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Sensor Networks– Part III

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Target Tracking

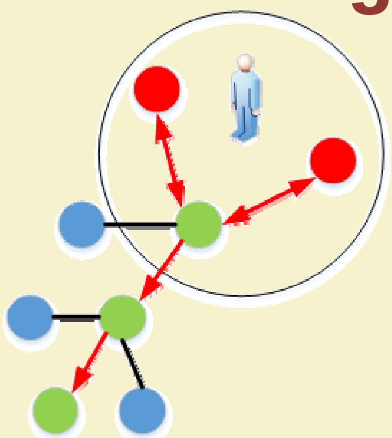


Fig a: Push-based formulation: Nodes compute the position of the target and periodically notify the sink node. A cluster structure is commonly used in this case

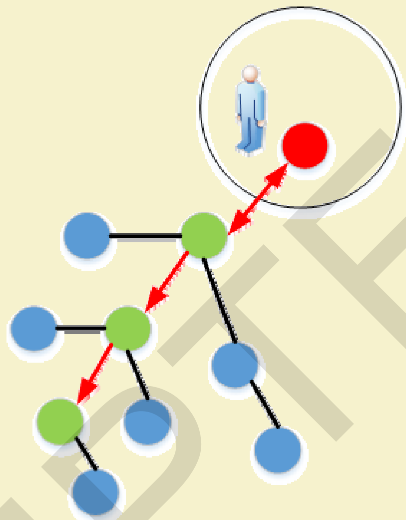


Fig b: Poll-based formulation: Nodes register the presence of the target to permit a low-cost query. Data reports are sent toward the sink only when there is a query to be answered. Tree structure is often used in this case

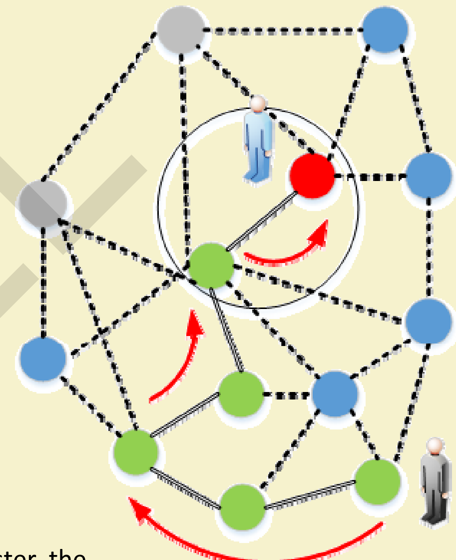
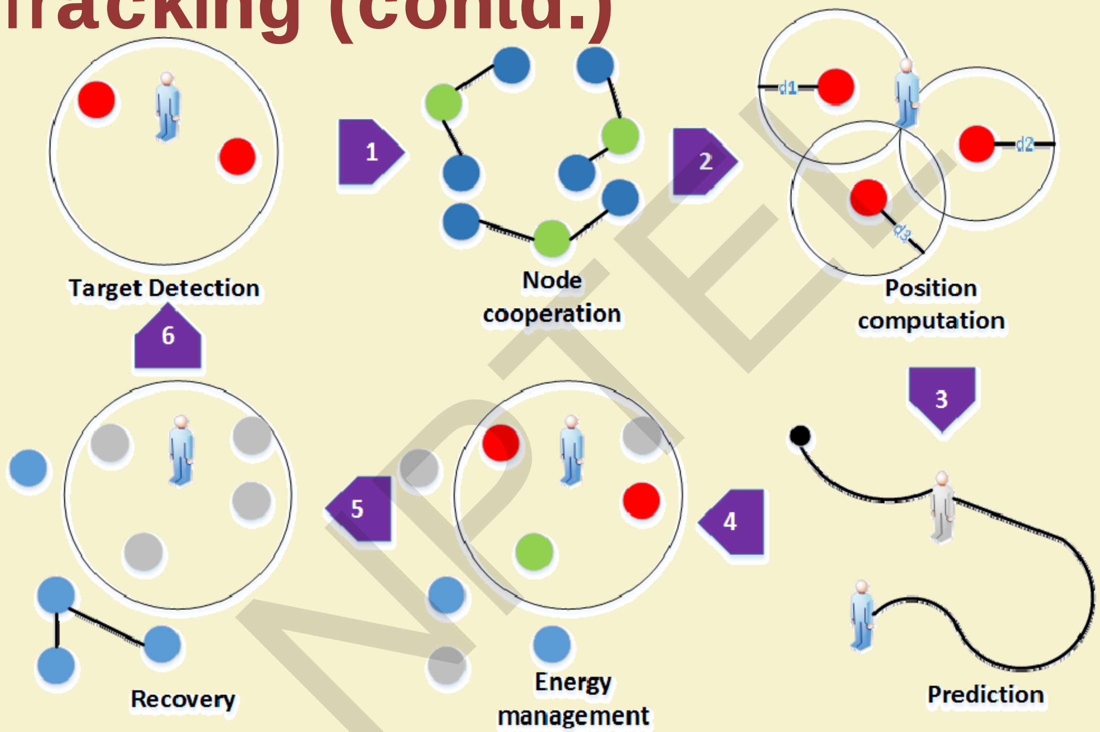


Fig c: Guided formulation: Some nodes (beacon nodes) define a trajectory to the target. The tracker follows this trail to intercept the target. Face structure is often used in this case

Source: Éfren L. Souza, Eduardo F. Nakamura, and Richard W. Pazzi. 2016. Target Tracking for Sensor Networks: A Survey. ACM Computing Survey, 49, 2, 2016

Target Tracking (contd.)



Source: Éfren L. Souza, Eduardo F. Nakamura, and Richard W. Pazzi. 2016. Target Tracking for Sensor Networks: A Survey. ACM Computing Survey, 49, 2, 2016

WSNs in Agriculture

✓ AID: A Prototype for Agricultural Intrusion Detection Using Wireless Sensor Network

- A set of sensor nodes are deployed over an agricultural field
- Each of the board are enabled with two type of sensors:

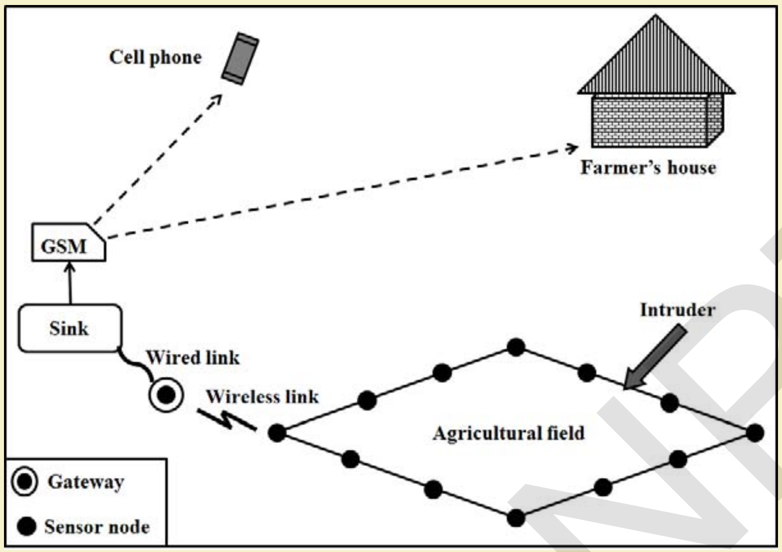
    a) Passive Infrared (PIR)

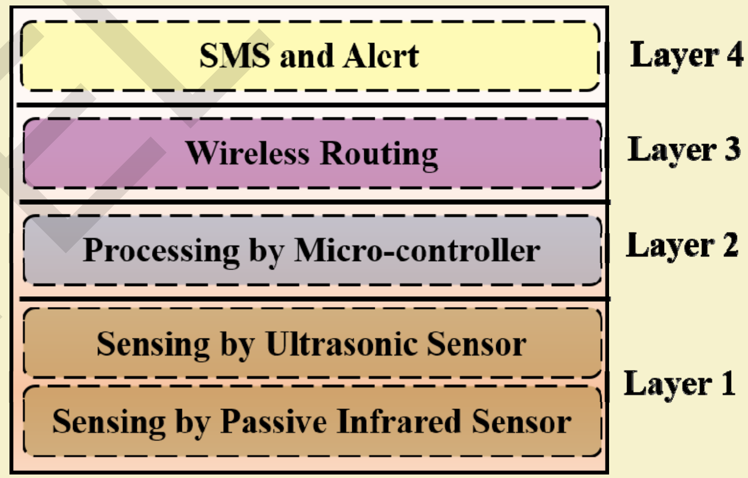
    b) Ultrasonic

- When an intruder enters into the field through the boundary (perimeter) of the field, the PIR sensor detects the object.
- The ultrasonic sensor senses the distance at which the object is located

Source: Sanku Kumar Roy, Arijit Roy, Sudip Misra, Narendra S Raghuwanshi, Mohammad S Obaidat, AID: A Prototype for Agricultural Intrusion Detection Using Wireless Sensor Network, IEEE International Conference on Communications (ICC), 2015

WSNs in Agriculture (contd.)





Source: Sanku Kumar Roy, Arijit Roy, Sudip Misra, Narendra S Raghuwanshi, Mohammad S Obaidat, AID: A Prototype for Agricultural Intrusion Detection Using Wireless Sensor Network, IEEE International Conference on Communications (ICC), 2015

Wireless Multimedia Sensor Networks (WMSNs)

- Incorporation of low cost camera (typically CMOS) to wireless sensor nodes
- Camera sensor (CS) nodes
  - capture multimedia (video, audio, and the scalar) data, expensive and resource hungry, directional sensing range
- Scalar sensor (SS) nodes
  - sense scalar data (temperature, light, vibration, and so on), omni-directional sensing range , and low cost
- WMSNs consist of less number of CS nodes and large number of SS nodes

Source: S. Misra, G. Mali, A. Mondal, "Distributed Topology Management for Wireless Multimedia Sensor Networks: Exploiting Connectivity and Cooperation", International Journal of Communication Systems (Wiley), 2014

Wireless Multimedia Sensor Networks (WMSNs)

- WMSNs Application
  - In security surveillance, wild-habitat monitoring, environmental monitoring, SS nodes cannot provide precise information
  - CS nodes replace SS nodes to get precise information
  - Deployment of both CS and SS nodes can provide better sensing and prolong network lifetime

Source: S. Misra, G. Mali, A. Mondal, "Distributed Topology Management for Wireless Multimedia Sensor Networks: Exploiting Connectivity and Cooperation", International Journal of Communication Systems (Wiley), 2014

