WIRELESS SENSOR NETWORKS
(18MCA55E)
UNIT – III
"Infrastructure Establishment"

FACULTY:

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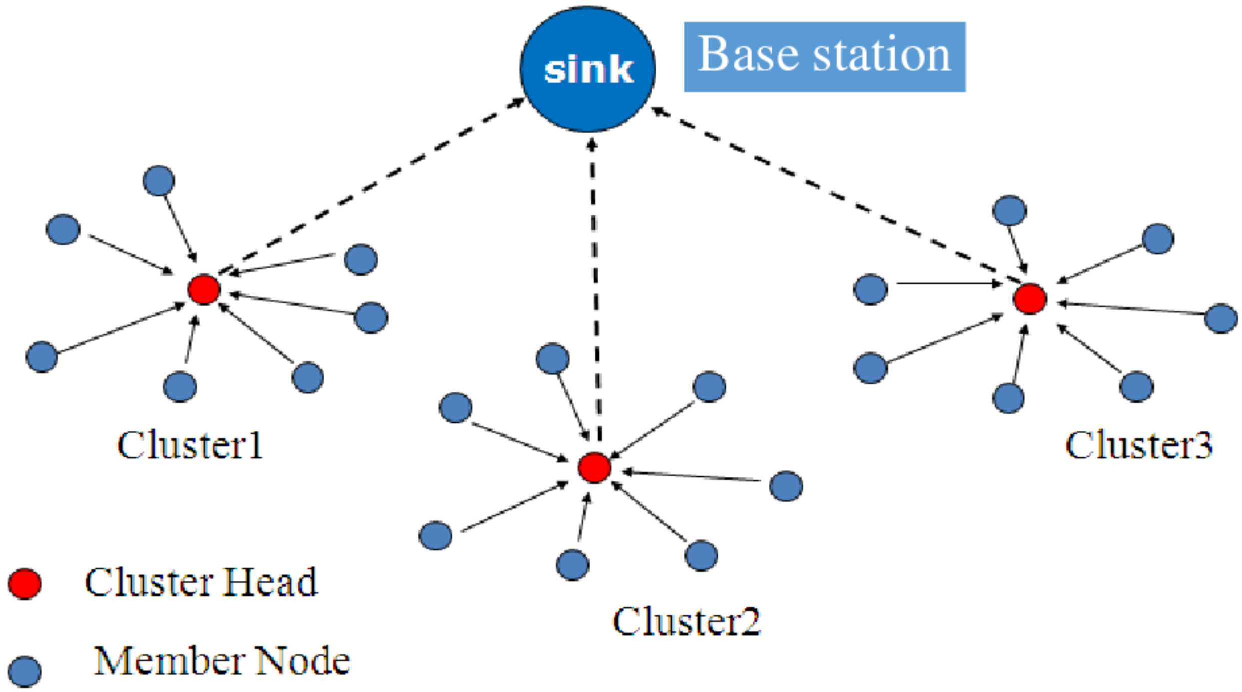
CONTENT

CLUSTERING

- What is Clustering?
  - Clustering is a critical mission in Wireless Sensor Networks for energy efficiency and network constancy.
  - Clustering in wireless sensor networks is well known and in use for a long time.
  - Currently clustering over a distributed methods is being progressing for dealing with the issues like network lifetime and energy.

CLUSTERING IN WSN



CLUSTERING OBJECTIVES

- In the cluster technique, there are some objective cluster listed as follows:
  - Allows aggregation
  - Limits data transmission.
  - Improve network lifetime.
  - Minimize network traffic and the dispute for the channel.
  - Data aggregation and updates take place in cluster heads.

ADVANTAGES OF CLUSTERING

- There are some demerits of clustering technique, listed as follows
  - It supporting network scalability and decreasing energy consumption through data aggregation.
  - It can focus the route setup within the cluster and consequently reduce the size of the routing table stored at the node.
  - It can also store communication bandwidth because it reduce the scope of inter-cluster interactions to cluster head.
  - It avoids redundant passes of messages among sensor nodes.

TYPES OF CLUSTERING ALGORITHM

- Event-to-Sink Directed Clustering
- Load balanced clustering scheme
- Low-Energy Adaptive Clustering

EVENT-TO-SINK DIRECTED CLUSTERING:

- Is type of protocol that supply high efficiency from where of energy consumption.
- a node find out an event, it transmit its report to the sink.
- A sensor node sends this collected data to cluster head so avoiding redundancy.

LOAD BALANCED CLUSTERING SCHEME

- In load balanced clustering scheme a helper node is selected to help the cluster head to perform its data aggregation and data processing task helper node sends the data to base station.
- Cluster head process the received data and transmit it to helper node.
- Helper node sends this data to base station Multi hop data transmission is used to avoid early death of helper node.

LOW-ENERGY ADAPTIVE CLUSTERING

- Is one of types in clustering algorithms.
- The aim of this type was to select nodes from the network to be as cluster heads in such a way that every node have a chance to be a cluster head.
- Low-Energy Adaptive Clustering involves two phases of operation
  - Preparation the phase
  - Stable state phase

TIME SYNCHRONIZATION

- Time Synchronization in wireless networks is extremely important for basic communication, but it also provides the ability to detect movement, location, and proximity.
- The synchronization problem consists of four parts:
  - Send time
  - Access time
  - Propagation time
  - Receive time

THE PROBLEMS OF TIME SYNCHRONIZATION

- Why Need for Time Synchronization?
  - Many of the applications of WSN needs the event with time stamp
  - Ordering of the samples for reporting
  - Events are reported by multiple nodes
  - When WSN is energy save enabled, it need all nodes to be in sync in order to be in Idle or Active mode
  - Medium Access Layer (MAC) Scheduling
  - Order of messages may change while transmission

TIME SYNCHRONIZATION IN WIRELESS SENSOR NETWORK

- Time synchronization is a required service for many applications and services in distributed systems in general.
- Numerous protocols for time synchronization have been proposed for both wired and wireless systems.
- for example, the Network Time Protocol (NTP) is a widely deployed, scalable, robust, and self-configurable synchronization approach.

- Particularly in combination with the Global Positioning System (GPS), it has been shown to achieve accuracy in the order of a few microseconds.
- However, approaches such as NTP are not suitable for WSNs due to these networks' unique characteristics and constraints.
  - Reasons for Time Synchronization
  - Challenges for Time Synchronization

REASONS FOR TIME SYNCHRONIZATION

- Sensors in a WSN monitor objects in the physical world and report activities and events to interested observers.
- For example, proximity detecting sensors, such as magnetic, capacitive, or acoustic sensors, trigger an event when a moving object (e.g., a car) passes.
- As a consequence, it is important that an observer can establish the correct logical order of events.

