Backbone Discovery In Thick Wireless Linear Sensor Netorks

October 28, 2014

Imad Jawhar[1], Xin Li[2], Jie Wu[3], and Nader Mohamed[1]

[1]College of Information Technology, United Arab Emirates University, Al Ain, UAE

[2]College of Computer Science and Technology, Nanjing University of Aeronautics and Astronautics, China

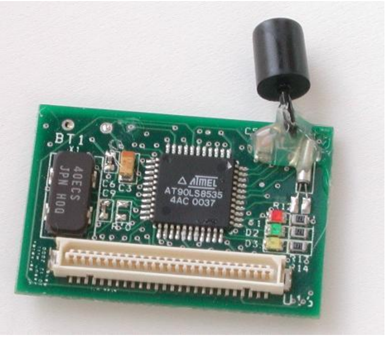
[3]Department of Computer and Information Sciences, Temple University, Philadelphia, PA, USA

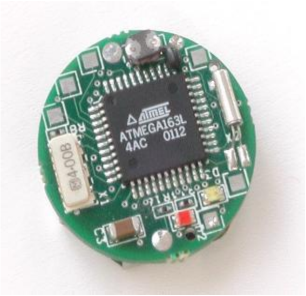
Outline

- **Introduction**: Linear Sensor Networks (**LSNs**). **Applications** and **architectures**
- **Thick LSN model** and **definitions**
- **Algorithms** for **backbone discovery** in thick LSNs
- Related **caching** and **routing** strategies
- **Conclusions** and future research

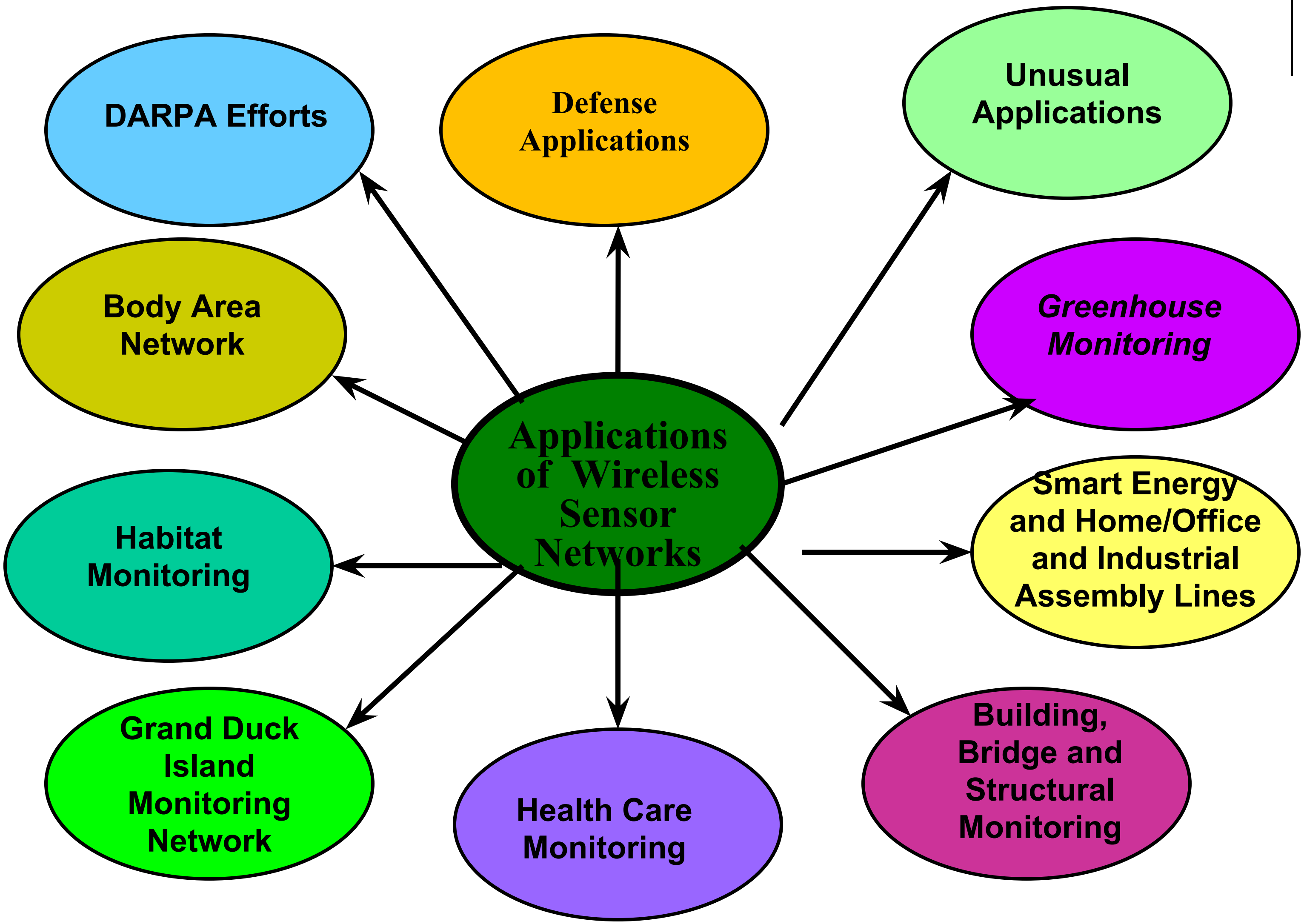
Wireless Sensor Networks

- Wireless sensor networks (**WSN**) advancements in technology
- Sensor networks **application**: environmental, military, agriculture, inventory control, healthcare, etc.





