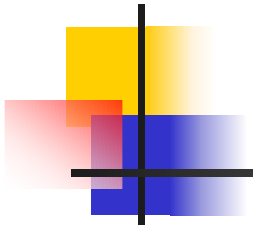
Query handling is another additional feature. Users using hand held devices should be able to request data from the network. User queries are of three types:

- Historical queries: Used for analysis of historical data stored at the BS, e.g., “What was the temperature 2 hours back in the northwest quadrant?”
- One time query: Gives a snapshot of the network, e.g., “What is the current temperature in the northwest quadrant?”.
- Persistent: Used to monitor the network over a time interval with respect to some parameters, e.g., “Report the temperature for the next 2 hours”.



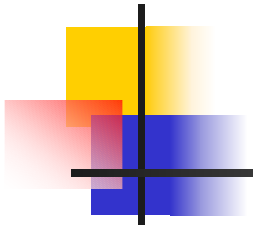
Routing Issues in Sensor Networks

- In traditional wired networks each node is identified by a unique address, which is used for routing. Sensor networks, being data centric do not require routing between specific nodes.
- Adjacent nodes may have similar data. So it is desirable to aggregate this data and send it.
- The requirements of the network change with application, hence it is application specific.



Routing in Sensor Networks – Flat Routing

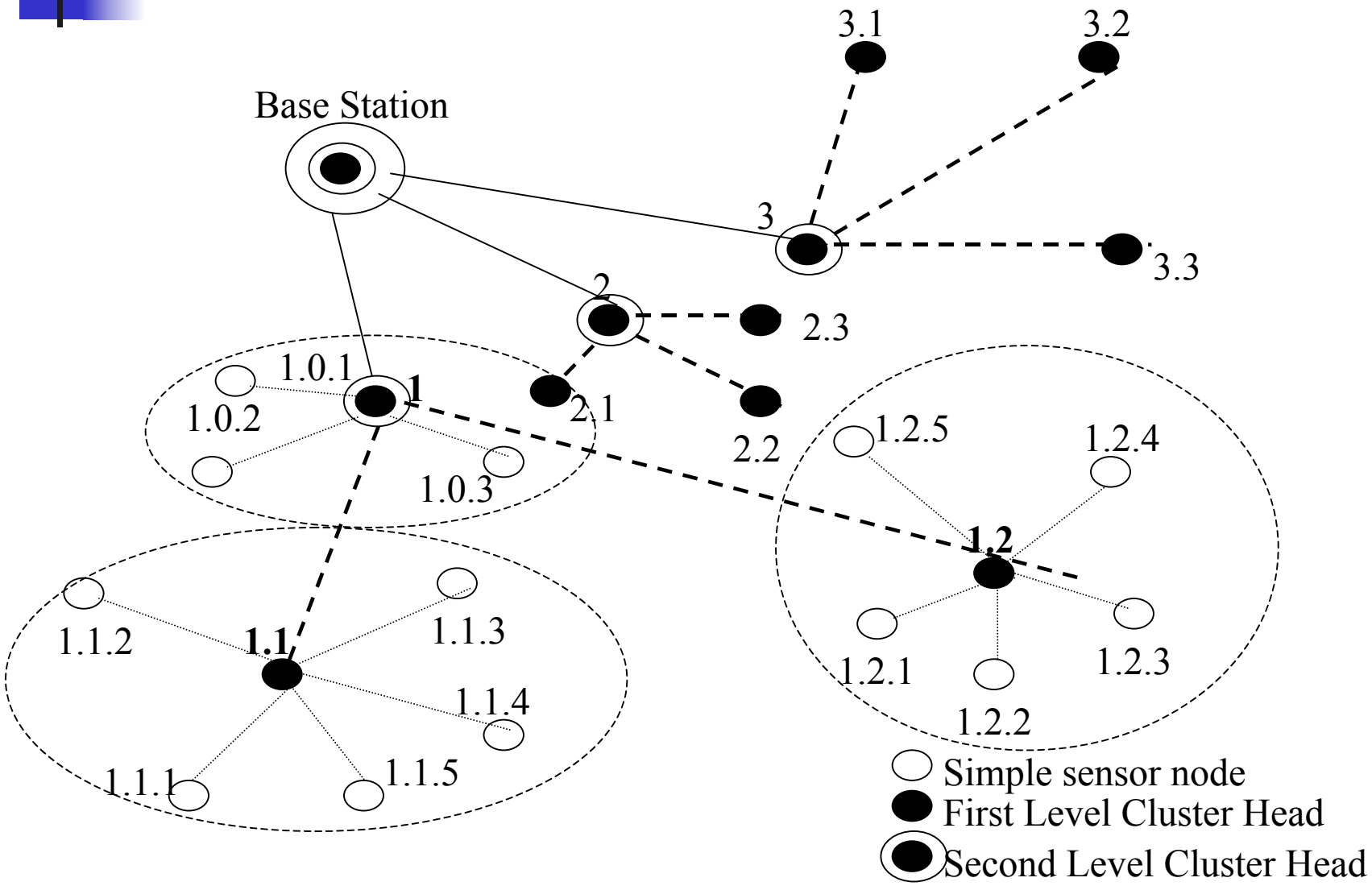
- **Directed Diffusion**
  - The query is flooded throughout the network.
  - Events start from some specific points and move outwards to reach the requesting node
  - This type of data collection does not fully exploit the feature of sensor networks that adjacent nodes have similar data.
- **Sensor Protocols for Information via Negotiation** (SPIN)
  - Disseminates the information at each node to every node in the network.
- **Cougar**
  - This is a warehousing approach. The data is extracted in a pre-defined manner and stored in a central database (BS). Query processing takes place on the BS. Cougar is a unique model for query representation in sensor networks.