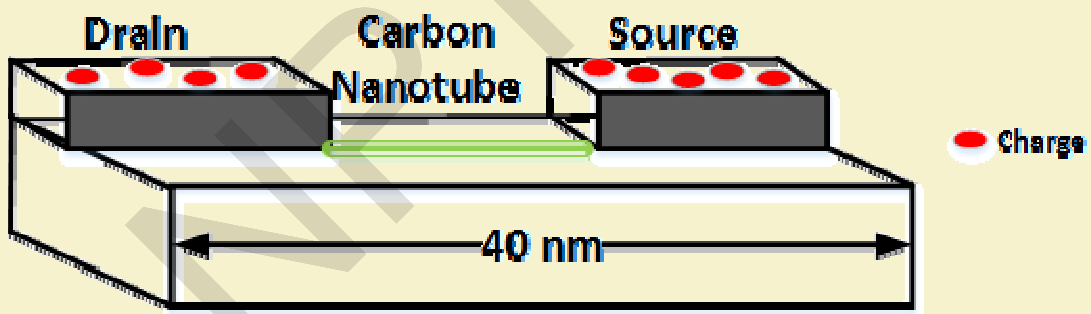
Topology Management in WMSNs

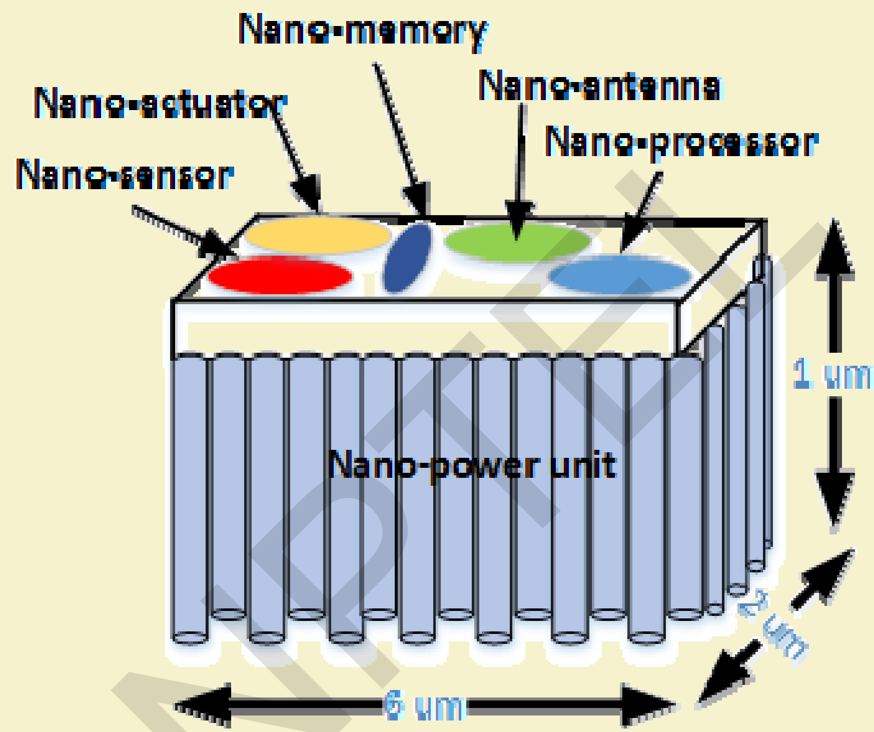
- Video data are larger in size (e.g., 1024 bytes) which require larger bandwidth and consume high battery power
- Coverage of the event should be provided as soon as the event occurs
- Connectivity is another important metric that should be provided during video data transfer from the event area to the control center
- Therefore, Misra et al. proposed the distributed topology management of the WMSNs considering coverage, connectivity, and network lifetime
- Coverage of the event is provided by using Coalition Formation Game between the CS and SS nodes

Source: S. Misra, G. Mali, A. Mondal, "Distributed Topology Management for Wireless Multimedia Sensor Networks: Exploiting Connectivity and Cooperation", International Journal of Communication Systems (Wiley), 2014

Nanonetworks

- Nanodevice has components of sizes in the order nano-meters.
- Communication options among nanodevices
  - Electromagnetic
  - Molecular





Source: Akyildiz and Jornet, "Electromagnetic Wireless Nanosensor Networks", Nano Communication Networks, 2010

Molecular Communication

- Molecule used as information
- Information packed into vesicles
- Gap junction works as mediator between cells and vesicles
- Information exchange between communication entities using molecules
- Performed at NTT, Japan lab

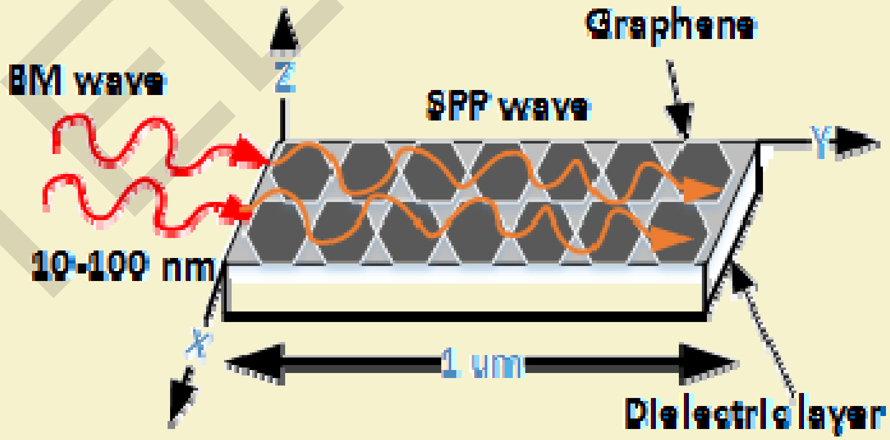
Sources:

Jornet and Akyildiz, "Graphene-based plasmonic nano-antenna for terahertz band communication in nanonetworks", IEEE JSAC, 2013

S. Hiyama, Y. Masitani, T. Suda, "Molecular transport system in molecular communication", NTT Documo Technical Journal, Vol. 10, No. 3

Electromagnetic-based Communication

- Surface Plasmonic Polarition (SPP) generated upon electromagnetic beam
- EM communication for Nanonetworks centers around 0.1-10 Terahertz channel



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Underwater Acoustic Sensor Networks

- In a layered shallow oceanic region, the inclusion of the effect of internal solitons on the performance of the network is important.
- Based on various observations, it is proved that non-linear internal waves, i.e., Solitons are one of the major scatters of underwater sound.
- If sensor nodes are deployed in such type of environment, inter-node communication is affected due to the interaction of wireless acoustic signal with these solitons, as a result of which network performance is greatly affected.

Source: A. Mandal, S. Misra, M. K. Dash, T. Ojha, "Performance Analysis of Distributed Underwater Wireless Acoustic Sensor Networks in the Presence of Internal Solitons", International Journal of Communication Systems (Wiley)

Oceanic forces and their impact

- The performance analysis of UWASNs renders meaningful insights with the inclusion of a mobility model which represents realistic oceanic scenarios.
- The existing works on performance analysis of UWASNs lack the consideration of major dominating forces, which offer impetus for a node's mobility.
- The existing works are limited to only shallow depths and coastal areas. Therefore, in this paper, Mandal et al. used a physical mobility model, named oceanic forces mobility model (OFMM), by incorporating important realistic oceanic forces imparted on nodes. In this model, nodes move in 3D ocean column.

Source: A. K. Mandal, S. Misra, T. Ojha, M. K. Dash, M. S. Obaidat, "Oceanic Forces and their Impact on the Performance of Mobile Underwater Acoustic Sensor Networks",*International Journal of Communication Systems* (*Wiley*)

3-Dimensional Localization in USNA

- Silent & energy-efficient scheme for mobile UWSNs
- Iterative approach
  - Less initiators nodes (anchors) required
- Only 3 surface anchor nodes required
- Mobility prediction
  - Enhanced accuracy

Source: T. Ojha and S. Misra, "MobiL: A 3-Dimensional Localization Scheme for Mobile Underwater Sensor Networks", *Proceedings of the 19th Annual National Conference on Communications* (*NCC 2013*), IIT Delhi, New Delhi, India, Feb. 15-17, 2013.

HASL: High-Speed AUV-Based Silent Localization for Underwater Sensor Networks

Beacon Sending

- Get GPS
- Start Dead-reckoning
- Broadcast beacon at const. interval

Beacon Reception

- Silent listening
- Receive 'Effective' set of beacon message

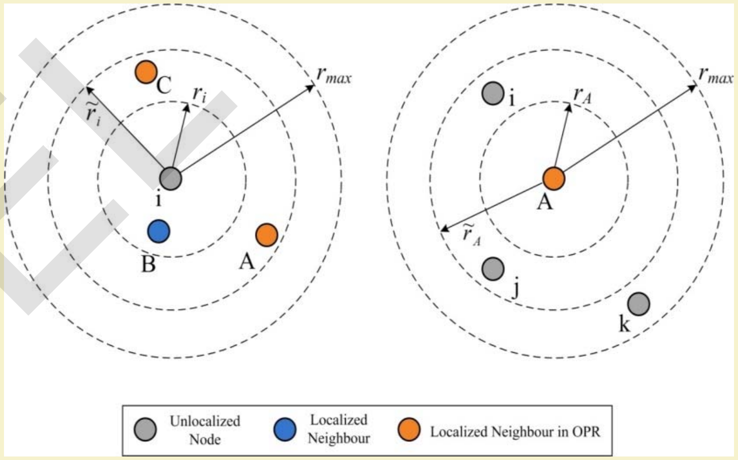
Location Estimation

- Trilateration
- Get **z** from pressure sensor

Source: T. Ojha and S. Misra, "HASL: High-Speed AUV-Based Silent Localization for Underwater Sensor Networks", *Proceedings of the 9th International Conference on Heterogeneous Networking for Quality, Reliability, Security and Robustness*(*Qshine 2013*), Springer, Greater Noida, India, January 2013.

Opportunistic localization

- **Objective**
  - **Unlocalized nodes:** to localize with minimum localization delay.
  - **Localized nodes:** select a transmission power level such that max. no. of nodes can be localized with min. energy consumption.



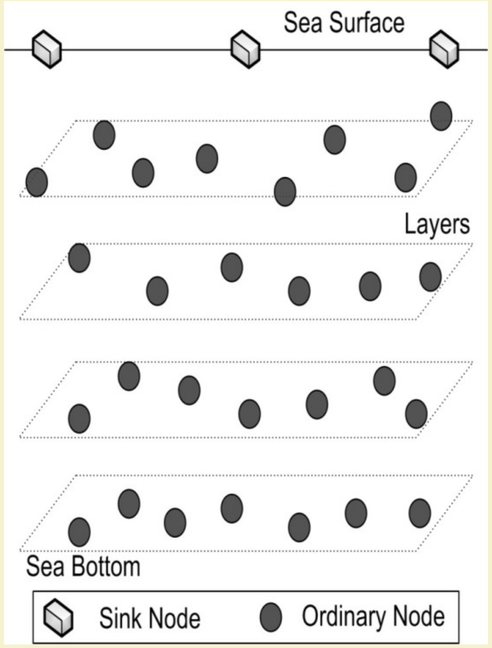
Perspective of unlocalized node

Perspective of localized node

Source: S. Misra, T. Ojha, A. Mondal, "Game-theoretic Topology Control for Opportunistic Localization in Sparse Underwater Sensor Networks", *IEEE Transactions on Mobile Computing*, vol. 14, no. 5, pp. 990-1003, 2014.