- For example, The real times have the ordering,

$$t1 < t2 < t3$$

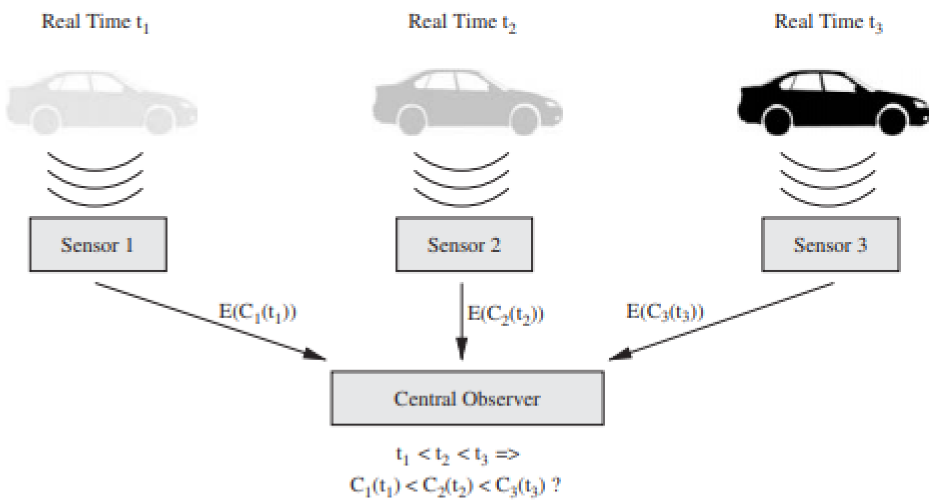
- the sensor time stamps must reflect this order, that is

$$C1(t1) < C2(t2) < C3(t3)$$

- Further, to accurately determine the velocity of the moving object, the time difference between sensor time stamps should correspond to the time difference of the real times, that is,

$$\Delta = C2(t2) - C1(t1) = t2 - t1$$

DETECTION OF SPEED AND DIRECTION OF MOVING OBJECTS USING MULTIPLE SENSORS



CHALLENGES FOR TIME SYNCHRONIZATION

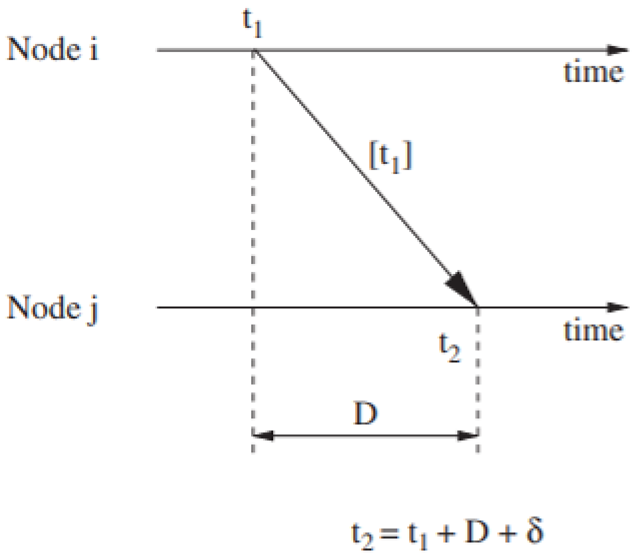
- Traditional time synchronization protocols have been designed for use in wired networks and do not consider the challenges inherit to low-cost low-power sensor nodes and the wireless medium.
- Some of which are discussed in this section, They are,
  - Environmental Effects
  - Energy Constraints
  - Wireless Medium and Mobility
  - Additional Constraints

BASICS OF TIME SYNCHRONIZATION

- Synchronization is typically based on some sort of message exchange among sensor nodes.
- If the medium supports broadcast (as is the case in wireless systems), multiple devices can be synchronized simultaneously with a low number of messages.
- In this there are two section:
  - Synchronization Messages
  - Non-determinism of Communication Latency

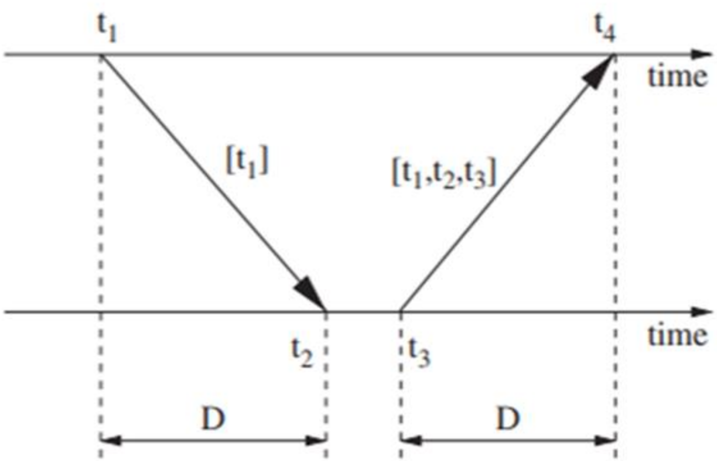
SYNCHRONIZATION MESSAGES

- Most existing time synchronization protocols are based on pairwise synchronization, where two nodes synchronize their clocks using at least one synchronization message.
- Network-wide synchronization can be achieved by repeating this process among multiple node pairs until every node in a network has been able to adjust its clock.



ONE-WAY MESSAGE EXCHANGE

The simplest approach of pairwise synchronization occurs when only a single message is used to synchronize two nodes, that is one node sends a time stamp to another node.