Applications of WSNs



Applications of WSNs

Judging by the interest shown by military, academia, and the media, innumerable applications do exist for WSNs:

- Weather monitoring
- Security and tactical surveillance
- Distributed computing
- Fault detection and diagnosis in:
  - Machinery
  - Large bridges
  - Tall structures
- Detecting ambient conditions such as:
  - Temperature
  - Movement
  - Sound
  - Light
  - Radiation
  - Stress
  - Vibration
  - Smoke
  - Gases

Linear Sensor Networks (LSNs)

- **Existing WSN** research is 2-D or 3-D deployment.
- Assumption that the network used for sensors does **not** have a **predetermined structure**.
- **Linear alignment** of sensors can arise in many **applications**
- **Linear** characteristic can be utilized for **enhancing** the **routing** and **reliability** in the such systems.
- We can design **adapted protocols** for this special kind of sensor networks.

Applications of LSNs

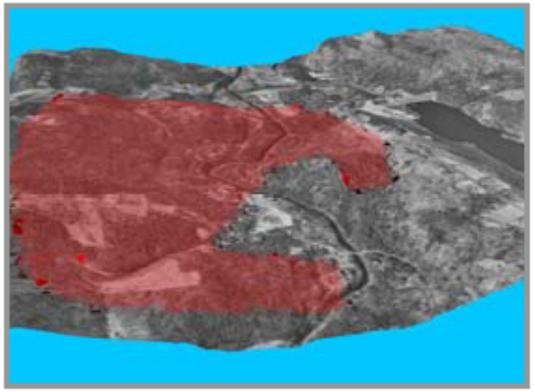
- Monitoring and protection of **oil, gas, and water pipeline** infrastructure using wireless sensor networks.

Oil, Gas, and Water Pipeline Use

- UAE (2006):
  - 2,580 Km of gas pipelines
  - 2,950 Km of oil pipelines
  - 156 Km of refined products pipelines.
- Desalinated water.
- Saudi Arabia: 3,800 Km.
- Use pipelines for transportation from plants to cities and populated areas.
- Oil and gas industries heavily depend on pipelines for connecting shipping ports, refineries, and wells.
- Types of pipelines: above ground, underground, under-water.

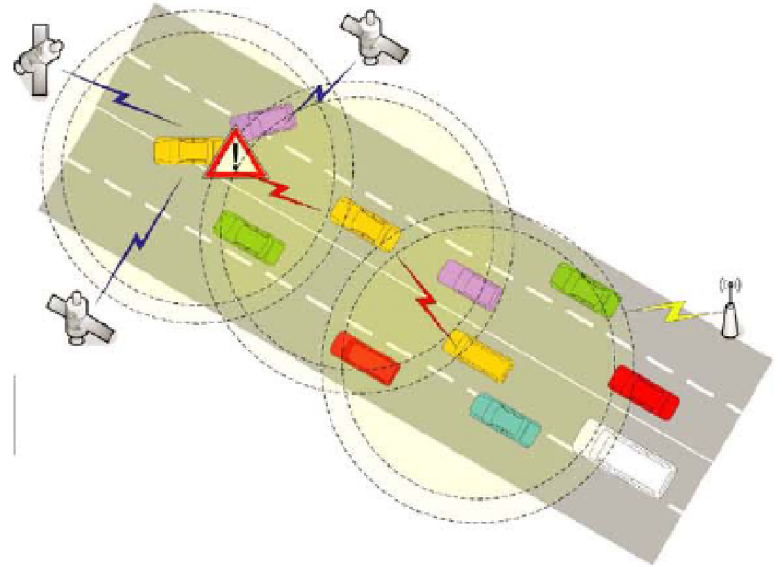
Border Monitoring

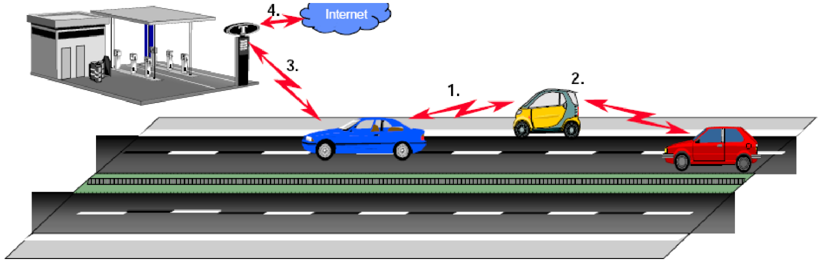
- Monitoring international borders for different activities.
- Illegal smuggling of goods, or drugs, unauthorized border crossings by civilian or military vehicles or persons, or any other kind of activities.
- Different deployment strategies.
- Deploy sensors by dropping them in a measured and controlled fashion from a low-flying airplane, installing them on a fence, etc.
- Resulting topology: linear sensor network with a relatively uniform node density distribution.
- Issues:
  - Distance/density of different nodes
  - Considering nature of the terrain.
  - Available infrastructure.
  - Desired level of performance and reliability



IVC Network

- Roadside networks used to monitor vehicular activities.
- Vehicle-to-Vehicle (V2V) via infrastructure.
- Vehicles-to-Infrastructure (V2I) communication.
- Internet access of vehicles (gateways on road side).
- Alert to potential problems ahead, traffic conditions, accidents, road blockages, emergency braking, dangerous crossings, etc.
- Vehicle controls can even take critical actions before the driver can respond in time.