A Self-Organizing Virtual Architecture

- ✓ Tic-tac-toe-arch: A self-organizing virtual architecture for underwater sensor networks.
  - Calculating the duration of connectivity between the underwater nodes
  - A self-organizing network architecture by utilizing the dynamic formation of virtual topology



Source: T. Ojha, M. Khatua and S. Misra, "Tic-Tac-Toe-Arch: A Self-organizing Virtual Architecture for Underwater Sensor Networks", *IET Wireless Sensor Systems*, Vol. 3, No. 4, December 2013, pp. 307-316.

Virtual Topology Formation

- Broadcast “REQ”
- Receive “RPLY”

Neighbour Finding

Best Neighbour Selection

- Calculate t_d
- Select Neighbour with Max. t_d

- Set the selected node in ‘Active’ mode for t_d time

Set Duty Cycle

Thank You!!

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Sensor Networks – Part IV

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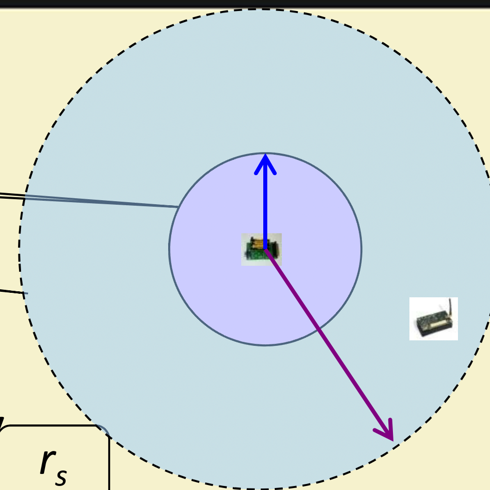
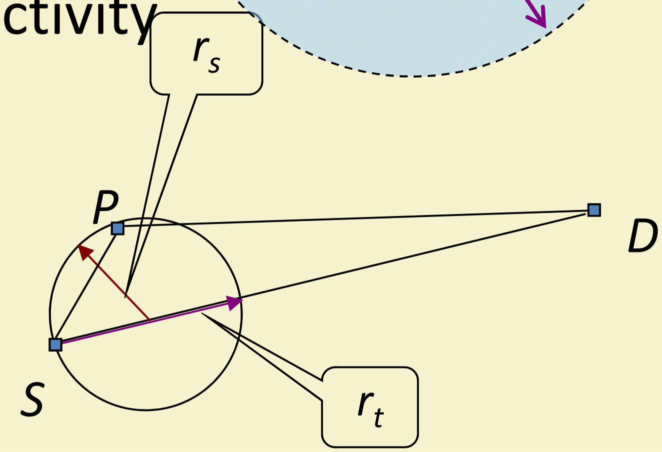
WSN Coverage

- ✓ Coverage – area-of-interest is covered satisfactorily
- ✓ Connectivity – all the nodes are connected in the network, so that sensed data can reach to sink node
- ✓ Sensor Coverage studies how to deploy or activate sensors to cover the monitoring area
  - Sensor placement
  - Density control
- ✓ Two modes
  - Static sensors
  - Mobile sensors

- Definitions:
  - Sensing range r_s
  - Transmission range r_t



- Relationship between coverage and connectivity
  - If transmission range ≥ 2 * sensing range,
  - coverage implies connectivity
  - Most sensors satisfy the condition!
    - Coverage is the main issue



Coverage

- Determine how well the sensing field is monitored or tracked by sensors
- To determine, with respect to application-specific performance criteria,
  - in case of static sensors, where to deploy and/or activate them
  - in case of (a subset of) the sensors are mobile, how to plan the trajectory of the mobile sensors.
- These two cases are collectively termed as the coverage problem in wireless sensor networks.

Coverage (contd.)

- The purpose of deploying a WSN is to collect relevant data for processing or reporting
- Two types of reporting
  - event driven
    - e.g. forest fire monitoring
  - on demand
    - e.g. inventory control system
- Objective is to use a minimum number of sensors and maximize the network lifetime

Coverage (contd.)

- The coverage algorithm proposed are either centralized or distributed and localized
  - Distributed: Nodes compute their position by communicating with their neighbors only.
  - Centralized: Data collected at central point and global map computed.
  - Localized: Localized algorithms are a special type of distributed algorithms where only a subset of nodes in the WASN participate in sensing, communication, and computation.
- Sensor deployment methods
  - Deterministic versus random
- Sensing and communication ranges
- Objective of the problem: maximize network lifetime or minimum number of sensors.

Coverage Problems in Static WSNs

- Most problems can be classified as
  - Area coverage
  - Point coverage
  - Barrier coverage

Area Coverage

- Energy-efficient random coverage
- Connected random coverage
- A network is connected if any active node can communicate with any other active node
- Zhang and Hou proved that if the communication range R_c is at least twice the sensing range R_s, then coverage implies connectivity

Source: *Zhang and Hou, "Maintaining Sensing Coverage and Connectivity in Large Sensor Networks", Ad Hoc & Sensor Wireless Networks, Vol. 1, pp. 89-124, 2005.*

Area Coverage (contd.)

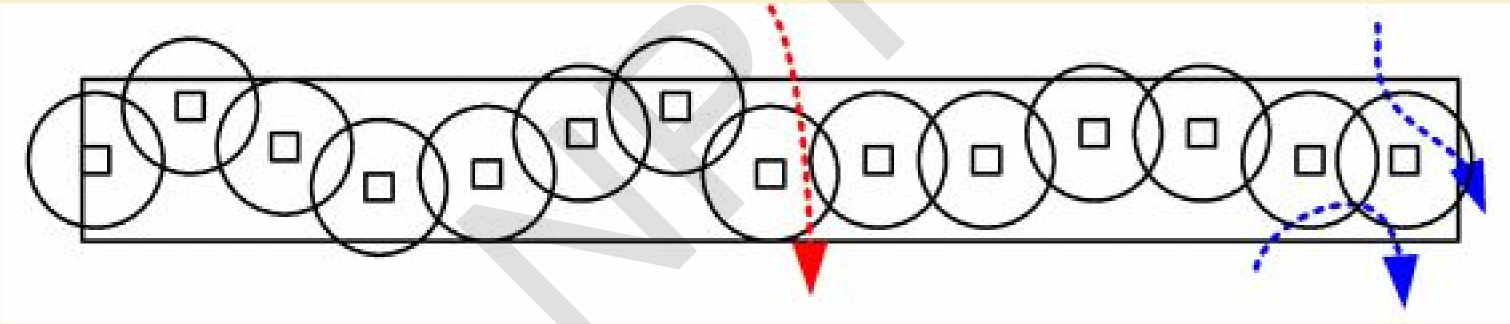
- An important observation is that an area is completely covered if there are at least two disks that intersect and all crossing are covered
- Based on these they proposed a distributed, localized algorithm called optimal geographical density control

Point Covergae

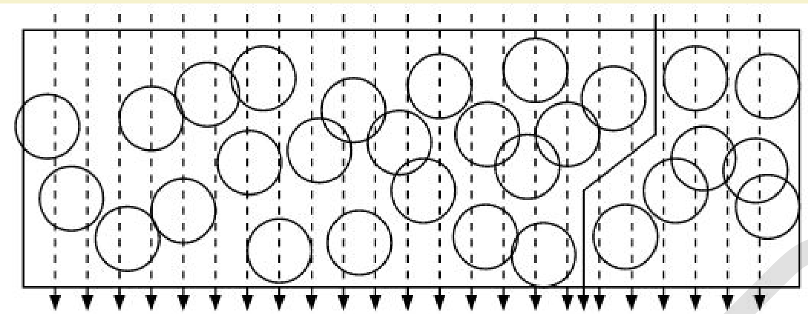
- Objective is to cover a set of points
  - Random point coverage – Distribute sensors randomly, so that every point must be covered by at least one sensor at all times
  - Deterministic point coverage – Do the same in a deterministic manner.

Barrier Coverage

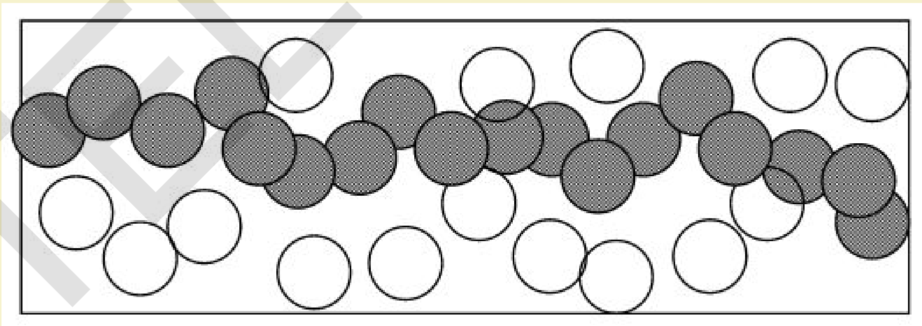
- 1-barrier coverage – covered by at least 1 sensor
- 2-barrier coverage – covered by at least 2 sensors
- K-barrier coverage – covered by at least k sensors



Barrier Coverage (contd.)



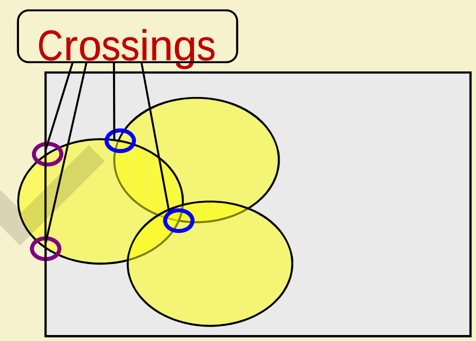
Weak Coverage



Strong Coverage

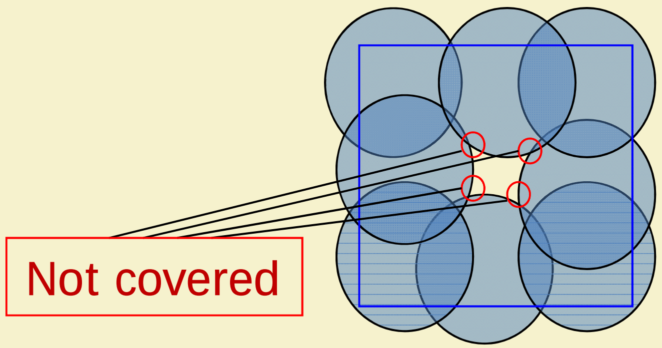
Coverage Maintenance

- A continuous region R is covered if
  - Exist crossings in R
  - Every crossing in R is covered



✓ Crossings: intersection points between disk boundaries or between monitored space boundary and disk boundaries

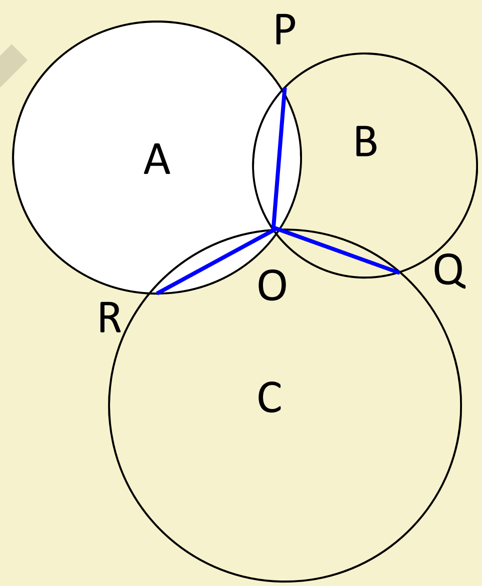
✓ A crossing is covered if it is in the interior region of at least one node's coverage disk