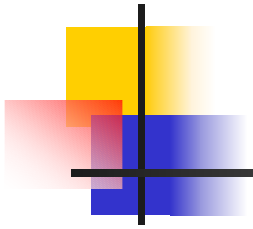


Hierarchical Routing in Sensor Networks

- Hierarchical clustering schemes are the most suitable for wireless sensor networks.
- The network consists of a Base Station (BS), away from the nodes, through which the end user can access data from the sensor network.
- BS can transmit with high power.
- Nodes cannot reply directly to the BS due to their low power constraints, resulting in asymmetric communication.

Hierarchical Routing (Cont'd)

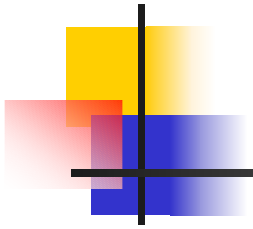




Cluster Based Routing Protocol

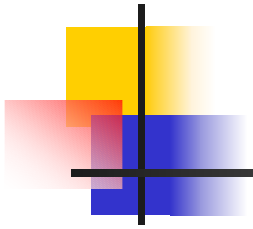
Cluster Based Routing Protocol (CBRP)

- Here the cluster members just send the data to the cluster head (CH).
- The CH routes the data to the destination.
- Not suitable for a highly mobile environment, as a lot of HELLO messages are sent to maintain the cluster.



Low-Energy Adaptive Clustering Hierarchy (LEACH)

- LEACH is a family of protocols containing both distributed and centralized schemes.
- It utilizes randomized rotation of local cluster BSs (CHs) to evenly distribute the energy load among sensors.
- It makes use of a TDMA/CDMA MAC scheme to reduce inter and intra-cluster collisions.