Railroad/subway monitoring

- Sensors to monitor fatigue-critical components in structure of a railroad bridge.
- Sensors can monitor dynamic strains caused by the passing of trains.
- Provide early detection of critical and dangerous cracks.
- LSNs can be used to improve deployment cost, maintenance, and scalability.
- Research: investigate the optimal parameters for such systems: density and distance of nodes, data rates, sensor technology.
- **Other applications: River, and sea cost monitoring, etc.**

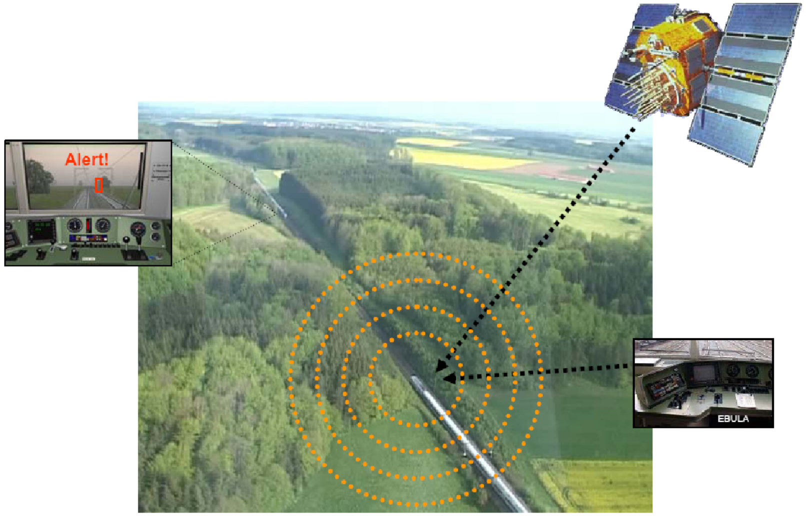
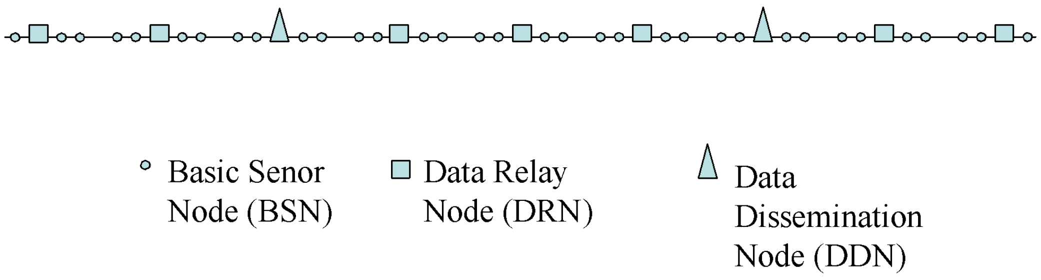
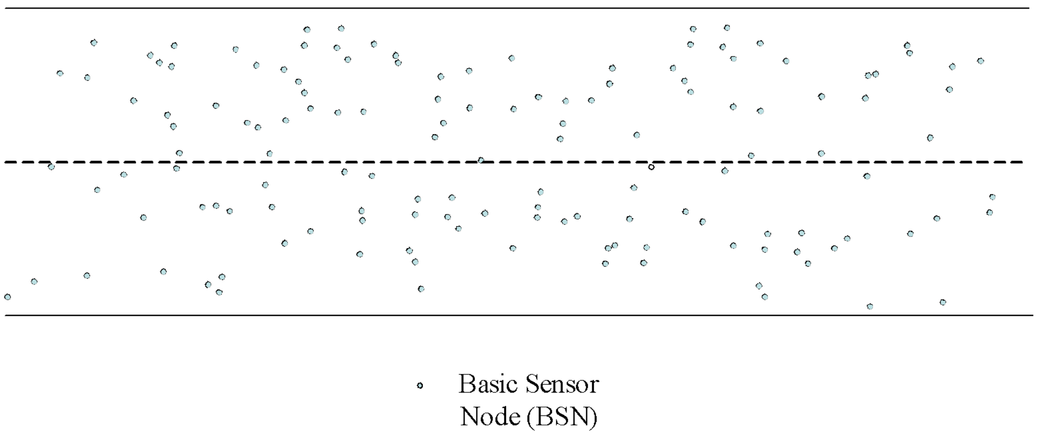


Fig. 1: Interaction of the components of RCAS

Classification of LSNs

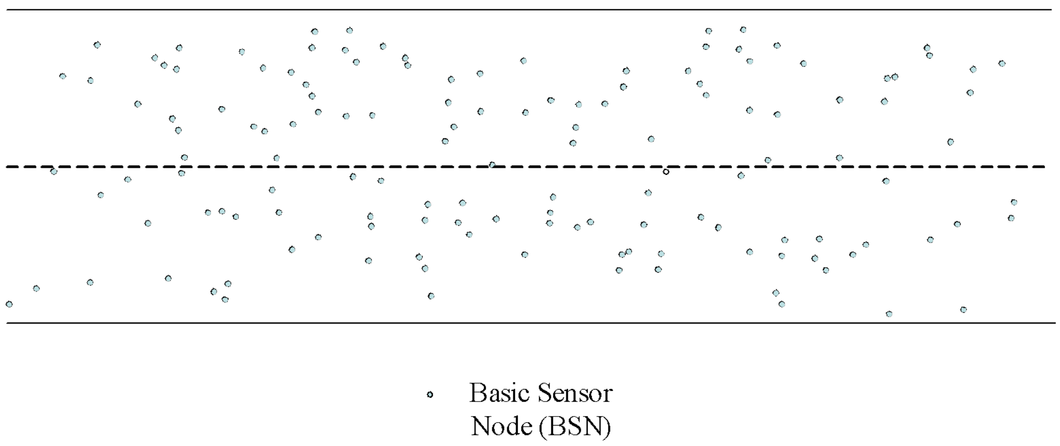
- Classification depends on deployment strategy and node types.
  - Thin LSNs:
    - Nodes along a line
  - Thick LSNs:
    - SNs scattered in **2-D** random form between two **parallel lines** extending for **long distance**
    - **Backbone nodes** have **aggregation**, **compression**, and **routing** responsibilities