Source: *Zhang and Hou, "Maintaining Sensing Coverage and Connectivity in Large Sensor Networks", Ad Hoc & Sensor Wireless Networks, Vol. 1, pp. 89-124, 2005.*

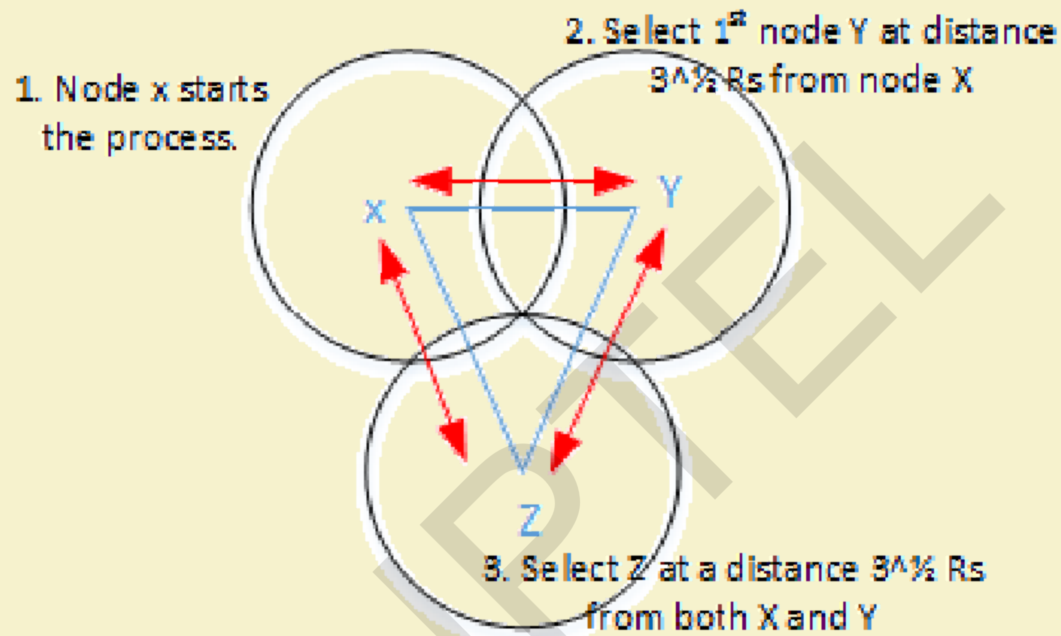
Optimality Conditions

- Optimality conditions for minimizing overlap while covering crossings
  - If nodes A and B are fixed, node C should be placed such that OR = OQ
  - If nodes A, B, and C all can change their locations, then OP = OR = OQ
  - If all nodes have the same sensing range, the distance between them is $\sqrt{3} \cdot r_s$



Optimal Geographical Density Control (OGDC) Algorithm

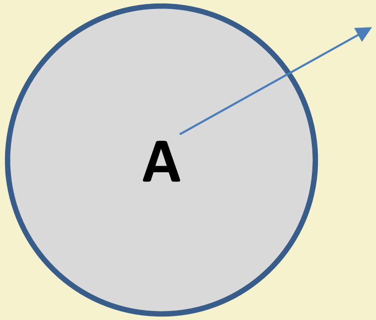
- A node (A) volunteers as a starting node
  - Broadcasts a message containing
    - Ideal direction (randomly selected)
- Another node (B) closest to the ideal distance and angle becomes active
- A node (C) covering P and closest to the optimal location becomes active
- Repeatedly cover uncovered crossings with nodes that incur minimum overlap.
- A node sleeps if its coverage area is completely covered



Source: https://www.researchgate.net/figure/269392166_fig2_Fig-2-Optimal-Geographical-Density-Control-OGDC-algorithm

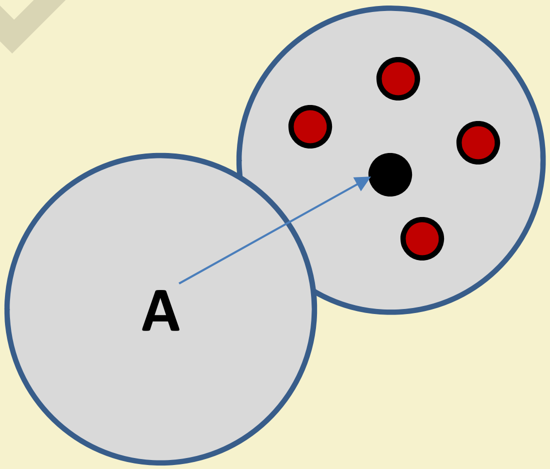
Optimal Geographical Density Control (OGDC) Algorithm (contd.)

- Select a starting node
  - Each node voluntarily participates with probability p
  - Chooses a back-off time randomly
  - If it does not hear anything from its neighbors, declares itself as starting node
  - Declares its position and preferred direction



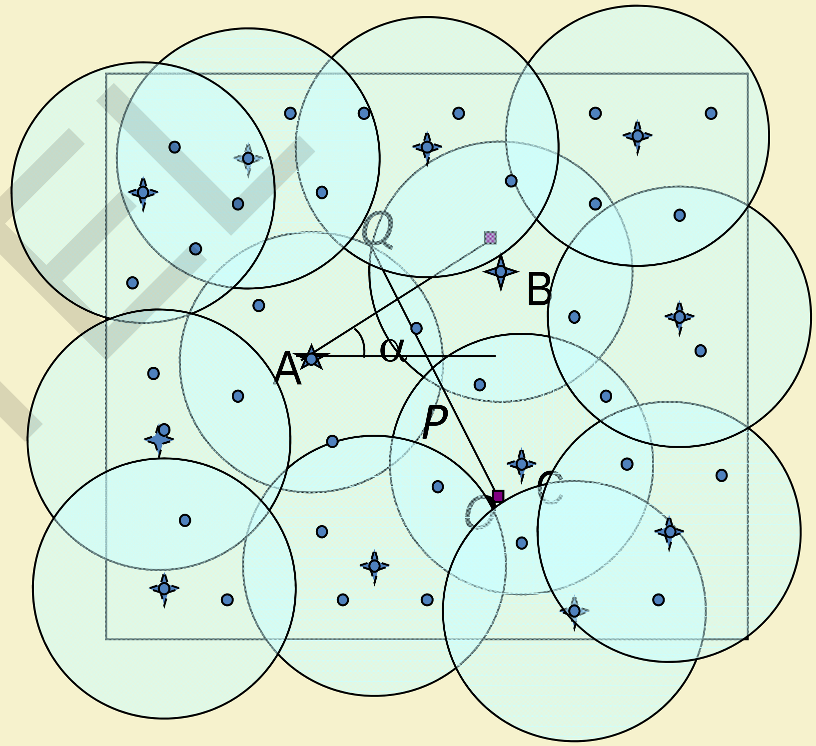
Optimal Geographical Density Control (OGDC) Algorithm (contd.)

- On receiving message from a starting node
  - Each node computes the deviation from desired position (based on distance and angle)
  - Chooses a back-off time randomly
  - When back-off expires, it sends power ON message.
  - Then, it declares its position and preferred direction



Optimal Geographical Density Control (OGDC) Algorithm (contd.)

- The process continues until the entire area is covered
- The nodes already covered go to sleep mode



Optimal Geographical Density Control (OGDC) Algorithm: Highlights

- A node initiates the process with desired distance and angle
- Other nodes calculates the deviation, and the optimal one is chosen
- The process continues for all nodes
- All covered nodes go to sleep mode
- This process is continued at each round

Thank You!!

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Sensor Networks– Part V

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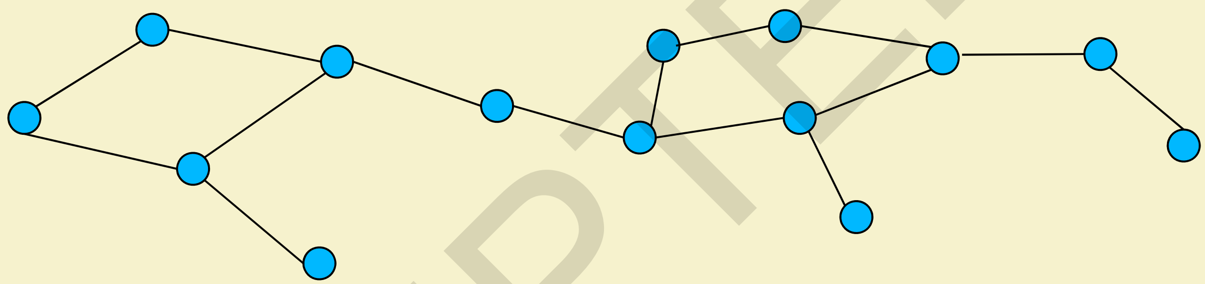
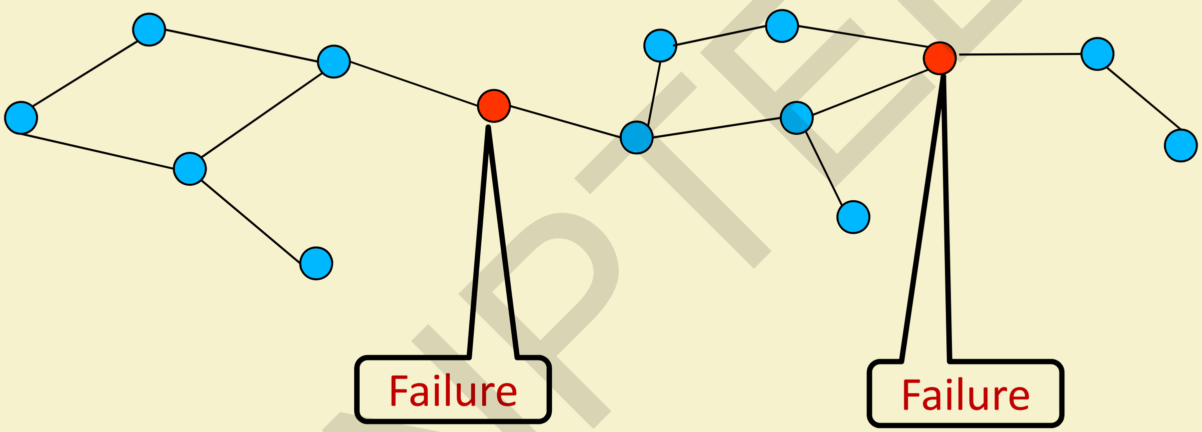
Stationary Wireless Sensor Networks

- Sensor nodes are static
- Advantages:
  - Easy deployment
  - Node can be placed in an optimized distance—Reduce the total number of nodes
  - Easy topology maintenance
- Disadvantages:
  - Node failure may results in partition of networks
  - Topology cannot be change automatically