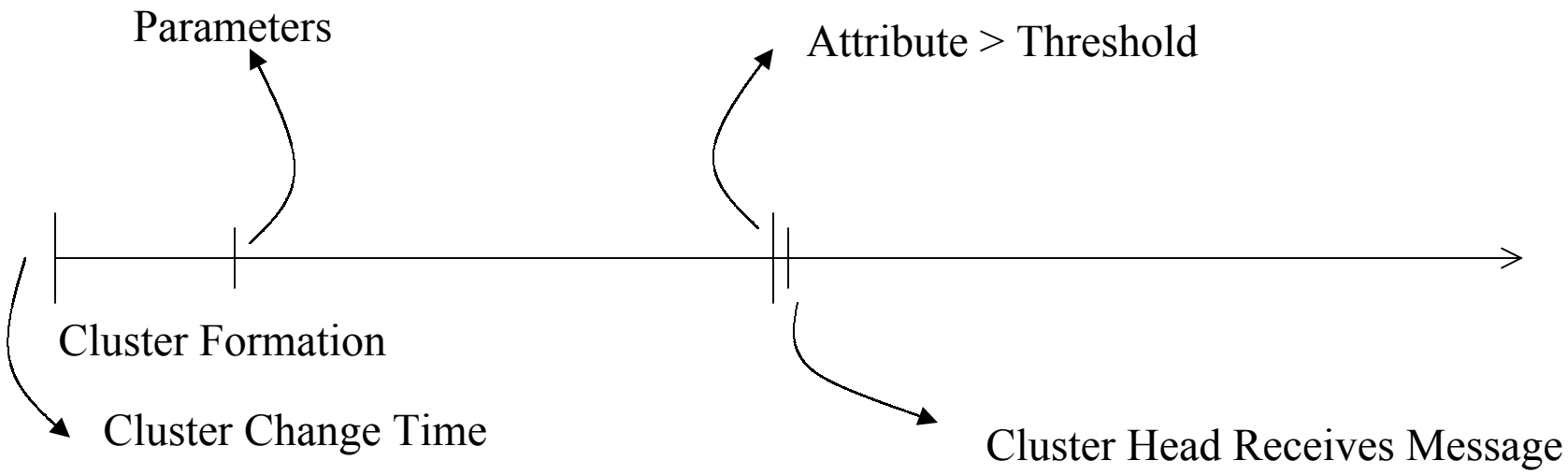


Reactive Network Protocol:TEEN

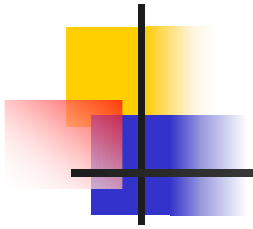
TEEN (**T**hreshold-sensitive **E**nergy **E**fficient sensor **N**etwork protocol)

- It is targeted at reactive networks and is the first protocol developed for such networks.
- In this scheme at every cluster change time, the CH broadcasts the following to its members:
  - *Hard Threshold (HT):* This is a threshold value for the sensed attribute.
  - *Soft Threshold (ST):* This is a small change in the value of the sensed attribute which triggers the node to switch on its transmitter and transmit.

Reactive Network Protocol:TEEN

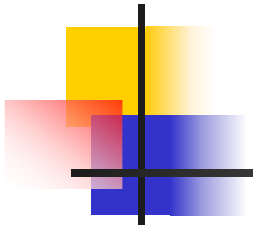


Time Line for TEEN



TEEN (Cont'd)

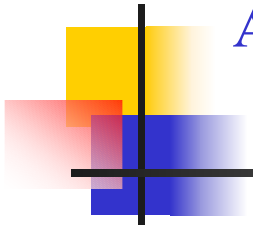
- The nodes sense their environment continuously.
- The first time a parameter from the attribute set reaches its hard threshold value, the node switches on its transmitter and sends the sensed data.
- The sensed value is stored in an internal variable, called Sensed Value (SV).
- The nodes will transmit data in the current cluster period only when the following conditions are true:
  - -- The current value of the sensed attribute is greater than the hard threshold.
  - -- The current value of the sensed attribute differs from SV by an amount equal to or greater than the soft threshold.



TEEN (Cont'd)

Important features:

- Suited for time critical sensing applications.
- Message transmission consumes more energy than data sensing. So the energy consumption in this scheme is less than the proactive networks.
- The soft threshold can be varied.
- At every cluster change time, the parameters are broadcast afresh and so, the user can change them as required.
- The main drawback is that if the thresholds are not reached, then the nodes will never communicate.



Adaptive Periodic Threshold-sensitive Energy Efficient sensor Network protocol (APTEEN)

Functioning:

The cluster heads broadcasts the following parameters:

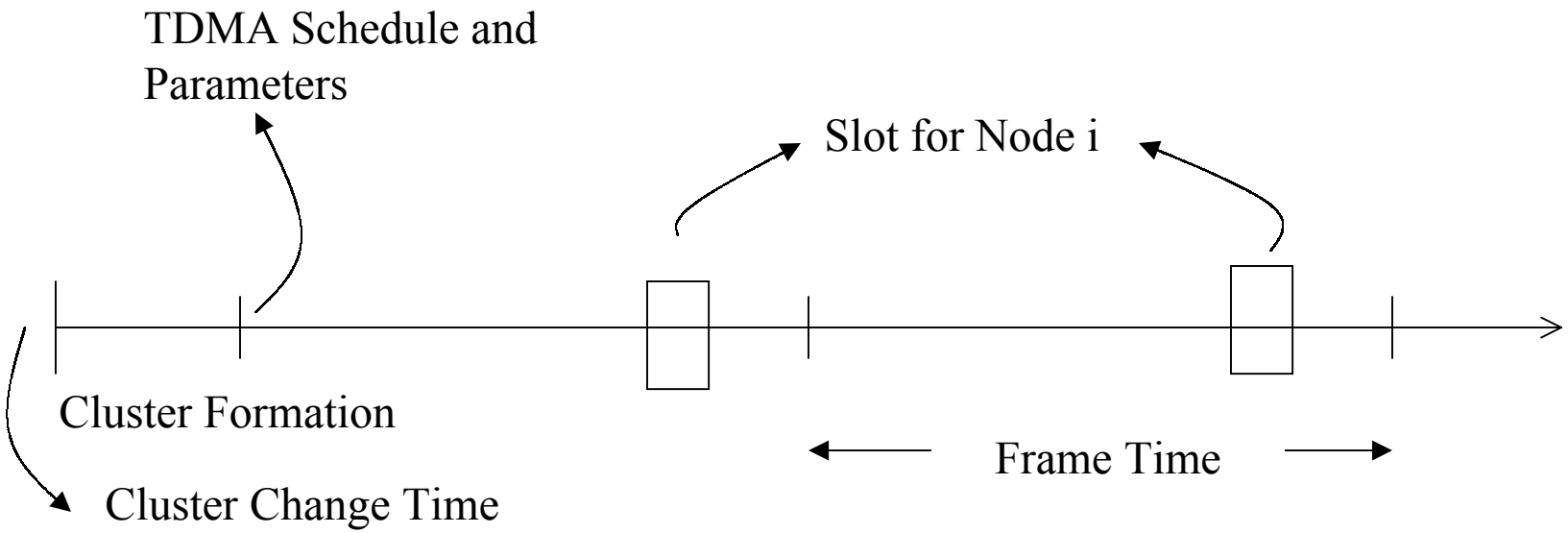
Attributes (A): This is a set of physical parameters which the user is interested in obtaining data about.

Thresholds: This parameter consists of a Hard Threshold (HT) and a Soft Threshold (ST).

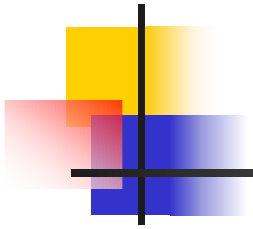
Schedule: This is a TDMA schedule, assigning a slot to each node.

Count Time (CT): It is the maximum time period between two successive reports sent by a node.

Adaptive Periodic Threshold-sensitive Energy Efficient sensor Network protocol (APTEEN)

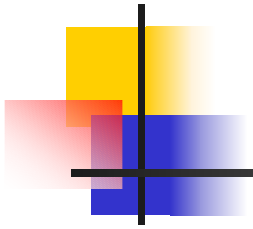


Time line for APTEEN



APTEEN (Cont'd)

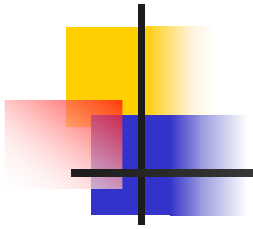
- The node senses the environment continuously.
- Only those nodes which sense a data value at or beyond the hard threshold transmit.
- Once a node senses a value beyond HT, it next transmits data only when the value of that attribute changes by an amount equal to or greater than the ST.
- If a node does not send data for a time period equal to the count time, it is forced to sense and retransmit the data.
- A TDMA schedule is used and each node in the cluster is assigned a transmission slot.



APTEEN (Cont'd)

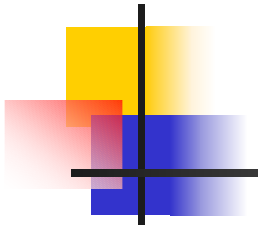
Main features of the scheme:

- It combines both proactive and reactive policies.
- It offers a lot of flexibility by allowing the user to set the count-time interval (CT) and the threshold values for the attributes.
- Energy consumption can be controlled by changing the count time as well as the threshold values.
- The main drawback of the scheme is the additional complexity required to implement the threshold functions and the count time.



Hierarchical vs Flat Topologies

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 on 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 can not be controlled	Energy dissipation adapts to traffic pattern
Fair channel allocation	Fairness not guaranteed



Adapting to the Inherent Dynamic Nature of Wireless Sensor Networks

Certain objectives that need to be achieved are:

- Exploit spatial diversity and density of sensors.
- Build an adaptive node sleep schedule.
- Explore the tradeoff between data redundancy and bandwidth consumption.
- The nodes on deployment should create and assemble a network, adapt to device failure and degradation, manage mobility of sensor nodes and react to changes in task and sensor requirements.
- Adaptability to traffic changes. Certain nodes may detect an event that could trigger a number of updates and at other times very little traffic may be present.
- Allowing finer control over an algorithm rather than simply turning it on and off.