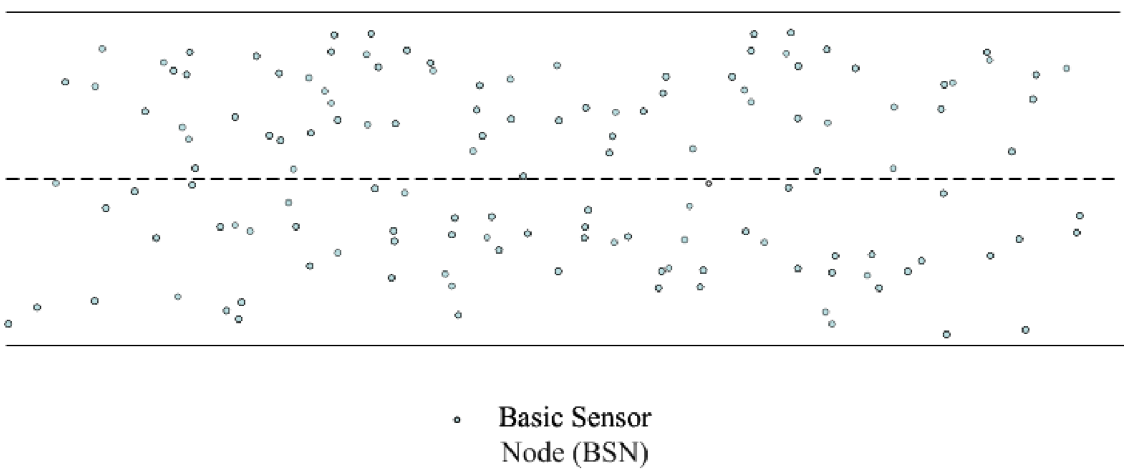
Why New Protocols Needed for Thick LSNs

- **Speed-up** route the **route discovery** and **maintenance**
- **Reduce** control **overhead** and **bandwidth** utilization for route discovery
- Increased **routing fault tolerance** and **reliability**
- Reduce control **overhead** for route **maintenance**
- Increased efficiency of **location management**



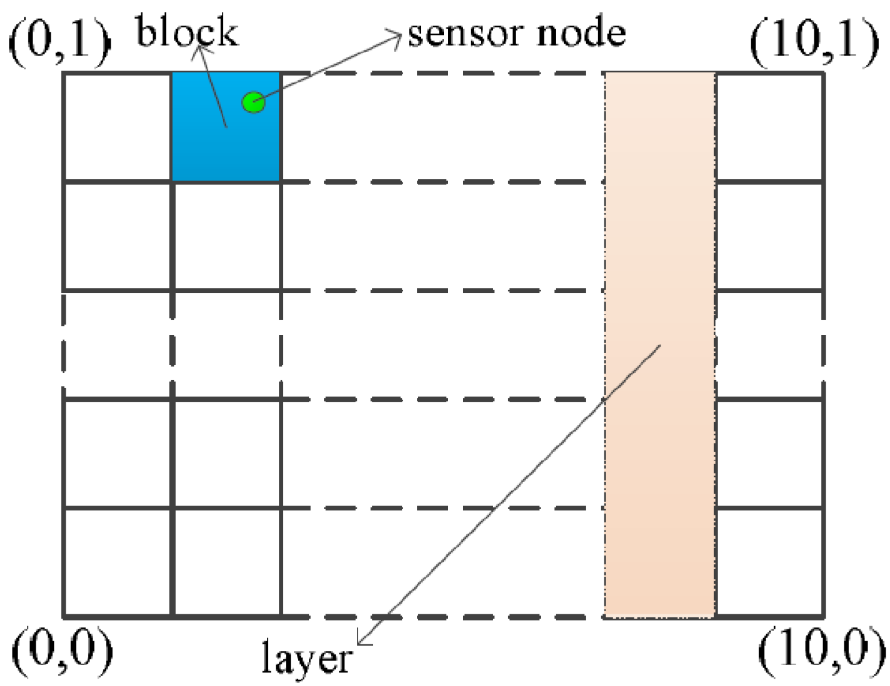
Why New Protocols Needed for Thick LSNs

- **Speed-up** route the **route discovery** and **maintenance**
- **Reduce** control **overhead** and **bandwidth** utilization for route discovery
- Increased **routing fault tolerance** and **reliability**
- Reduce control **overhead** for route **maintenance**
- Increased efficiency of **location management**



Network Model - Area Partition

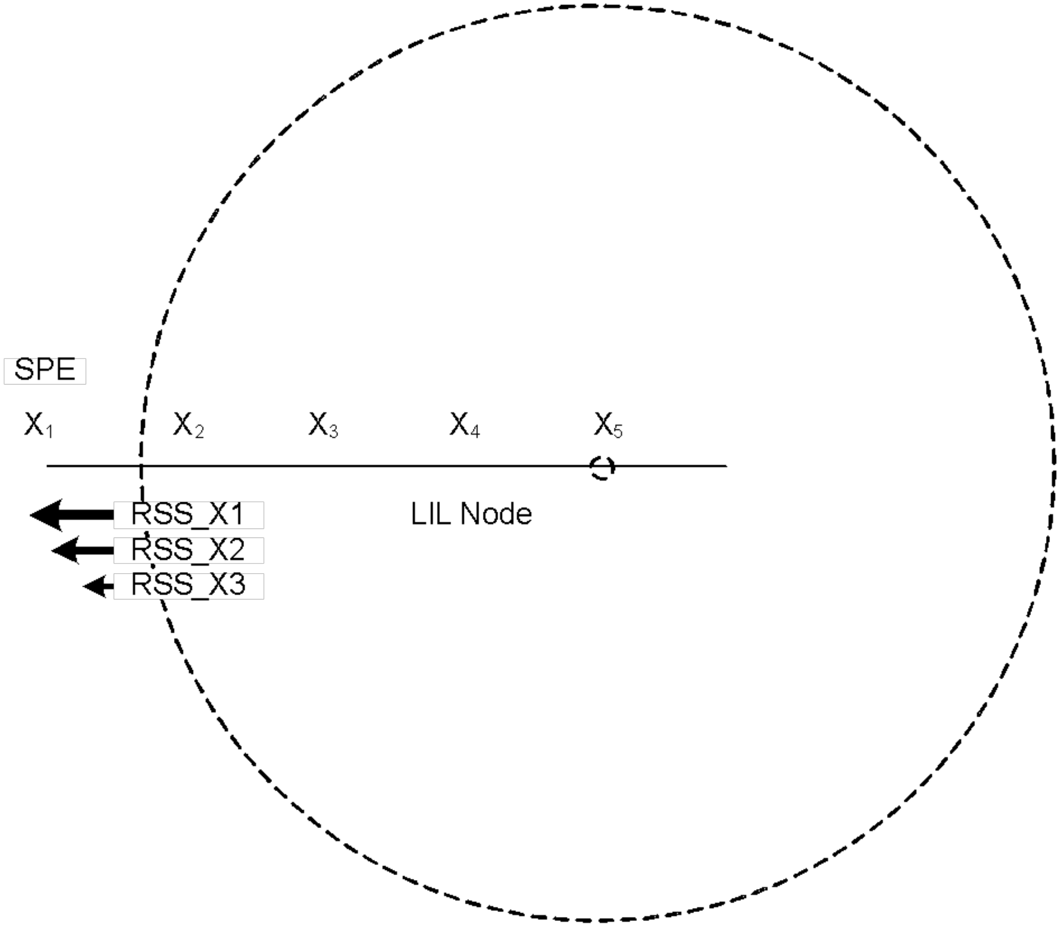
- **Area divided into blocks (squares):** nodes located randomly in the area of [0, 0] x [10, 1].
- **Layer:** Set of **vertically** aligned **blocks**. Considered a cluster.