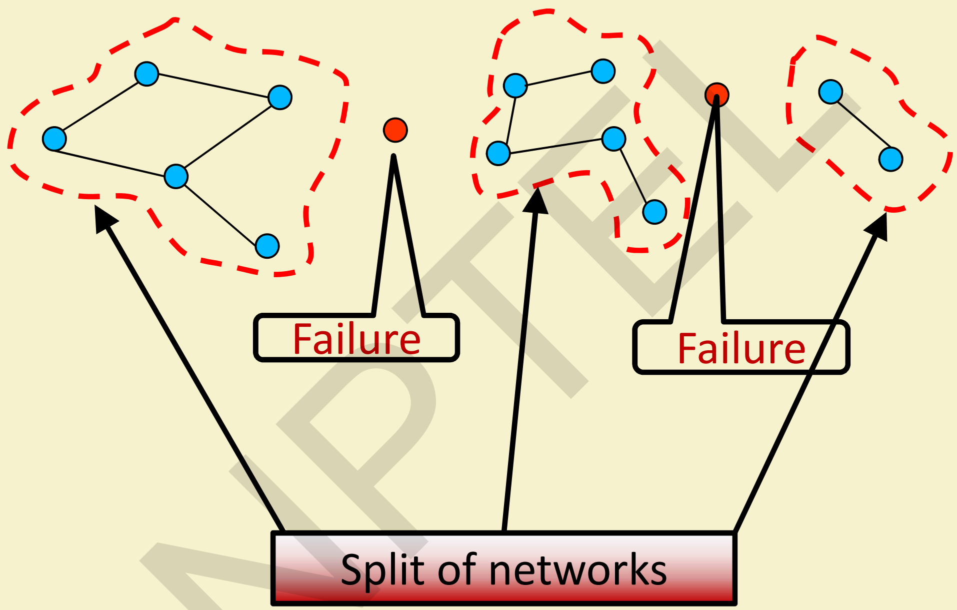
Stationary Wireless Sensor Networks (Contd.)



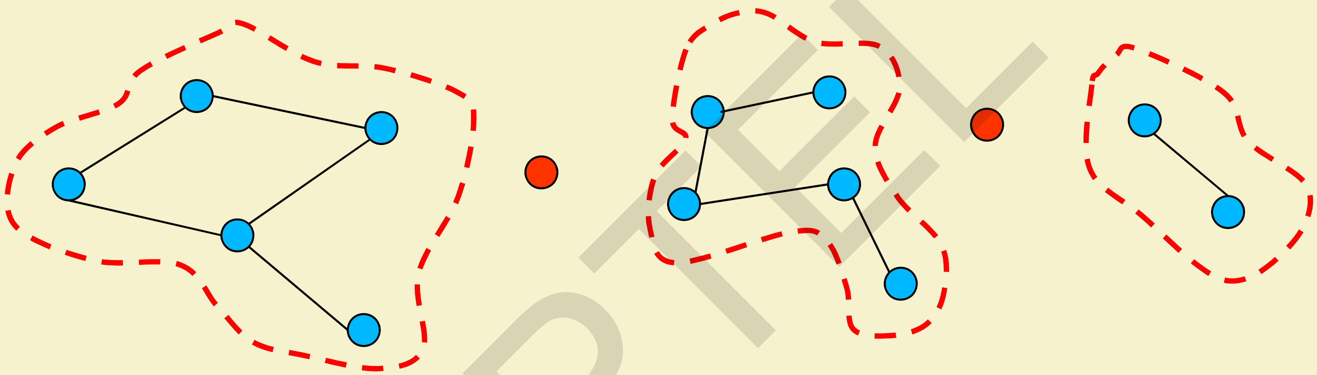
Stationary Wireless Sensor Networks (Contd.)



Stationary Wireless Sensor Networks (Contd.)



Stationary Wireless Sensor Networks (Contd.)



Solution?

To mobilize the sensor nodes

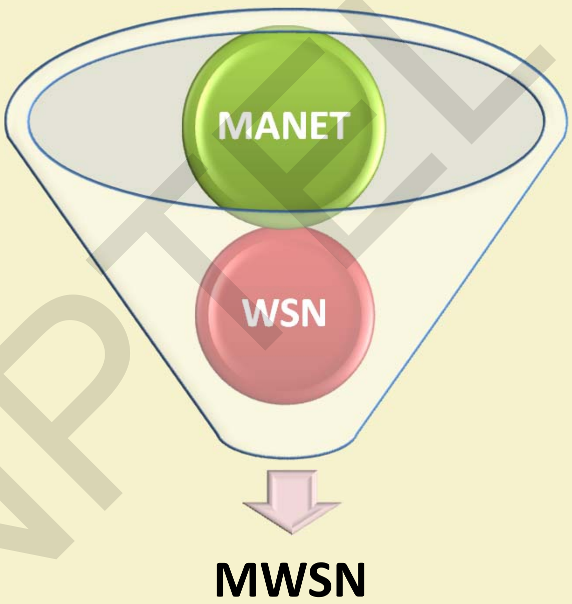
Mobile Wireless Sensor Networks (*MWSN*)

Mobile Wireless Sensor Networks

- MWSN is Mobile Ad hoc Network (MANET)
- Let us remember from previous lectures:-
- MANET-Infrastructure less network of mobile devices connected wirelessly which follow the self-CHOP properties
  - Self-Configure
  - Self-Heal
  - Self-Optimize
  - Self-Protect

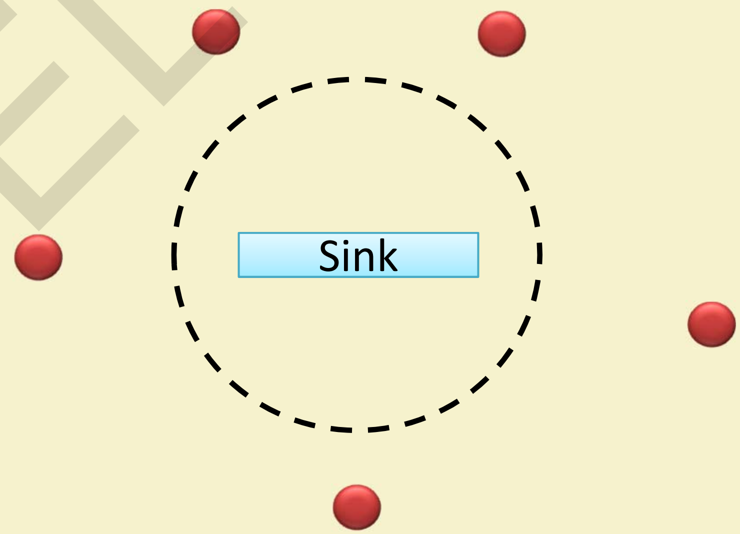
- Wireless Sensor Networks-
  - Consists of a large number of sensor nodes, densely deployed over an area.
  - Sensor nodes are capable of collaborating with one another and measuring the condition of their surrounding environments (i.e. Light, temperature, sound, vibration).

Mobile Wireless Sensor Networks (contd.)



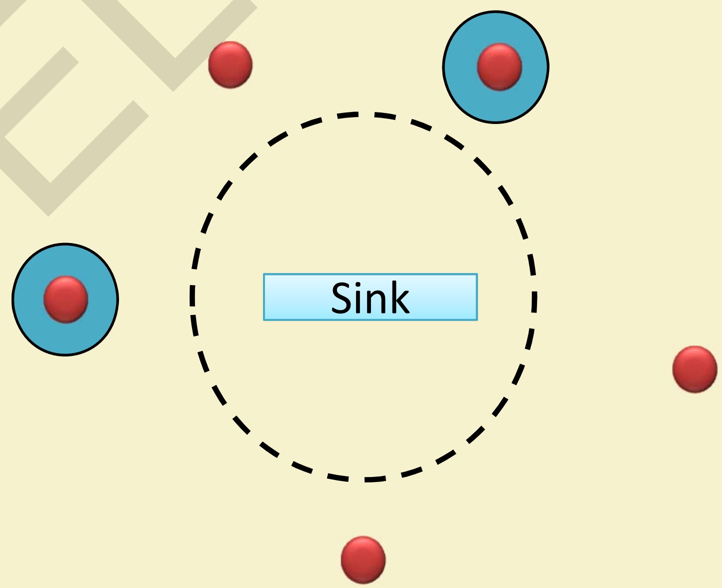
Components of MWSN

✓ Mobile Sensor Nodes



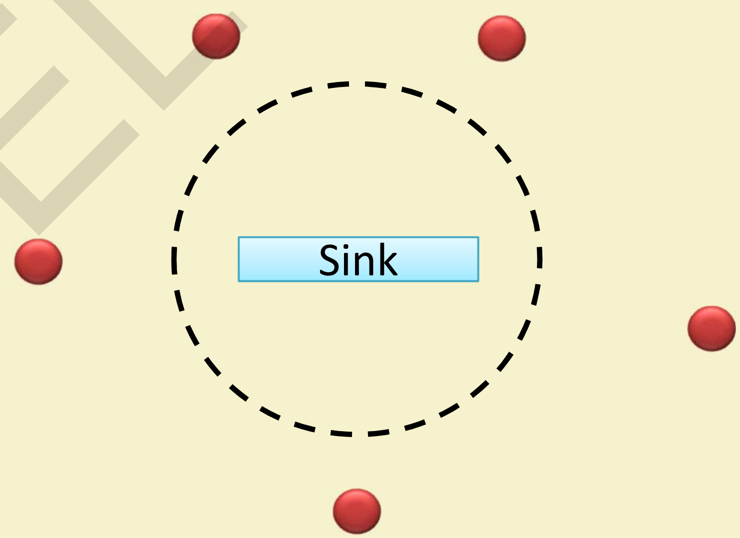
Components of MWSN

- Mobile Sensor Nodes
  - Sense physical parameters
  - from the environment



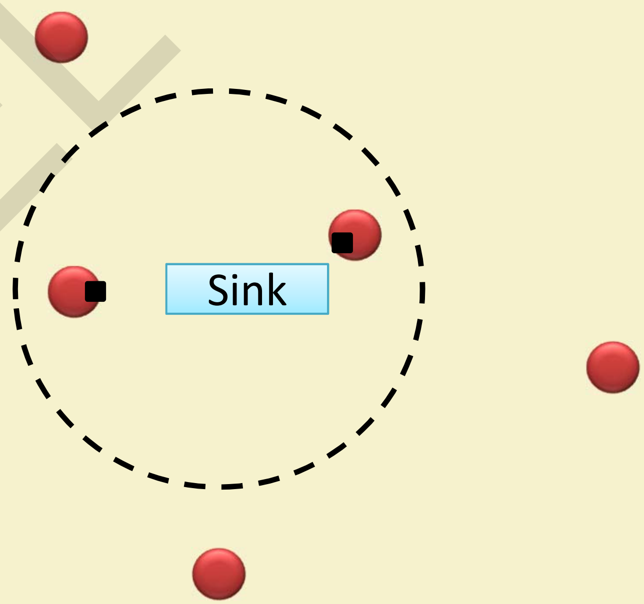
Components of MWSN

- Mobile Sensor Nodes
  - Sense physical parameters
  - from the environment
  - When these nodes come
  - in close proximity of sink,
  - deliver data



Components of MWSN

- Mobile Sensor Nodes
  - Sense physical parameters from the environment
  - When these nodes come in close proximity of sink, deliver data