$$t_2 = t_1 + D + \delta$$
$$t_4 = t_3 + D + \delta$$

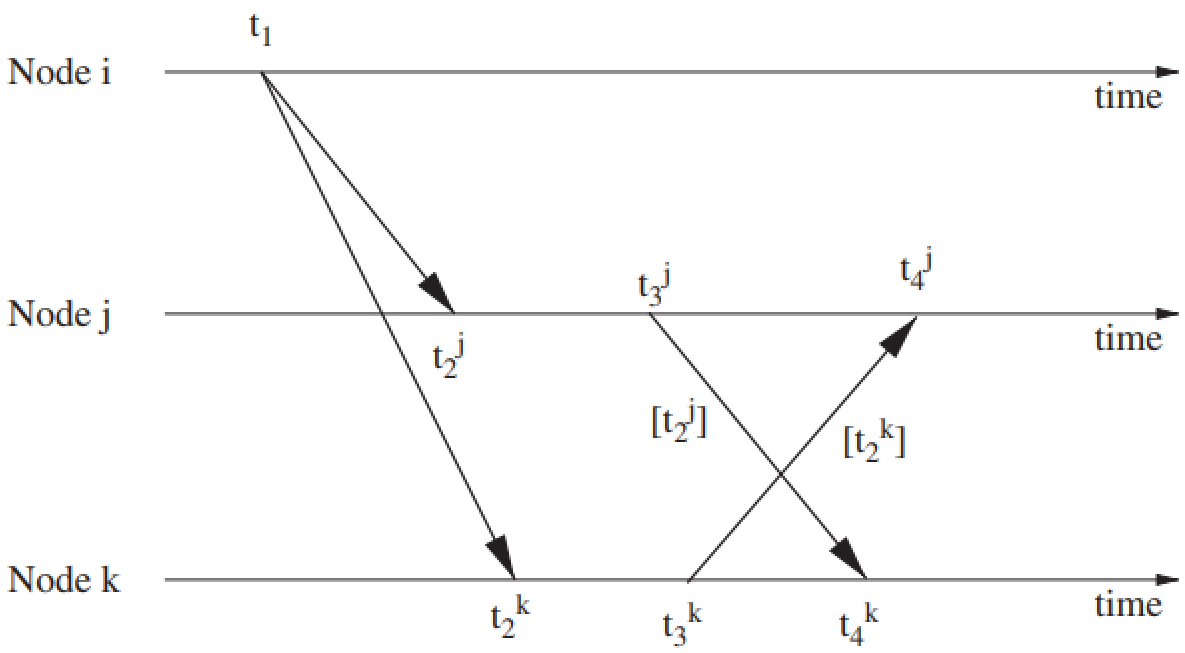
TWO-WAY MESSAGE EXCHANGE

A somewhat more accurate approach is to use two synchronization messages.

RECEIVER–RECEIVER SYNCHRONIZATION:

- A different approach is taken by protocols that apply the receiver–receiver synchronization principle, where synchronization is based on the time at which the same message arrives at each receiver.
- This is in contrast to the more traditional sender–receiver approach of most synchronization schemes.
- In broadcast environments, these receivers obtain the message at about the same time and then exchange their arrival times to compute an offset (i.e., the difference in reception times indicates the offset of their clocks).

RECEIVER–RECEIVER SYNCHRONIZATION SCHEME



NON-DETERMINISM OF COMMUNICATION LATENCY

- The non-determinism of the communication latency significantly contributes to the precision that can be achieved.
- In general, this latency experienced by synchronization messages is the sum of several components.
  - Send delay
  - Access delay
  - Propagation delay
  - Receive delay

Send delay:

- This is the time spent by the sender to generate the synchronization message and pass the message to the network interface.
- This includes delays caused by operating system behavior (system call interface, context switches), the network protocol stack, and the network device driver.

Access delay:

- This is the time spent by the sender to access the physical channel and is mostly determined by the medium access control (MAC) protocol in use.
- Contention based protocols such as IEEE 802.11's CSMA/CA must wait for an idle channel before access is allowed.

Propagation delay:

- The actual time needed for the message to travel from the sender to the receiver is called propagation delay.
- When the nodes share the same physical medium, propagation delays are very small and are often negligible in critical path analysis.

Receive delay:

- This is the time spent by the receiver device to receive the message from the medium, to process the message, and to notify the host of its arrival.

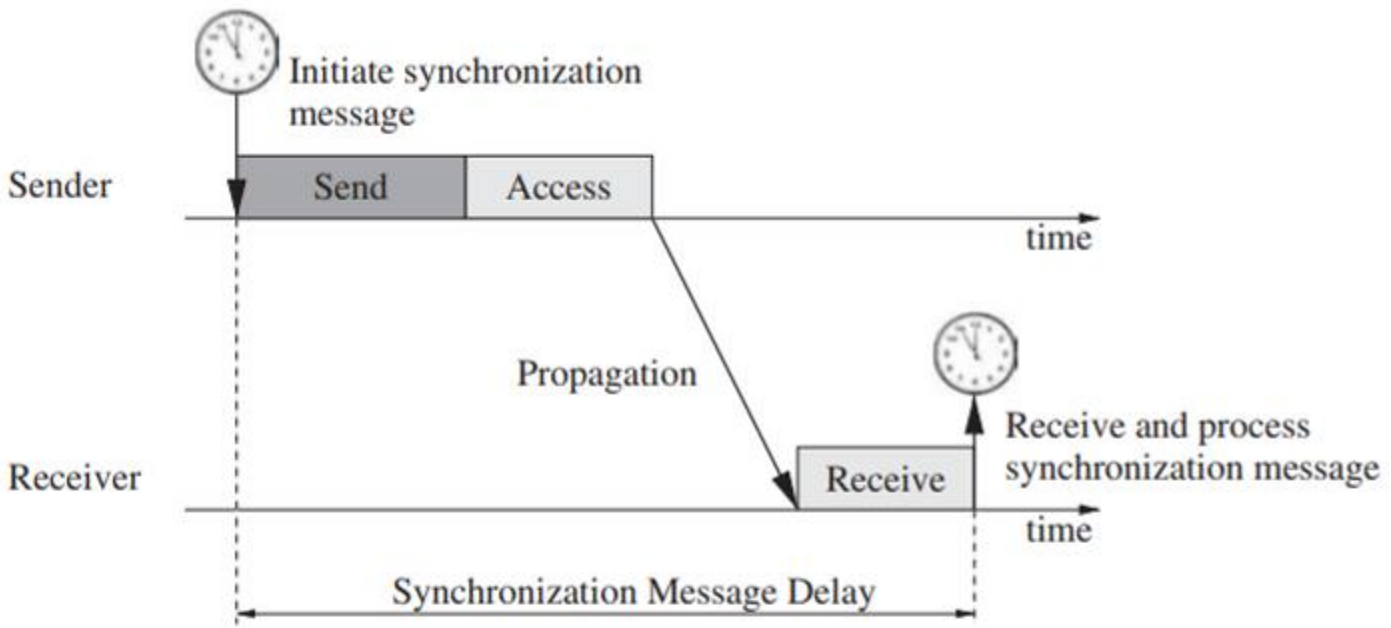


Figure 9.5 End-to-end delay experienced by a synchronization message.

FLOODING TIME SYNCHRONIZATION PROTOCOL

- The Flooding Time Synchronization Protocol synchronizes the time to possibly multiple receivers utilizing a single radio message
- Linear regression is used in FTSP to compensate for clock drift. FTSP has two types they are.,
  - Time-Stamping in FTSP
  - Multi-Hop Synchronization