Network Model - Area Partition

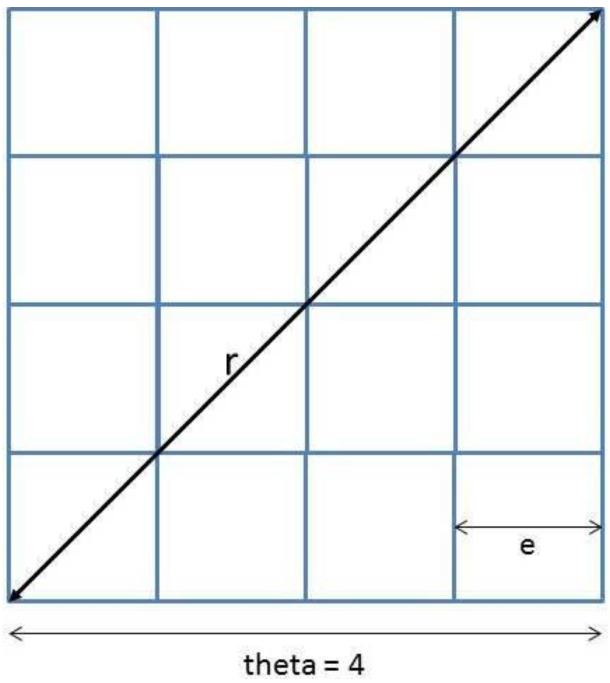
- **Area divided into blocks (squares):** nodes located randomly in the area of [0, 0] x [10, 1].
- **Layer:** Set of **vertically** aligned **blocks**. Considered a cluster.

Network Model - Received Signal Strength (RSS)