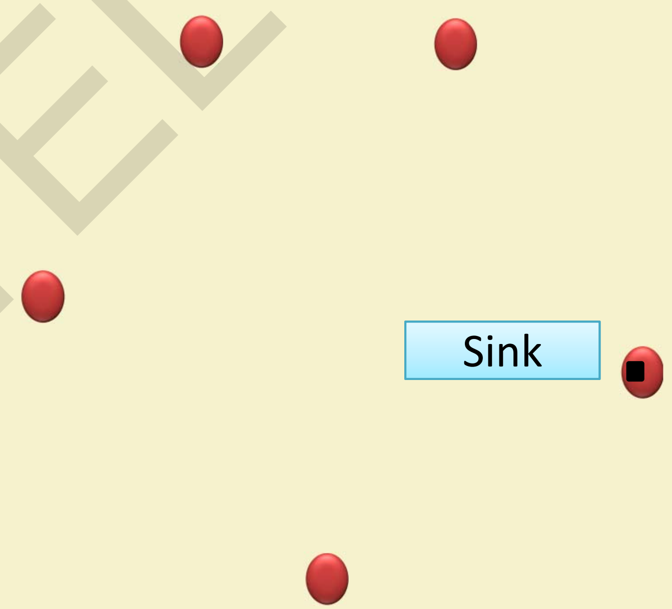


Components of MWSN

- Mobile Sink
  - Moves in order to collect data from sensor nodes
  - Based on some algorithm sink moves to different nodes in the networks

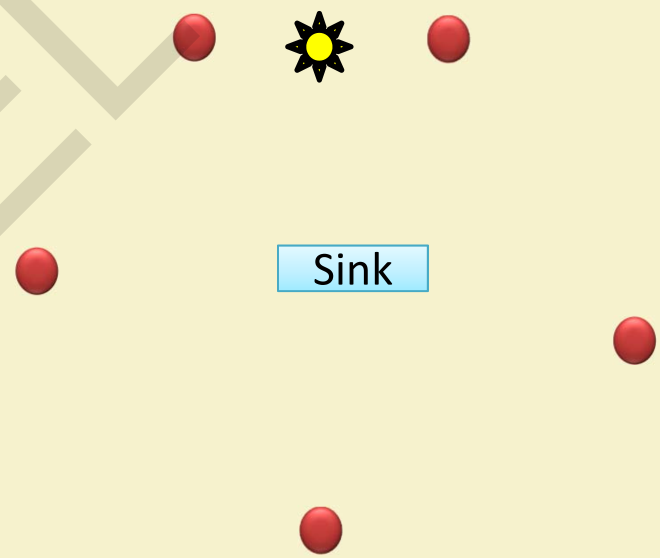
Components of MWSN

- Mobile Sink
  - Moves in order to collect data from sensor nodes
  - Based on some algorithm sink moves to different nodes in the networks



Components of MWSN

- Data Mules
  - A mobile entity
  - Collects the data from sensor nodes
  - Goes to the sink and delivers the collected
  - data from different
  - sensor nodes



Underwater MWSNs

- ✓ Senses different parameters under the sea or water levels
- ✓ Can be linked with Autonomous Underwater Vehicles (AUVs)
- ✓ Applications: Monitoring-marine life, water quality etc.

Terrestrial MWSNs

- ✓ Sensor nodes typically deployed over land surface
- ✓ Can be linked with Unmanned Aerial Vehicles (UAVs)
- ✓ Applications: Wildlife monitoring, surveillance, object tracking

Aerial MWSNs

- ✓ Nodes fly on the air and sense data (physical phenomena or multimedia data)
- ✓ Typical example is Unmanned Aerial Vehicles (UAVs)
- ✓ Applications: Surveillance, Multimedia data gathering

Possible Entity as Mobile Nodes in Daily-life

- Human
  - Mobility can not be predict
  - Cell phone can gather information and deliver data to an access point
- Vehicles
  - Sensor equipped on it
  - Sense data from different geographical locations and transmit to road side unit (RSU)
- Mobile Robot
  - Controllable sensor node
  - Collect data by predefined instructions
  - Deliver the data to a specific unit

Human-centric Sensing

- Today, smartphones and PDAs are equipped with several sensors, e.g., accelerometer and gyroscope
- Miniaturization & proliferation of such devices give rise to new sensing paradigms such as,
  - Participatory sensing
  - People-centric sensing
  - Opportunistic sensing
- Basic idea:
  - Humans carry their devices and **move** around
  - Sensors embedded within the devices record readings
  - Sensory readings are then transmitted

Human-centric Sensing (contd.)

- Three distinct roles (not necessarily mutually exclusive) played by humans
  - Sensing targets: Humans themselves are sensed, e.g., personal health monitoring
  - Sensor operators: Humans use sensors and applications in smartphones & PDAs to sense surroundings
  - Data source: Humans disseminate & collect data without actually using any sensor, e.g., updates posted in social networking sites
- Challenges in human-centric sensing:
  - Energy of devices
  - Participant selection
  - Privacy of users

Source: M. Srivastava, T. Abdelzaher, and B. Szymanski, “Human-centric sensing,” Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, vol. 370, no. 1958, pp. 176–197, Jan. 2012.

Participatory Sensing

- Proposed by Burke et al., 2006
- Distributed sensing by devices carried by humans
- Goal: Not just collect data, but allow common people to access data and share knowledge
- Collected data provides:
  - Quantitative information, e.g., CO_2 level
  - Endorsement of authenticity, e.g., via geo-tagged location & timestamp

Source: J. Burke, D. Estrin, M. Hansen, A. Parker, N. Ramanathan, S. Reddy, and M. B. Srivastava, "Participatory sensing," in Workshop on World-Sensor-Web (WSW'06): Mobile Device Centric Sensor Networks and Applications, Boulder, Colorado, USA, 2006, pp. 117–134.

Delay Tolerant Networks

- Lack of end-to-end communication paths
- High latency
- Asymmetric data rates; erroneous channels
- WSN and MWSN:
    - Typically assume the availability of end-to-end path between any sensor node and BS
- We saw data MULEs earlier
    - Such WSNs, in general, belong to the category of delay tolerant wireless sensor networks (DT-WSNs)

Thank You!!

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UAV Networks

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Features of UAV Networks

- Mesh or Star networks.
- Flexible deployment and management of new services using SDN.
- Routing protocol should be adaptive in nature.
- Contribute towards greening of the network.
- Multi-tasking.
- Large coverage area.
- Easily reconfigurable for varying missions.

Key Issues

- Frequently change in network topology.
- Relative position of UAV may change.
- Malfunctioning of UAVs
- Intermittent link nature.
- Lack of suitable routing algorithm.

Considerations in UAV Networks

Feature	Single UAV System	Multi-UAV System
Failures	High	Low
Scalability	Limited	High
Survivability	Poor	High
Speed of Mission	Slow	Fast
Cost	Medium	High
Bandwidth required	High	Medium
Antenna	Omni-directional	Directional
Complexity of Control	Low	High
Failure to coordinate	Low	Present

Source: Lav Gupta, Raj Jain, and Gabor Vaszkun. "Survey of important Issues in UAV communication networks." *IEEE Communications Surveys & Tutorials* 18.2 (2015): 1123-1152.

UAV Network Constraints

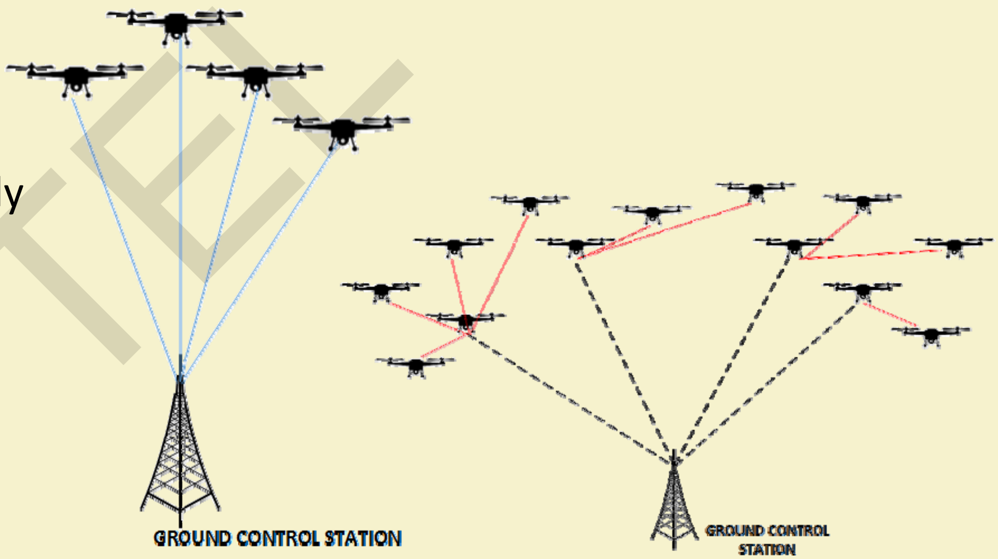
- Frequent link breakages
- Prone to malfunction
- Huge power requirements
- Very complex
- Physically prone to environmental effects: winds, rain, etc.

UAV Network Advantages

- High Reliability
- High Survivability
- Single Malfunction Proof
- Cost Effective
- Efficient
- Speeded up missions

UAV Network Topology: Star

- Typically two types –
  - Star Configuration,
  - Multi-star Configuration .
- In Star Configuration, UAV is directly connected to the ground station.
- In Multi-star Configuration, UAVs form multiple star topology. One node from each group connects to the ground station.
- High latency.
- Highly dependent on ground station.