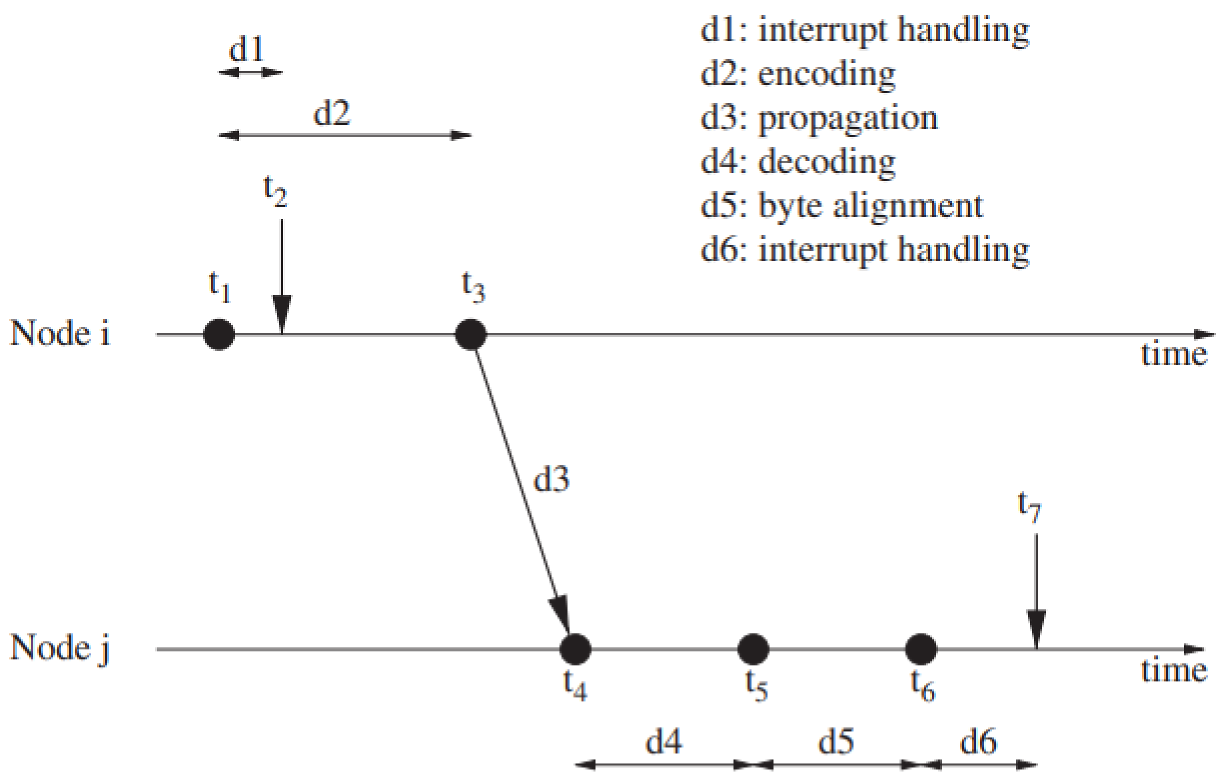
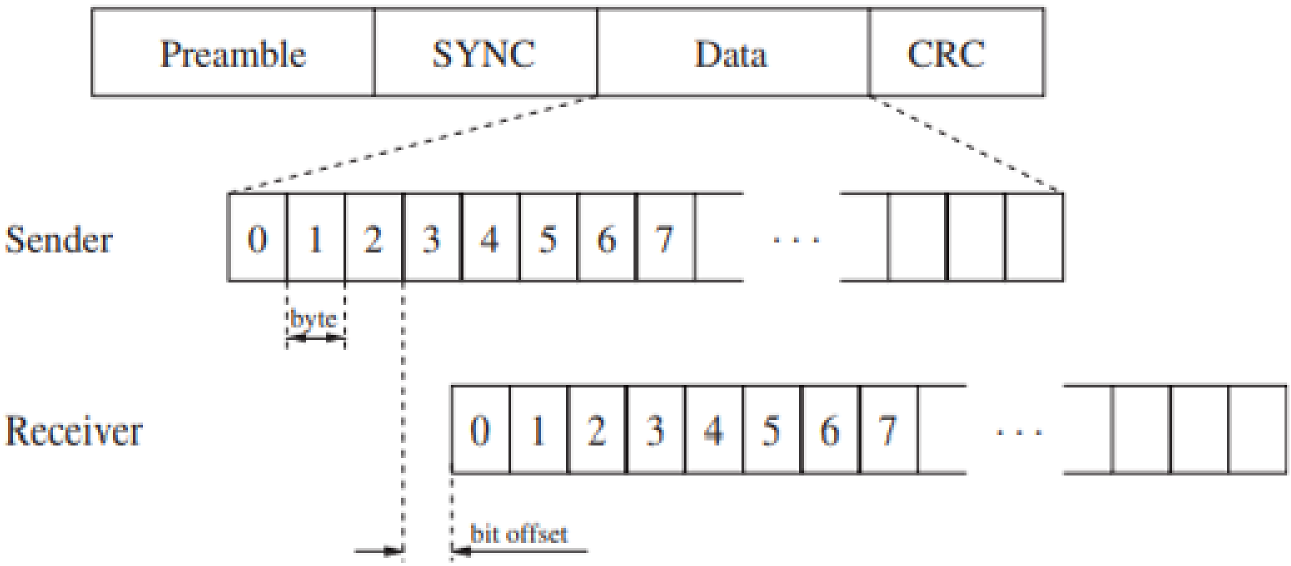


Figure 9.7 End-to-end delay of synchronization message.



TIME-STAMPING IN FTSP

In FTSP, a sender synchronizes one or more receivers with a single radio broadcast, where the broadcast message contains the sender's time stamp (which is the estimated global time at the transmission of a given byte of the message).

MULTI-HOP SYNCHRONIZATION

- Similar to TPSN, FTSP relies on an elected synchronization root to synchronize the network, where root election is based on unique node IDs (i.e., the node with the lowest ID is elected as the root node).
- The root node maintains the global time and all other nodes in the network synchronize their clocks to that of the root.

REFERENCE-BROADCAST SYNCHRONIZATION

- The Reference-Broadcast Synchronization (RBS) protocol relies on broadcast messages among a set of receivers to synchronize them with each other.
- In the wireless medium, broadcast messages will arrive at multiple receivers at approximately the same time.
- Types of errors in RBS:
  - Phase error
    - Due to nodes' clock that contains different times
  - Clock skew
    - Due to nodes' clock that run at different rates

TYPES OF ERRORS IN TRADITIONAL SYNCHRONIZATION PROTOCOL:

- Send time latency
  - Time spent at the sender to construct the message
- Access time latency
  - Time spent at the sender to wait for access to transmit the message
- Prorogation time latency
  - Time spent by the message in traveling from the sender to the receiver
- Receive time latency
  - Time spent at the receiver to receive the message from the channel and to notify the host