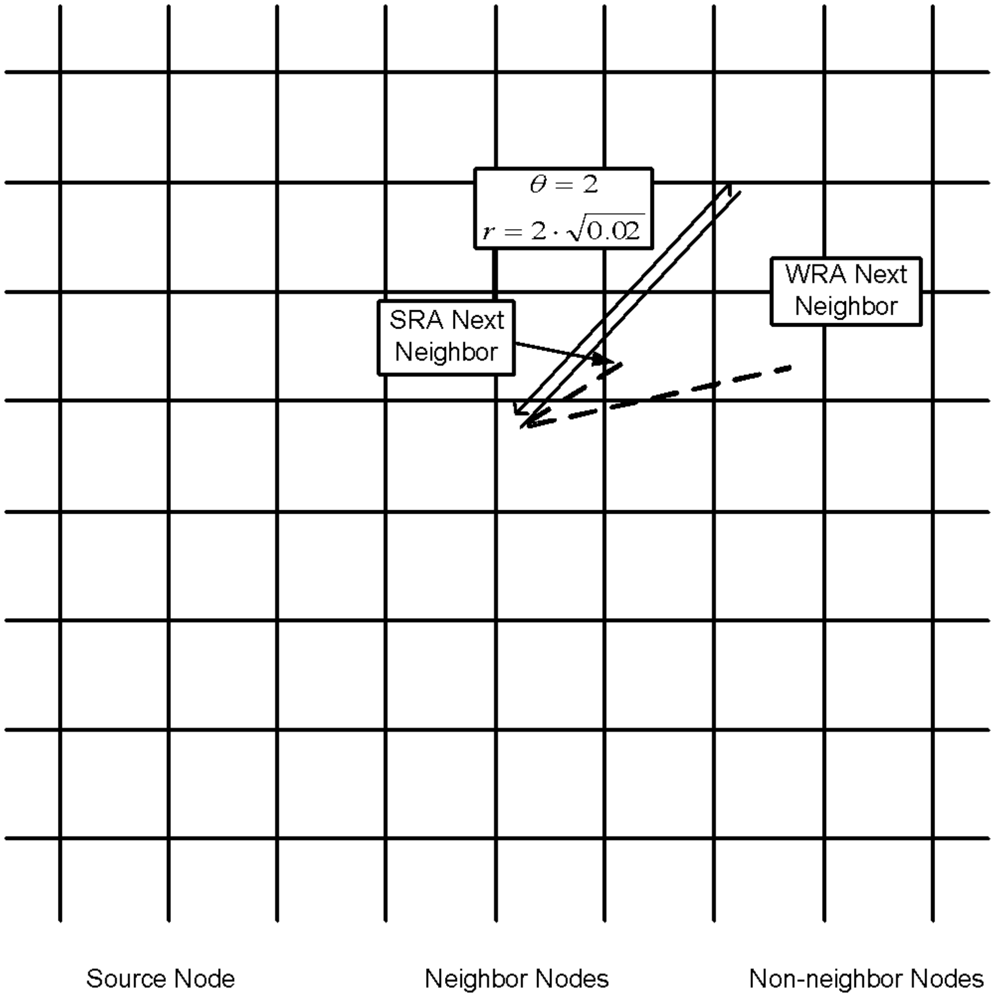
Network Model - Definitions

- **Node Density:** ***d*** (in our example in a square of length 0.1)
- ***Neighborhood, and Threshold* θ** : Define neighborhood as area where **RSS** strength **stronger** than **threshold θ**.
- **More intuitive** to express transmission range by ***θ***.
- If **r** indicates **actual transmission range** of SNs, then:
  - $\boldsymbol{r = \sqrt{0.02} \times \theta}$, when the edge of the block is 0.1
- ***θ=2***: nodes in **adjacent 2 blocks** can exchange messages.
  - In this case: $r = 2 \times \sqrt{0.02}$



Two Backbone Discovery Strategies

- Two **next-hop** selection **strategies**
  - **Weakest RSS** (**WR**) Strategy.
  - **Strongest RSS** (**SR**) Strategy.



Weakest RSS (WR) Strategy

- **Next hop neighbor** with the **weakest RSS** is selected.
- Leads to the selection of the neighbor that is **farthest** from the current node with the **most progress** towards the sink.
- **Advantage**: Data can be transferred from the source node to destination node (sink) as fast as possible leading to **lower end-to-end delay.**
- **Limitations**:
  - **Weaker link**, so might have more **errors** at the MAC level or need to use **lower data rate** to avoid errors (for energy per bit)
  - If we use **more power** in data transmission we can go to higher data rate with **less errors** but consume **more energy**.

Strongest RSS (SR) Strategy

- Node selects neighbor with **strongest RSS** as next-hop node.
- Leads to **selection** of nodes with **smaller distance** from transmitting node.
- **Advantage**:
  - **Stronger link**. With same transmission power.
  - Can **reduce** data **transmission range** resulting in **lower energy** consumption.
- Comes at the price of **increased end-to-end delay**.

Layer Information to Avoid Backward Selection

- **Layer** is taken into account to **avoid** the selection of nodes in the **backward** direction.
  - Algorithms do **not** select the neighbors with **lower number layers** as the next-hop node.
  - **Layer information** is included in broadcasted **messages**.

Discovered Backbone Caching

- **Discovery Completed (DCOP) Message:** When discovery reaches **end node DCOMP** message sent along **discovered backbone**.
- **Backbone Caching:** As **DCOMP** message **propagates** nodes **caches** backbone node **IDs**.
- **Two strategies:**
  - **Partial backbone caching**: *k* neighbor in each direction.
    - **Less memory overhead**
    - **Less information** for **routing** protocol
  - **Full backbone caching**: All backbone nodes cached.
    - **More memory overhead** but more information for routing.
    - Can help choosing direction with lower energy (**smart routing**)

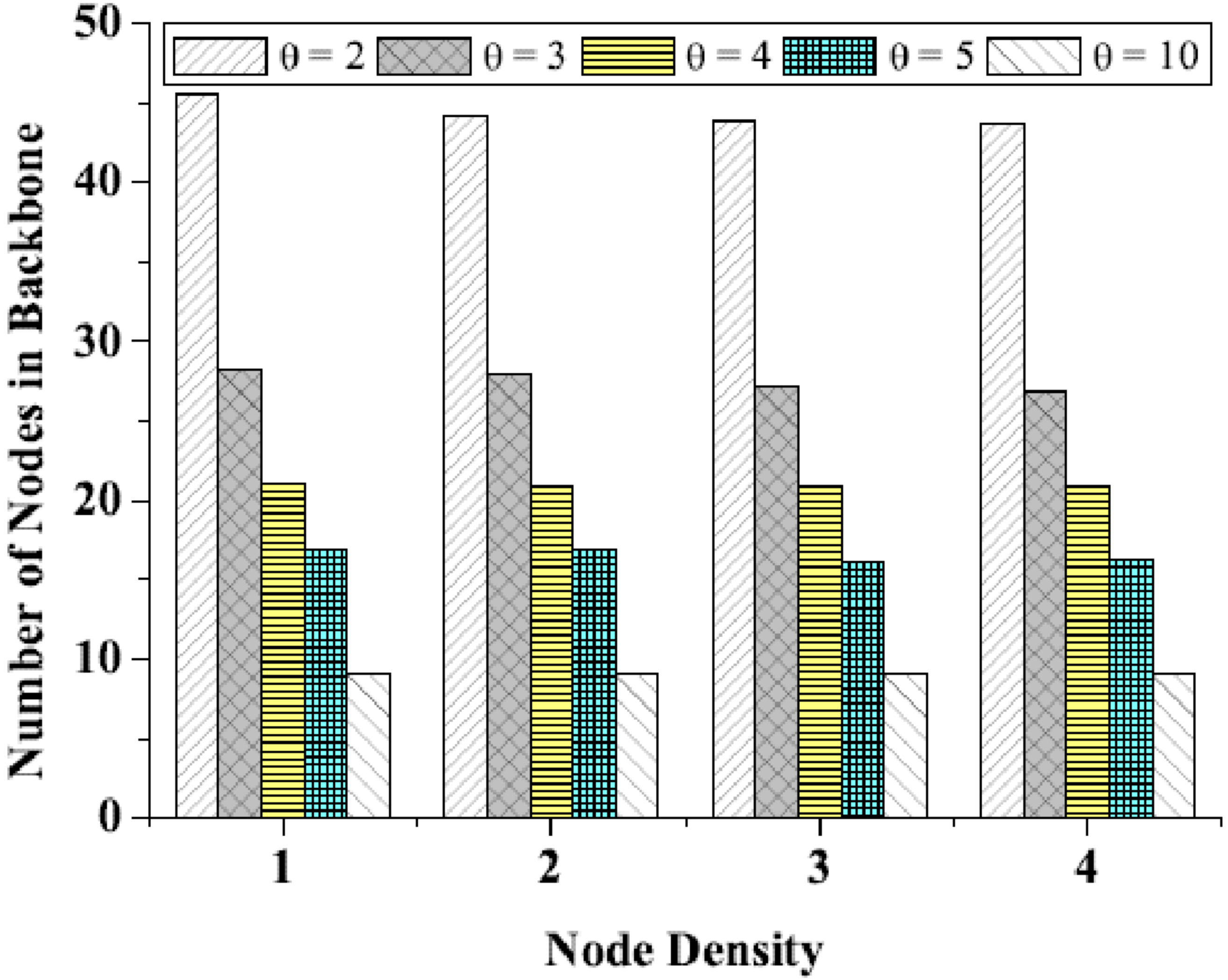
Example of Routing Process and Reaction to Node Failures