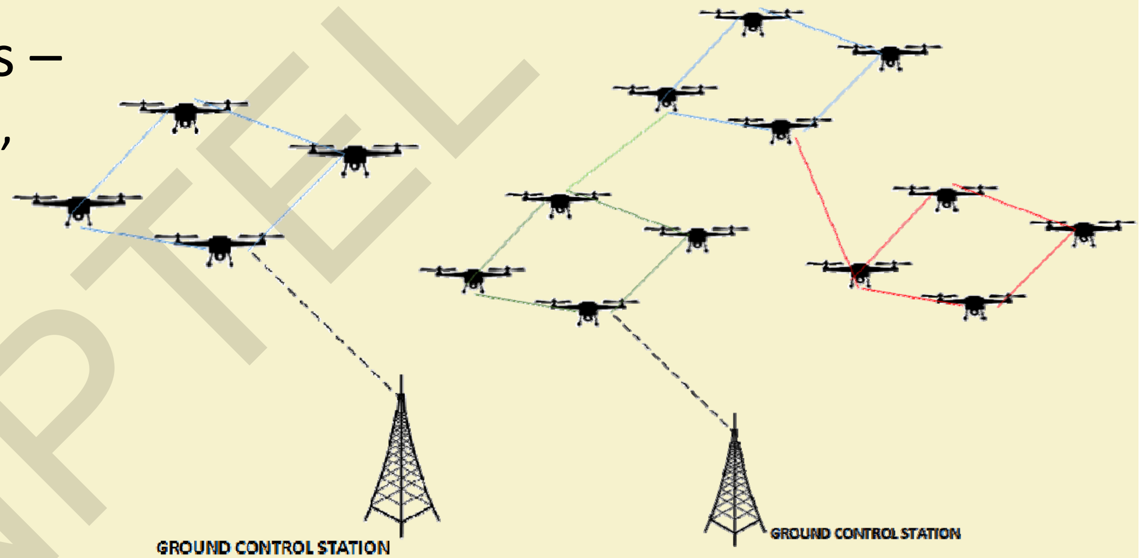


Star Configuration

Multi-star Configuration

UAV Network Topology: Mesh

- Typically two types –
  - Flat Mesh Network,
  - Hierarchical Mesh Network.
- Flexible
- Reliable
- Nodes are interconnected
- More secure



Flat Mesh Configuration

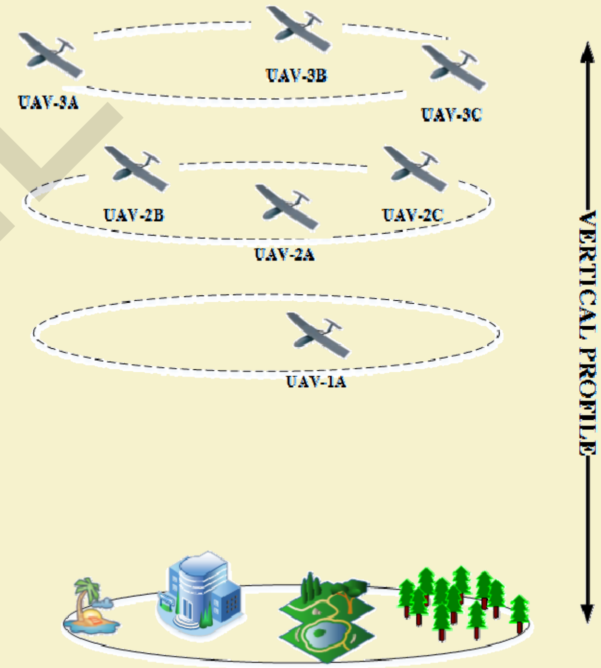
Hierarchical Mesh Configuration

UAV Topology Comparison

Star Network	Mesh Network
Point-to-point	Multi-point to multi-point
Central control point present	Infrastructure based may have a control center, Ad hoc has no central control center
Infrastructure based	Infrastructure based or Ad hoc
Not self configuring	Self configuring
Single hop from node to central point	Multi-hop communication
Devices cannot move freely	In ad hoc devices are autonomous and free to move. In infrastructure based movement is restricted around the control center
Links between nodes and central points are configured	Inter node links are intermittent
Nodes communicated through central controller	Nodes relay traffic for other nodes

FANETs: Flying Ad Hoc Networks

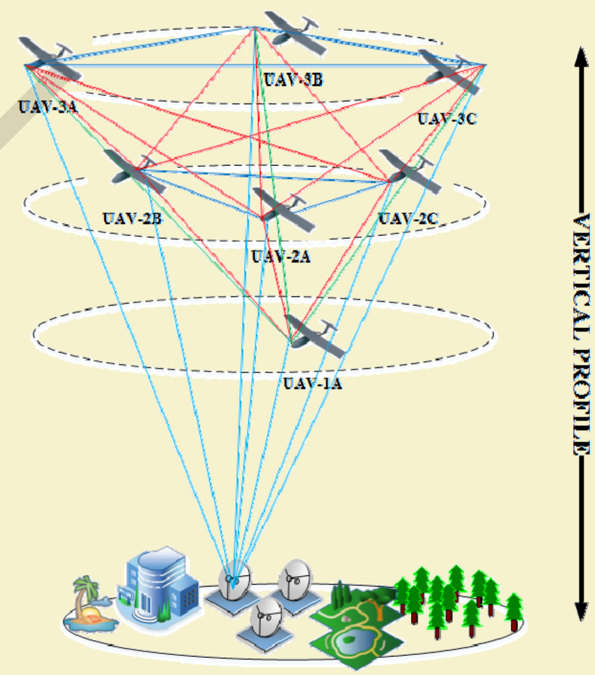
- Network formation using UAVs which ensures longer range, clearer line of sight propagation and environment-resilient communication.
- UAVs may be in same plane or organized at varying altitudes.
- Besides self-control, each UAV must be aware of the other flying nodes of the FANET to avoid collision.
- Popular for disaster-time and post-disaster emergency network establishment.



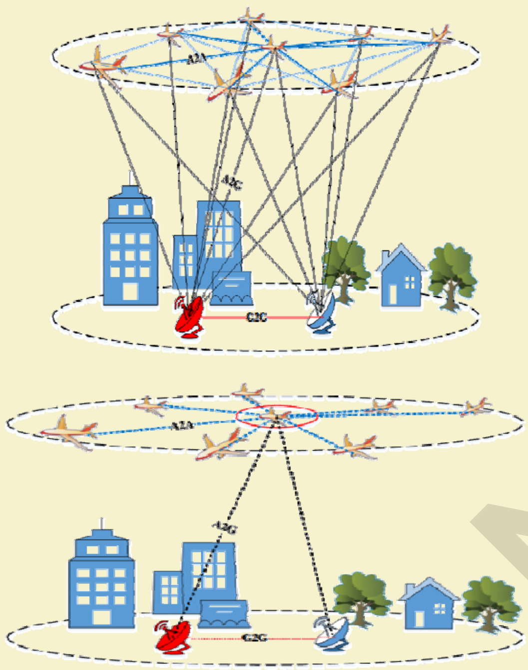
FANETs: Flying Ad Hoc Networks (contd.)

✓ Features:

- FANET Inter-plane communication
- FANET Intra-plane communication
- FANET- Ground Station communication
- FANET- Ground Sensor communication
- FANET-VANET communication

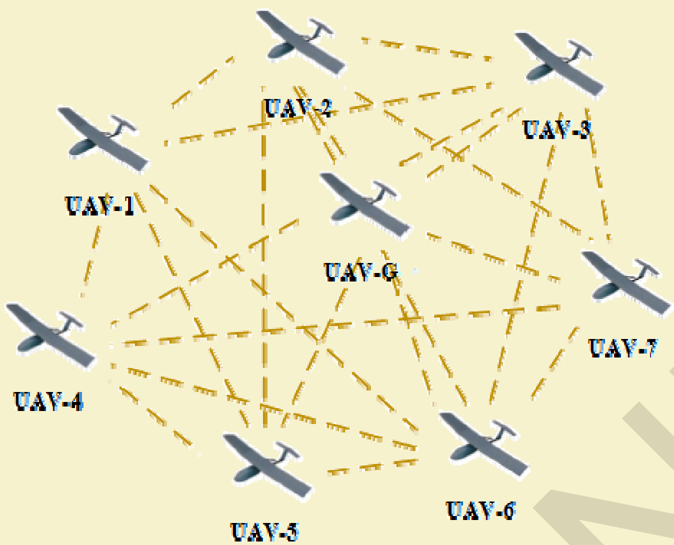


Ad-Hoc FANETs



- A2A links for data delivery among UAVs.
- Heterogeneous radio interfaces can be considered in A2A links, such as XBee-PRO (IEEE 802.15.4) and Wi-Fi (IEEE 802.11).
- Ground networks may be stationary WSNs or VANETS or Control stations.
- UAV-WSN link-up may be used for collaborative sensing as well as data-muling.
- UAV-VANETS link-up may be used for visual guidance, data-muling and coverage enhancement.

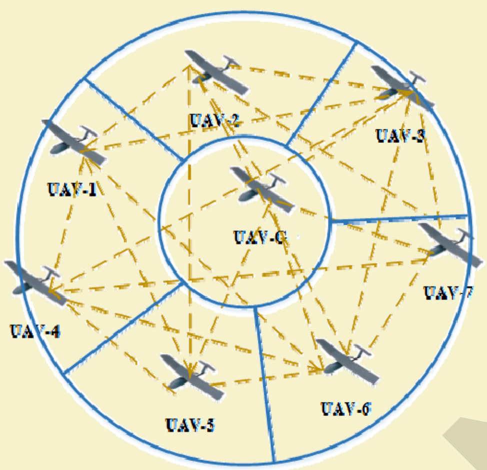
Gateway Selection in FANETs



- ✓ Main communication requirements of UAV networks are:
  - Sending back the sensor data.
  - Receiving the control commands.
  - Cooperative trajectory planning.
  - Dynamic task assignments.
- ✓ Number of UAV-ground remote connections should be controlled to avoid interference.
- ✓ Reduced nodes in the UAV network should act as gateways, to allow communication between all UAV and the ground

Source: F. Luo *et al.*, "A Distributed Gateway Selection Algorithm for UAV Networks," in *IEEE Transactions on Emerging Topics in Computing*, vol. 3, no. 1, pp. 22-33, March 2015.

Gateway Selection in FANETs (contd.)

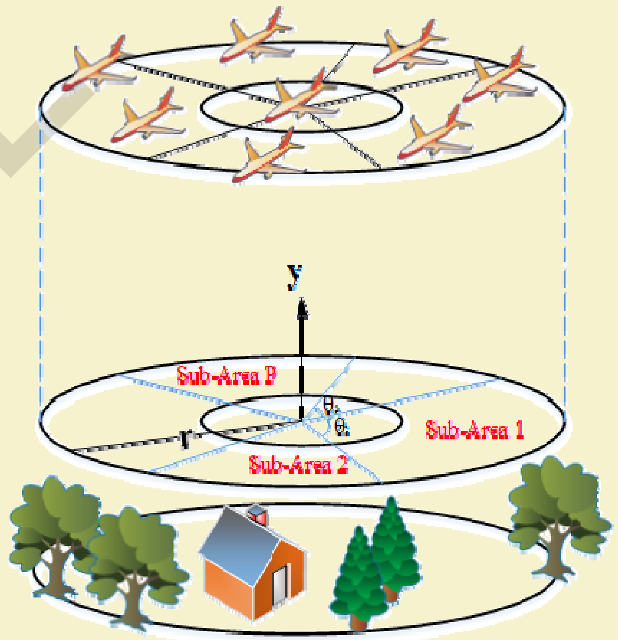


- Entire UAV network coverage area divided into sub-areas.
- Sub-areas collectively cover the entire communication area.
- Size of sub-area to be controlled and adjusted dynamically.
- Adjustments based on UAV-interconnections and derived metrics.
- The derived metrics are optimized for several iterations till optimum state is achieved.

Source: F. Luo *et al.*, "A Distributed Gateway Selection Algorithm for UAV Networks," in *IEEE Transactions on Emerging Topics in Computing*, vol. 3, no. 1, pp. 22-33, March 2015.

Gateway Selection in FANETs (contd.)