CRITICAL PATH ANALYSIS FOR SYNCHRONIZATION MESSAGE EXCHANGE

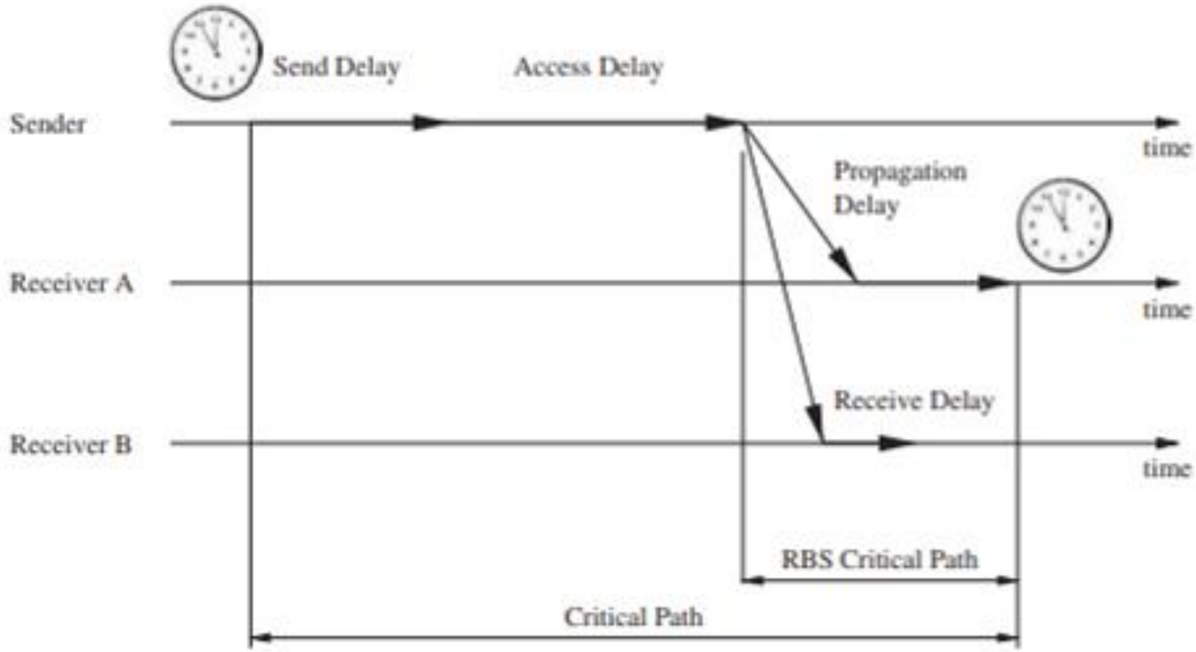
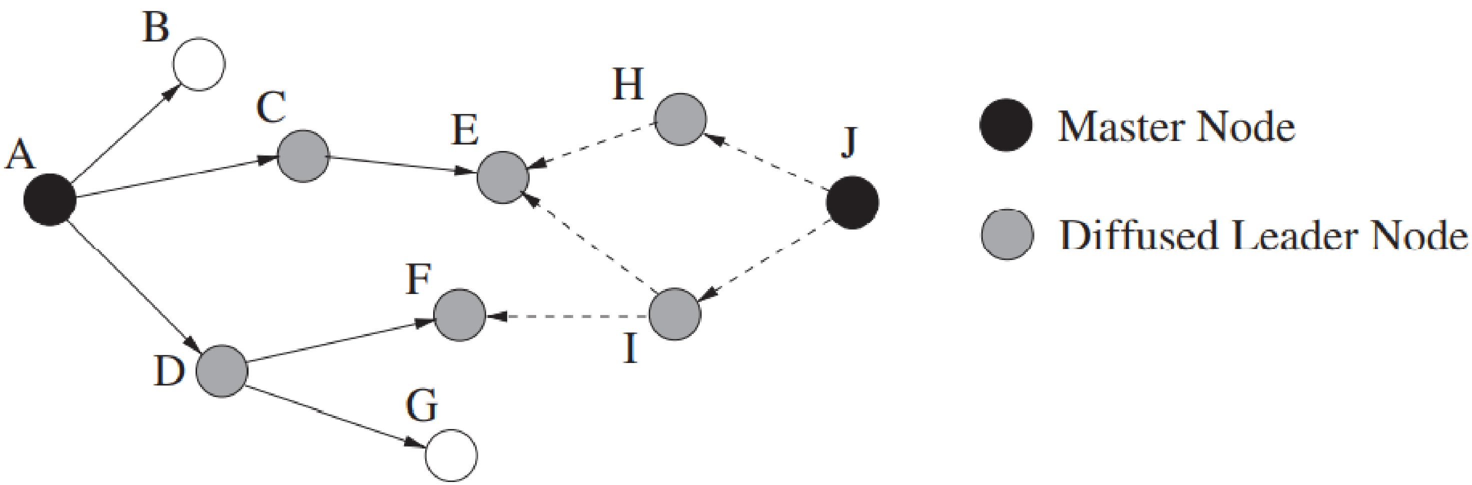


Figure 9.9 Critical path analysis for synchronization message exchanges.

TIME-DIFFUSION SYNCHRONIZATION PROTOCOL

- The Time-Diffusion Synchronization (TDP) protocol allows a sensor network to reach an equilibrium time, that is, nodes agree on a network-wide time and maintain their clocks within a small bounded deviation from this equilibrium.
- Nodes in the network dynamically structure themselves in a tree-like configuration using two types of elected roles: master nodes and diffused leader nodes.
- TDP's Time Diffusion Procedure (TP) is responsible for diffusing timing information messages from master nodes to their neighboring nodes, some of which become diffused leader nodes responsible for further propagating the master nodes' messages

CONCEPT OF SYNCHRONIZATION WITH TDP (WITH N = 2 FOR BOTH MASTERS)



CLOCK SYNCHRONIZATION PROTOCOL FOR WIRELESS SENSOR NETWORKS WITH BOUNDED COMMUNICATION DELAYS

- clock synchronization problem for wireless sensor networks. In particular, we consider a wireless sensor network where nodes are equipped with a local clock and communicate in order to achieve a common sense of time.

CLOCKS AND COMMUNICATION DELAYS

- Computer clocks are based on hardware oscillators which provide a local time for each sensor network node.
- For nodes to be able to synchronize, they must have for a period a communication channel where message delays can be reliably estimated. The latency in channel can be decomposed into four components.

Send time:

- This is the time taken by the sender to construct the message, including delays introduced by operating system calls, context switching, and data access to the network interface.

Access time:

- This is the delay incurred while waiting for access to the transmission channel due to contention, collisions, and the like. The details of that are very MAC-specific.