- **Jump Always (JA) Algorithm:**
  - If message encounters a **failed node** it **increases** its transmission **range** to reach the node following current one.
  - If **MAX_JUMP_FACTOR** is reached and message is dropped.
- **Redirect Always (RA) Algorithm:**
  - Good when **no range** extension is possible.
  - If message reaches a **failed node**, it is redirected in the **opposite direction**. If already redirected it is dropped (redirection flag inside message is used).
- **Smart Redirect and Jump (SRJ) Algorithm:**
  - A **combination** of the first two algorithms **JA and RA.**
  - Node calculates total necessary energy to reach each of the sinks on both sides and transmits in the **least** necessary **energy** direction.

Analysis

- We **analyze** the algorithms from the following **aspects**:
  - Node **Selection** strategy
  - Total number of **hops** in backbone
  - Transmission **threshold**
  - Node **density**

Backbone Selection: WR Strategy (Smaller Number of Hops)

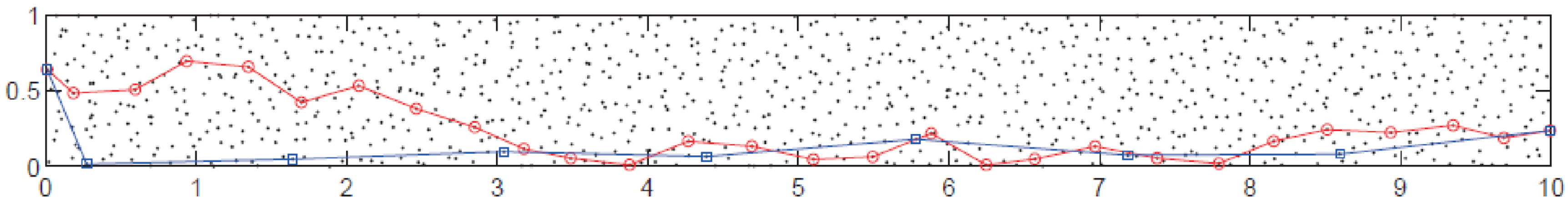


Weakest RSS (WR) Algorithm

- **WR Strategy**: Neighbor longer distance is selected. **Less hops** to destination
- **Density reduced effect** on minimal number of **hops** in backbone. Though there are **more neighbors** when the **density** is **high**
- As threshold **θ increases** number of **hops** in the backbone **decreases (inversely proportional).**
- But results in **higher energy consumption** resulting in earlier expected **failure** of discovered backbone.