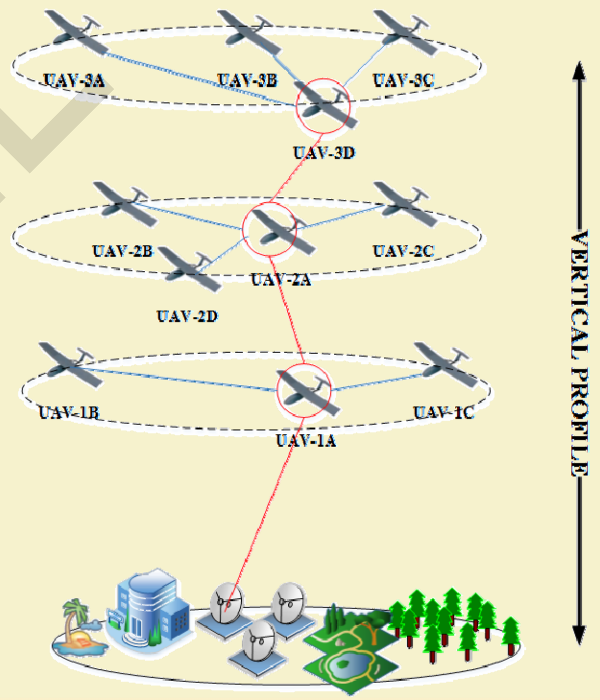
- Gateway selection initiated by selection of the most stable node in the sub-area.
- Consecutively, the partition parameters are optimized according to topology.
- Each UAV acquires the information of all UAVs within its 2 hops.



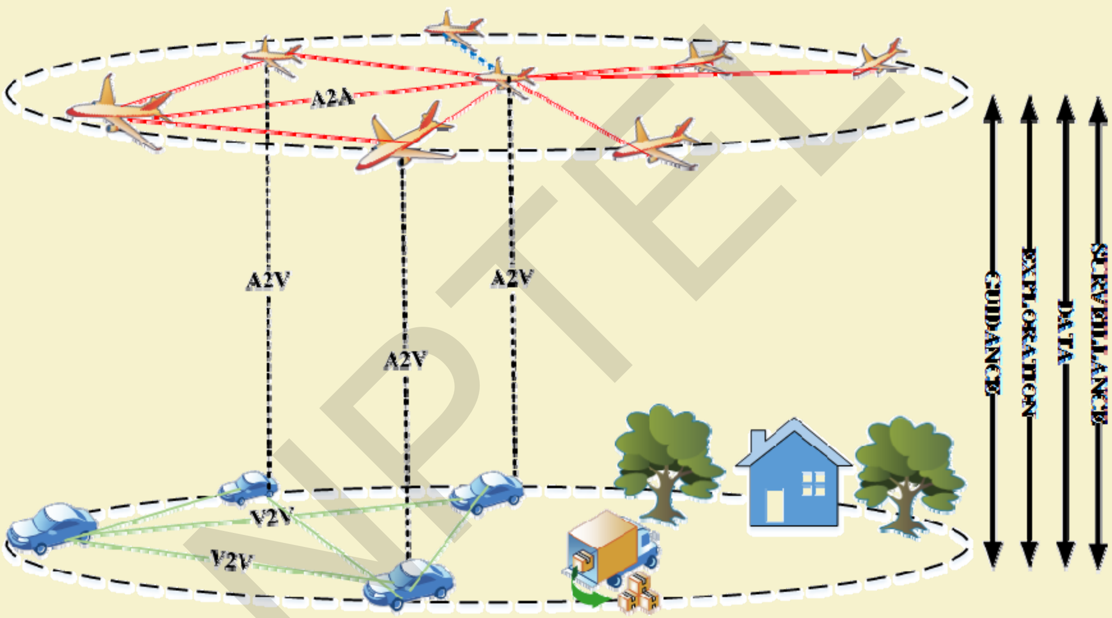
Source: F. Luo *et al.*, "A Distributed Gateway Selection Algorithm for UAV Networks," in *IEEE Transactions on Emerging Topics in Computing*, vol. 3, no. 1, pp. 22-33, March 2015.

Layered Gateway in FANETs

- Multi-layered UAV topologies select one gateway.
- The gateways from each layer communicate to forward information between layers, as well as from ground control.
- Will increase the delay between ground control and higher layers.
- Not suitable for time-critical relaying tasks.

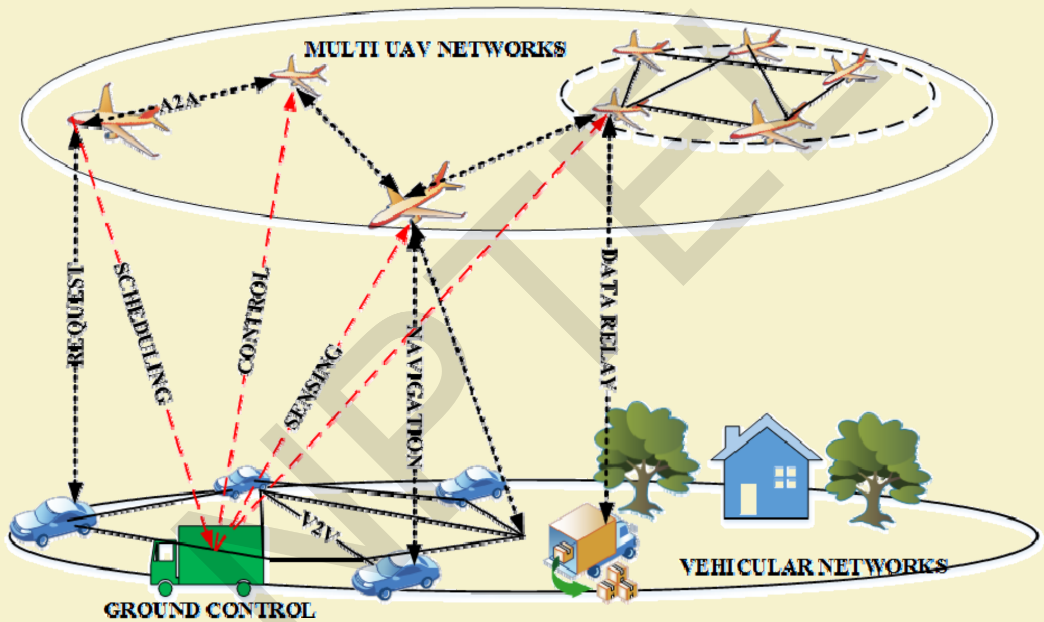


FANETs & VANETs



Source: Y. Zhou, N. Cheng, N. Lu and X. S. Shen, "Multi-UAV-Aided Networks: Aerial-Ground Cooperative Vehicular Networking Architecture," in *IEEE Vehicular Technology Magazine*, vol. 10, no. 4, pp. 36-44, Dec. 2015.

FANETs & VANETs (contd.)



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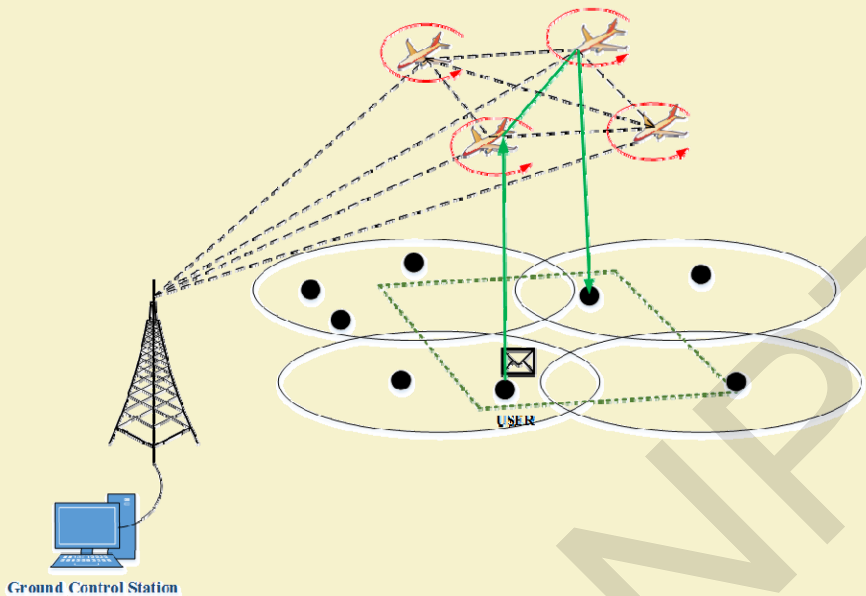
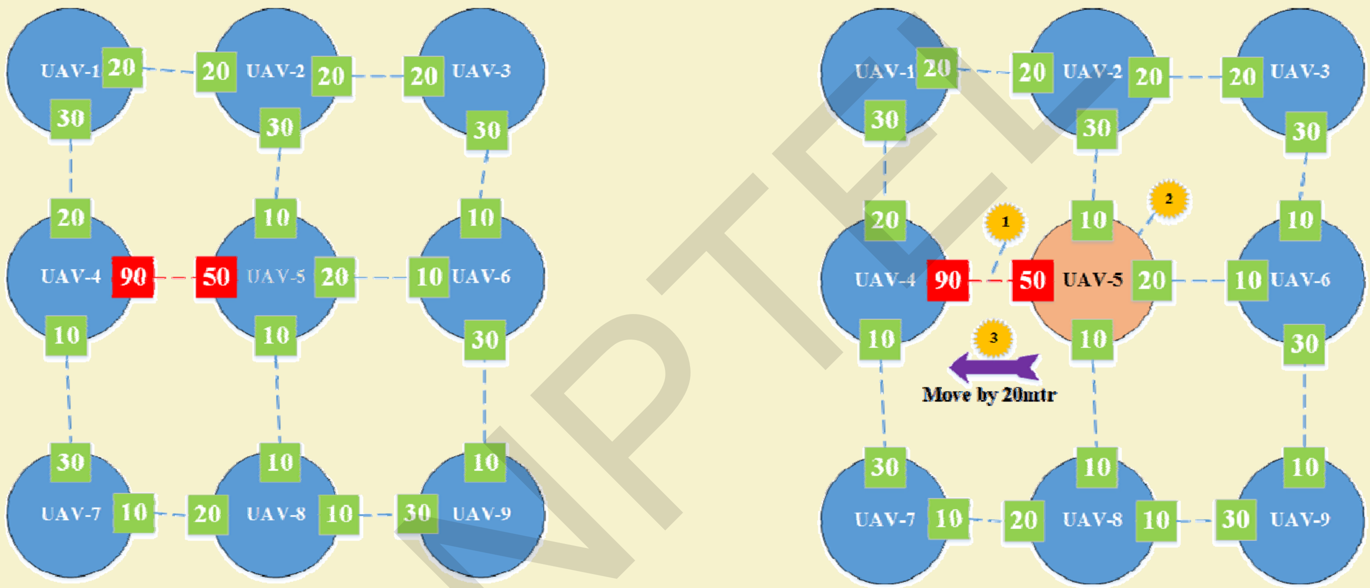
Trajectory Control for Increasing Throughput



- UAVs with queue occupancy above a threshold experience congestion resulting in communication delay.
- Control station instructs UAVs to change centers of trajectory.
- Command given based on traffic at "busy" communication link.
- To provide enhanced coverage, UAVs may be commanded to change radius of their trajectories.

Source: Fadlullah, Zubair Md, et al. "A dynamic trajectory control algorithm for improving the communication throughput and delay in UAV-aided networks." *IEEE Network* 30.1 (2016): 100-105.

Trajectory Control for Increasing Throughput (contd.)



Source: Fadlullah, Zubair Md, et al. "A dynamic trajectory control algorithm for improving the communication throughput and delay in UAV-aided networks." *IEEE Network* 30.1 (2016): 100-105.

Thank You!!