Propagation time:

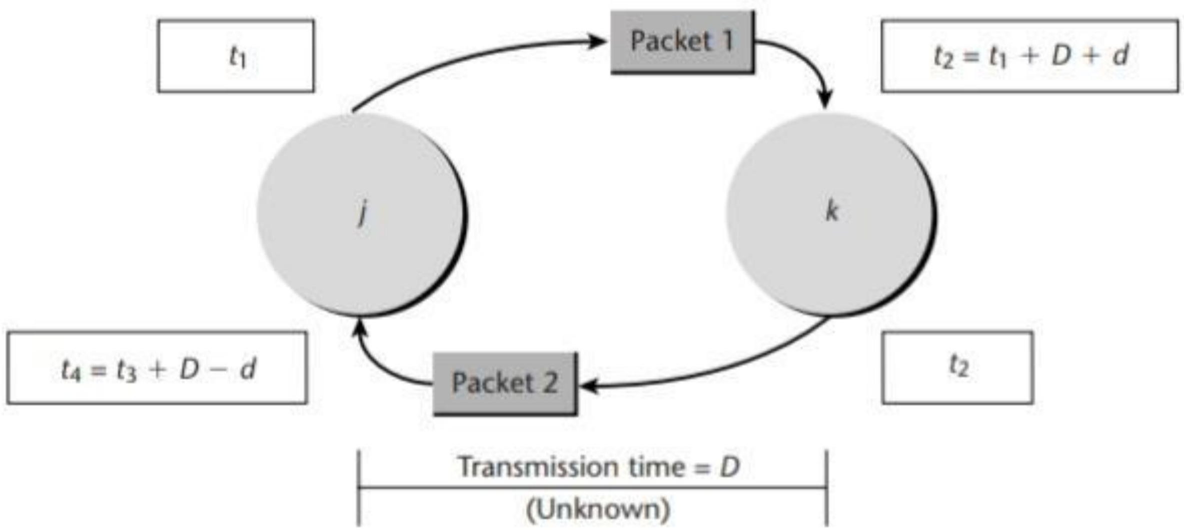
- This is the time for the message to travel across the channel to the destination node. It can be highly variable, from negligible for single-hop wireless transmission to very long in multi-hop wide-area transmissions.

Receive time:

- This is the time for the network interface on the receiver side to get the message and notify the host of its arrival.
- This delay can be kept small by time-stamping the incoming packet inside the network driver's interrupt handler

- Node i reads its local clock with time value t1 and sends this in a packet to node j.
- Node j records the time t2 according to its own clock when the packet was received. We must have t2 = t1 + D + d.
- Node j, at time t3, sends a packet back to i containing t1, t2, and t3.

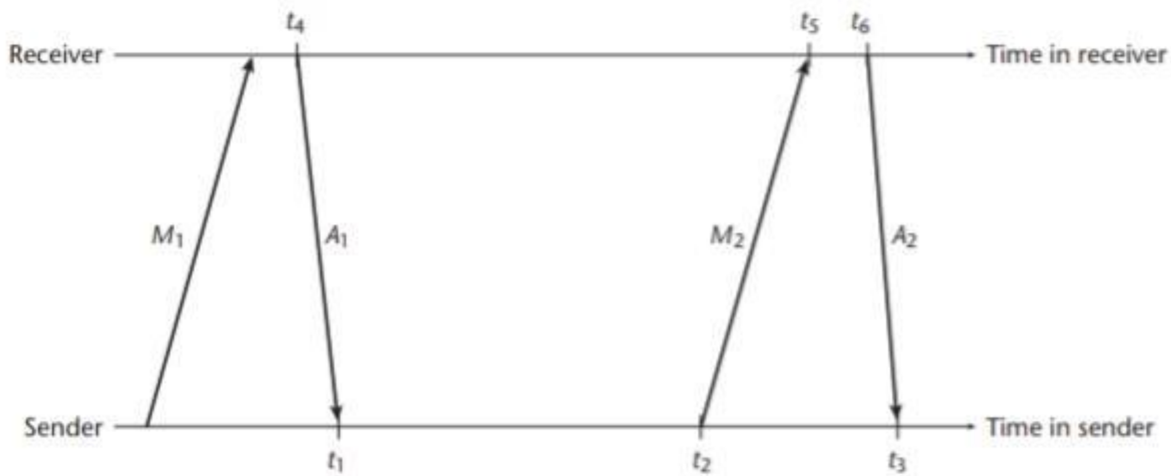
- Node i receives this packet at time t4. We must have $t4 = t3+D-d$.
- Therefore, node i can eliminate D from the above two equations and compute $d = (t2 - t1 - t4 + t3)/2$.
- Finally, node i sends the computed phase difference d back to node j.



t_1
Packet 1
$t_2 = t_1 + D + d$
j
k
$t_4 = t_3 + D - d$
Packet 2
t_2
Transmission time = D
(Unknown)

INTERVAL METHODS

- As we mentioned, in many situations involving temporal reasoning, the temporal ordering of events matters much more than the exact times when events occurred. In such situations, interval methods provide a lightweight protocol that can be used to Move clock readings around the network and perform temporal Comparisons.



Receiver
Time in receiver
Sender
Time in sender
t_4
t_5
t_6
M_1
A_1
M_2
A_2
t_1
t_2
t_3

- M1 was a message sent from node 1 to node 2 earlier, for other purposes. Now M2 will be used to carry information about the time stamp S1(E). The idle time duration
- 1 = t2 − t1 can be measured according to the local clock of node 1, as the time between receiving
- A1 and transmitting M2. The round-trip duration p1 = t5 − t4 can be measured according to the local clock of node 2, as the time between transmitting A1 and receiving M2. If sender node 1 piggybacks the idle time duration 1 on M2, then at time t5, the receiver node 2 can estimate the communication delay d via the bounds

$$0 \leq d \leq p1 - l11 - \rho 2/1 + \rho 1$$

REFERENCE BROADCAST :

- Reference Broadcasts Using Global Sources of Time
  - The Global Positioning System (GPS) continuously broadcasts time measured from an epoch started at 0h 6 January, 1980 UTC. However, unlike UTC, GPS is not perturbed by leap seconds and is therefore ahead of UTC by an integer number of seconds (15 seconds as of 2009). Even inexpensive GPS receivers can receive GPS time with a precision of 200ns (Dana 1997; Mannermaa et al. 1999).

EXAMPLE :

- Time signals are also being transmitted by terrestrial radio stations, for example, the National Institute of Standards and Technology uses radio stations WWV/WWVH and WWVB (Lichtenecker 1997) to continuously broadcast time based on atomic clocks. However, such approaches exhibit a number of challenges that prohibit their use for many WSNs. For example, GPS is not ubiquitously available (underwater, indoors, under dense foliage, during Mars exploration), requires a relatively high-power receiver which may not be feasible for tiny low-cost sensor nodes, and may be too large and costly to be added to small sensor nodes.

LIGHTWEIGHT TREE-BASED SYNCHRONIZATION

- The primary goal of the Lightweight Tree-Based Synchronization (LTS) protocol (Van Greunen and Rabaey 2003) is to provide a specified precision (instead of a maximum precision) with as little overhead as possible. LTS can be used with different algorithms for both centralized and decentralized multi-hop synchronization. To understand the approach taken by LTS, let us first consider the message exchange for the synchronization of a pair of nodes

- First, node j transmits a synchronization message time-stamped with the transmission time t1 to node k. Upon arrival of this message at node k at time t2, node k responds with a message carrying a time stamp t3 and the previously recorded times t1 and t2. This message is received by node j at time t4. Note that times t1 and t4 are based on node j’s clock, whereas times t2 and t3 are recorded using the clock of node k.