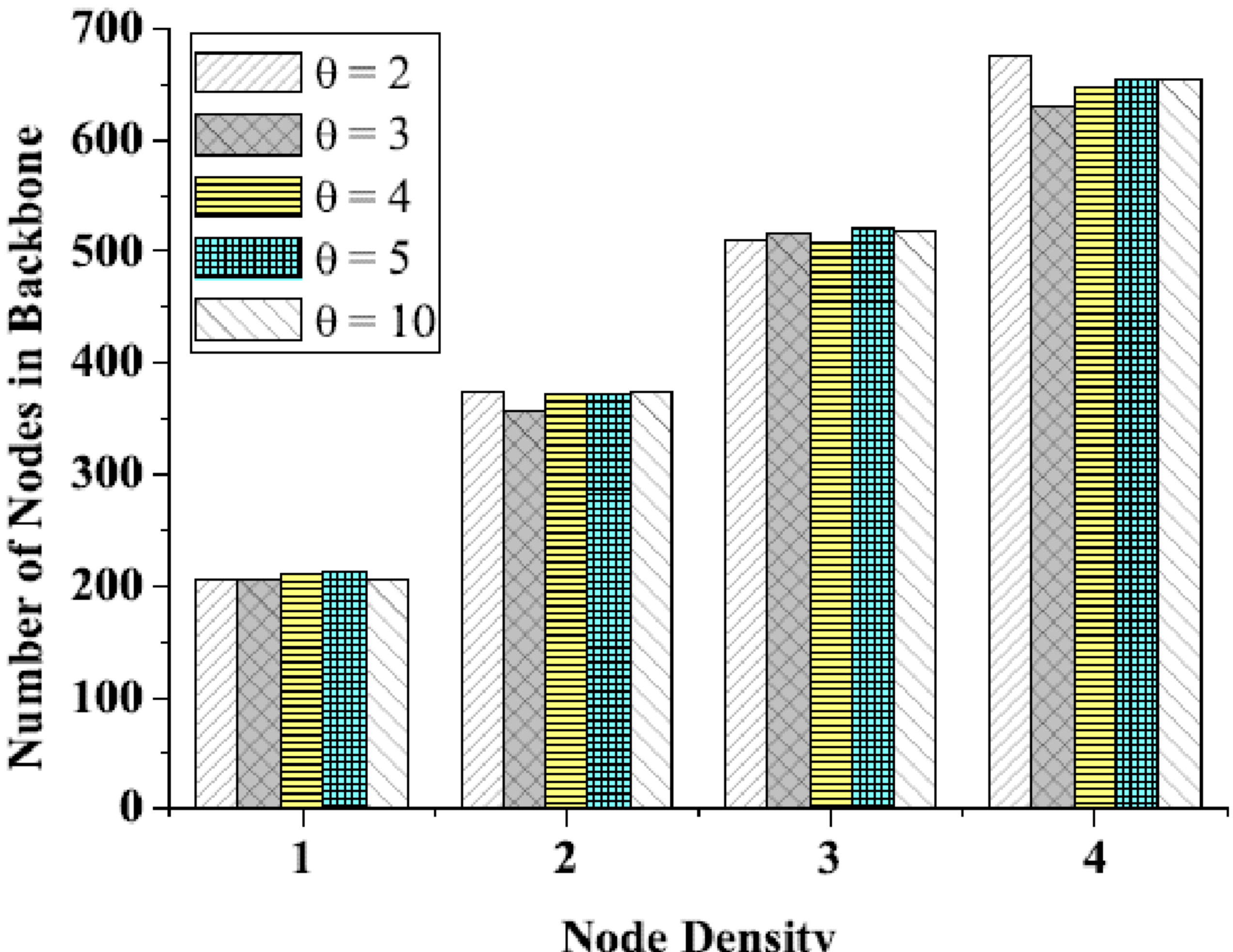
Illustration of Backbone Selection with WR Strategy

- With density ***d* = 1**



- For **red line**: **θ = 3** => **28 nodes** in **backbone**.
- For **blue line: θ = 10** => **9 nodes** in **backbone**.
- When transmission **range** is **large** enough, path tends to be a **straight** line.

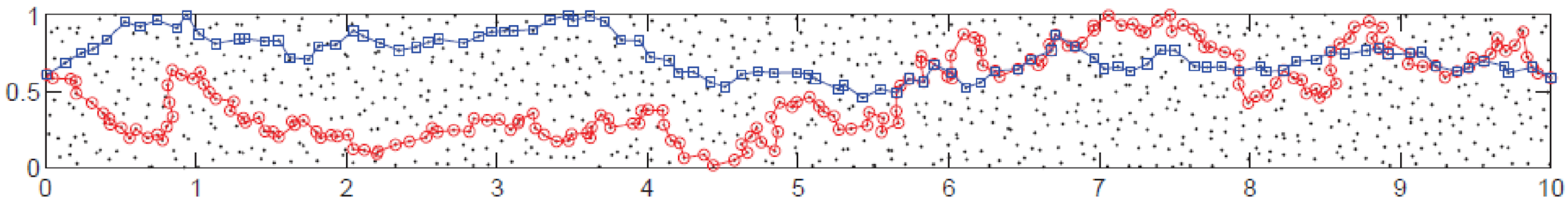
Backbone Selection: SR Strategy (Higher Number of Hops)



Backbone Selection – SR Strategy

- **Shorter distance neighbor** selected and number of **hops increases**.
- Node **transmission** range **θ** has **less effect** on number of **nodes** in backbone.
- Implies we can adjust trans. **range** to be **shorter**.
  - Effective way to **save energy** for nodes in backbone, and reduce interference. But **more end-to-end** delay
- When **density increases**, there are more nodes in area, and **more nodes** are selected.
  - **Large** number of **nodes** in backbone **unnecessary**.
  - Motivates us to let **more nodes** switch to **sleep** mode to save energy.

Backbone Selection – SR Strategy



- We let ***d* = 1 and *θ* = 1.2**, to **save energy** consumption (TX power exponentially proportional to TX range).
- **Red-colored** backbone => **195 nodes**. N**ext-hop** node is in layer ***more than or equal*** to that of sending node (can choose next-hop nodes in same layer)
- **Blue-colored** backbone => **100 nodes. Next-hop** node is in layer ***strictly more than*** that of sending node.
- ***Strictly more than*** is a **frequently** used method to select **one node** from each **cluster** (**layer** in our paper).

More Analysis – Some Final Notes

- Same algorithms work for the case of **thin LSNs**.
- **Thickness** of the **LSN varies** according to the requirements of the corresponding **application**.
- Energy consumption, ***P*, is proportional** to transmission range, r^{α}, where($2 \leq \alpha \leq 4$)
- We can easily get result for how **energy is consumed as** transmission range ***r*** **changes**

Conclusions

- Stated some of the **applications** for **thick LSNs** in order to **motivate** the research
- Presented **backbone discovery algorithms** for thick LSNs.
- **Backbone** can later be **used** for **efficient routing** of messages between **nodes** and **sinks** at either or both ends of the network.
- **Two** different **strategies** for backbone discovery are presented and analyzed. Based on c**riteria** for **next-hop** neighbor selection using **RSS** by sending node.

Conclusions – Cont'd

- Proposed algorithms can constitute a **good foundation** for further **future** research in this area.
- For **long thick LSNs**, which might extend for tens or hundreds of kilometers, **multiple segments** separated by sinks can be used to provide added **efficiency**, **reliability**, and **scalability** to the network and associated routing protocol.
- **Thick LSNs** offer a good amount of **issues** and **challenges** that need further investigation.
- Can **work** on more **optimizations** to enhance the **routing**, **reliability**, and **energy** efficiency.

Thank you.

Questions?