- Assuming a transmission delay D (which is further assumed to be the same in both directions) and an unknown clock offset between the clocks of nodes j and k, time t2 of node k is equal to t1 +D+ offset. Similarly, t4 is then equal to t3 +D−offset.
- The offset can then be calculated as: $offset = t2 - t4 - t1 + t3/2$.
- The centralized multi-hop version of LTS is based on a single reference node that is the root of a spanning tree comprising all nodes of the network.

TIMING-SYNC PROTOCOL FOR SENSOR NETWORKS

- The Timing-sync Protocol for Sensor Networks (TPSN) (Ganeriwal et al. 2003) is another traditional sender–receiver synchronization approach that uses a tree to organize a net- work.
- TPSN uses two phases for synchronization: the level discovery phase (executed during network deployment) and the synchronization phase.

FLOODING TIME SYNCHRONIZATION PROTOCOL

- The goals of the Flooding Time Synchronization Protocol (FTSP) (Mar´oti et al. 2004) are to achieve network-wide synchronization with errors in the microsecond range, scalability up to hundreds of nodes, and robustness to changes in network topology including link and node failures. FTSP differs from other solutions in that it uses a single broadcast to establish synchronization points between sender and receivers while eliminating most sources of synchronization error.

TYPES:

- Time-Stamping in FTSP In FTSP, a sender synchronizes one or more receivers with a single radio broadcast, where the broadcast message contains the sender's time stamp (which is the estimated global time at the transmission of a given byte of the message).
- Multi-Hop Synchronization- Similar to TPSN, FTSP relies on an elected synchronization root to synchronize the network, where root election is based on unique node IDs (i.e., the node with the lowest ID is elected as the root node).

REFERENCE-BROADCAST SYNCHRONIZATION

- The Reference-Broadcast Synchronization (RBS) protocol (Elson et al. 2002) relies on broadcast messages among a set of receivers to synchronize them with each other. In the wireless medium, broadcast messages will arrive at multiple receivers at approximately the same time. The variability in message delay will be dominated by the propagation delays and the time needed by the receivers to receive and process the incoming broadcast message.

TIME-DIFFUSION SYNCHRONIZATION

- The Time-Diffusion Synchronization (TDP) protocol (Su and Akyildiz 2005) allows a sensor network to reach an equilibrium time, that is, nodes agree on a network-wide time and maintain their clocks within a small bounded deviation from this equilibrium.
- Types of elected roles:
  - master nodes
  - diffused leader nodes

MINI-SYNC AND TINY-SYNC

- Two closely related protocols, called Mini-sync and Tiny-sync, provide pairwise synchronization (that can be used as basic building blocks to synchronize an entire sensor network) with low bandwidth, storage, and processing requirements (Yoon et al. 2007). The relationship of the clocks of two nodes in a sensor network can be expressed as: $C1(t) = a12C2(t)+b12$

LOCALIZATION

- Localization is necessary to provide a physical context to sensor readings, for example, in many applications such as environmental monitoring, sensor readings withoutknowledgeofthelocationwherethereadingswereobtainedaremeaningless.L ocation information is further necessary for services such as intrusion detection, inventory and supply chain management, and surveillance. Finally, localization is fundamental for sensor network services that rely on the knowledge of sensor positions, including geographic routing and coverage area management.

- The location of a sensor node can be expressed as a global or relative metric. A global metricisusedtopositionnodeswithinageneralglobalreferenceframe,forexample,aspro- vided by the GPS (longitudes and latitudes) and the Universal Transverse Mercator (UTM) coordinate systems (zones and latitude bands). Incontrast , relative metrics are base donarbitrary coordinate systems and reference frames, for example, a sensor's location expressed as distances to other sensors without any relationship to global coordinates.

LOCALIZATION SERVICES

- Software localization services are the adaptation of a software program by a localization company to meet the needs of a foreign audience linguistically, culturally, and legally.

RANGING TECHNIQUES

- The foundation of numerous localization techniques is the estimation of the physical distance between two sensor nodes. Estimates are obtained through measurements of certain characteristics of the signals exchanged between the sensors, including signal propagation times, signal strengths, or angle of arrival.

TYPES:

- Time of arrival
- Time difference of arrival
- Angle of arrival
- Receive signal strength

Time of arrival:

- The concept behind the time of arrival (ToA) method (also called time of flight method) is that the distance between the sender and receiver of a signal can be determined using the measured signal propagation time and the known signal velocity.

$$distij = (t2 - t1) \times v \ (10.1)$$

$$distij = (t4 - t1) - (t3 - t2)/2 \times v$$

Time difference of arrival:

- The time difference of arrival (TDoA) approach uses two signals that travel with different velocities .The receiver is then able to determine its location similar to the ToA approach. For example, the first signal could be a radio signal (issued at t1 and received at t2), followed by an acoustic signal (either immediately or after a fixed time interval t wait = t3 −t1). Therefore, the receiver can determine the distance as:

$$dist = (v1 - v2) \times (t4 - t2 - t\ wait)$$

Angle of arrival:

- Angle of Arrival Another technique used for localization is to determine the direction of signal propagation, typically using an array of antennas or microphones. The angle of arrival (AoA) is then the angle between the propagation direction and some reference direction known as orientation.

Receive signal strength:

- The concept behind the received signal strength (RSS) method is that a signal decays with the distancetraveled.Acommonlyfoundfeatureinwirelessdevicesisareceivedsignalstrength indicator (RSSI),which can be used to measure the amplitude of the incoming radio signal. Many wireless network card drivers readily export RSSI values, but their meaning may differfromvendortovendorandthereisnospecifiedrelationshipbetweenRSSIvaluesand the signal's power levels.

- Typically, RSSI values are in the range of 0… RSSI_Max, where common values for RSSI_Maxare 100, 128, and 256. In free space, the RSS degrades with thesquareofthedistancefromthesender.Morespecifically,theFriistransmissionequation expresses the ratio of the received power Pr to the transmission power Pt as:

$$\mathrm{Pr}/Pt = GtGr\lambda 2/(4\pi)2R2$$

- where Gt is the antenna gain of the transmitting antenna and Gr is the antenna gain of the receiving antenna. In practice, the actual attenuation depends on multipath propagation effects, reflections, noise, etc., therefore a more realistic model replaces R2 in Equation (10.4) with Rn with n typically in the range of 3 and 5.

RANGE BASED LOCATION ALGORITHMS:

- Triangulation
- Trilateration
- Iterative and collaborative multilateration
- GPS based location

Triangulation

- Triangulation uses the geometric properties of triangles to estimate sensor locations. Specifically, triangulation relies on the gathering of angle (or bearing) measurements as described in the previous section. A minimum of two bearing lines (and the locations of the anchor nodes or the distance between them) are needed to determine the location of a sensor node in two-dimensional space.

Trilateration

- Trilateration refers to the process of calculating a node's position based on measured distances between itself and a number of anchor points with known locations.

Iterative and Collaborative Multilateration

- While the late ration technique relies on the presence of at least three anchor nodes to position a fourth unknown node, this technique can be extended to determine locations of nodes without three neighboring anchor nodes. Once a node has identified its position using the beacon messages from the anchor nodes, it becomes an anchor and broadcasts beacon messages containing its estimated position to other nearby nodes. This iterative multilateration process.

GPS-Based Localization

- The Global Positioning System (GPS)(Hofmann-Wellenhof et al. 2008) is the most widely publicized location-sensing system, providing an excellent lateration framework for deter- mining geographic positions (Hightower and Borriello 2001). GPS (formally known as NAVSTAR – Navigation Satellite Timing and Ranging) is the only fully operational global navigation satellite system (GNSS) and it consists of at least 24 satellites orbiting the earth at altitudes of approximately 11,000 miles.

LEVELS OF GPS BASED LOCATION:

- The Standard Positioning Service (SPS) is a positioning service available to all GPS usersonacontinuousworldwidebasiswithoutrestrictionsordirectcharge.High-quality GPS receivers based on SPS are able to attain accuracies of 3m and better horizontally.
- The Precise Positioning Service (PPS) is used by US and Allied military users and is a more robust GPS service that includes encryption and jam resistance. For example, it uses two signals to reduce radio transmission errors, while SPS only uses one signal.

LOCALIZATION

- Localization is a process to compute the locations of wireless device in a network
- Localization and tracking
- The estimation of the state of a physical entity such as a physical phenomenon or a sensor node from a set of measurements.
- Tracking produces a series of estimates over time.

NODE SERVICES

- Services such as time synchronization and node localization that enable applications to discover properties of a node and the nodes to organize themselves into a useful network.

SELF-LOCALIZATION

- Methods that allow the nodes in a network to determine their geographic positions on their own as much as possible, during the network initialization process.

COLLABORATIVE MULTILATERATION

- Collaborative multilateration proceeds by computing substructures of the network called collaborative subtrees—these are subgraphs of the full network graph in which there are enough constraints to make the localization problem sufficiently over determined that error accumulation is avoided.

OTHER LOCALIZATION ALGORITHMS

- In settings where RSS and other ranging technologies cannot be used directly to estimate distances, there are Other ways.
- In every sensor network, each node knows what other nodes it can talk to directly its neighbors.
- If the sensor nodes are densely and uniformly deployed, then we can use hop counts to landmarks as a substitute to physical distance estimates.
- In this setting, each landmark floods the network with a broadcast message whose hop count is incremented as it is passed from node to node.

- The hop count in the message from a landmark that first reaches a node is the hop distance of that node to the landmark (standard graph-based breadth-first search).
  - In order to transform hop counts into approximate distances, the system must estimate the average distance corresponding to a hop.
  - This can be done either by using inter-landmark distances that are known in both hop and Euclidean terms, or by using prior information about the size of the area where the nodes are deployed and their density.
  - Once a node has approximate distances to at least three landmarks this way, then the previous uni-lateration and multilateration techniques can be used.

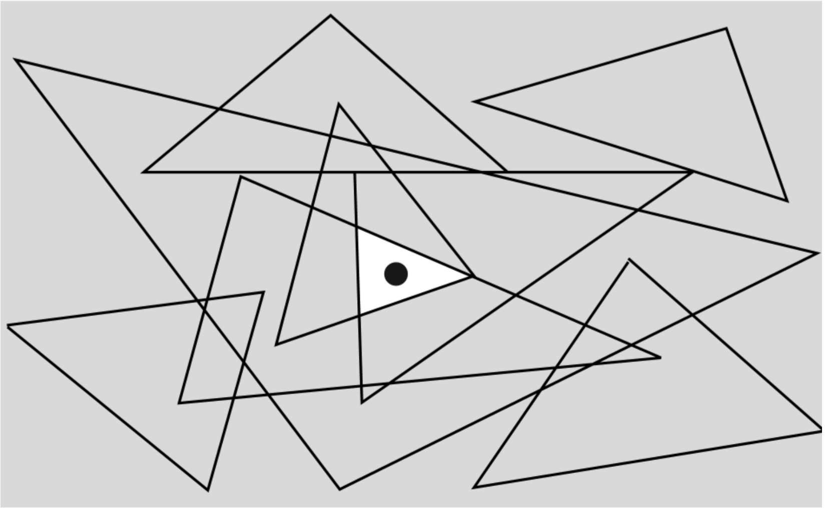
- Note that the presence or absence of a radio link between two nodes is a quantized form of received signal strength measurement.
  - If the radio range is known, the presence of a radio link can also be expressed as a convex constraint on the positions of the nodes, and convex programming techniques have been suggested for addressing the localization problem.
  - Another interesting option is to use RSS only for distance comparisons to landmarks and not for distance estimation.

- In the neighborhood of a node, a slight displacement that results in increased RSS from a landmark can be taken to indicate the node has moved closer to the landmark; correspondingly, reduced RSS from a landmark can be taken to indicate the node has moved farther from the landmark.
  - Even if sensor nodes cannot move, they can interrogate their neighbors for their RSS and thus can make inferences about relative distances to landmarks.
  - This becomes interesting for localization because of the following observation: if a node is contained in a triangle defined by three landmarks it can hear, then no matter how it moves differentially, the RSS from at least one of the three landmarks has to increase.

- On the other hand, if the node is outside the triangle defined by the three landmarks, then there will be some direction of motion so that RSS from all three landmarks decreases.
  - Again, in the absence of motion, a node can perform an approximate version of this test by interrogating all of its one-hop neighbors.
  - Approximate Point in Triangle (APIT) test, used for range-free localization.
  - For any triplet of landmarks that a node can hear, if the node passes the APIT test (i.e., for each one of its neighbors at least some landmark sounds stronger) with respect to these landmarks, then the node is declared to be in the triangle defined by the landmarks.

Node localization using multiple triangle containment tests

- Thus, the node can be localized to lie at the intersection of all landmark triangles that are known to contain it.



- It should be noted again that both false positives and false negatives are possible with APIT.
  - Anode maybe outside a landmark triangle but simply fail to have a neighbor in the direction in which all three landmarks have reduced RSS (false positive).
  - Or a node maybe inside such a triangle but have a neighbor who is outside and for which all three landmarks have reduced RSS (false negative).
  - APIT failures happen less than 14 percent of the time. The same paper argues that the accuracy of localization provided by k landmarks is O(1/k2).

THANK YOU

THE CONTENTS IN THIS E-MATERIAL IS TAKEN FROM THE TEXTBOOKS AND REFERENCE BOOKS GIVEN IN THE SYLLABUS