Cluster Tree Based Self Organization of Virtual Sensor Networks

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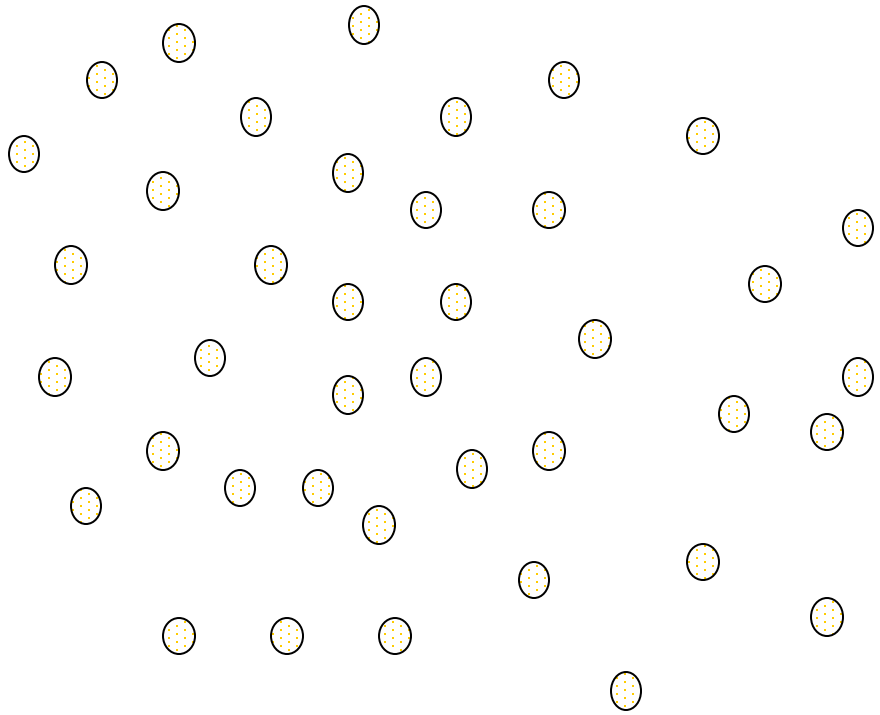
Outline

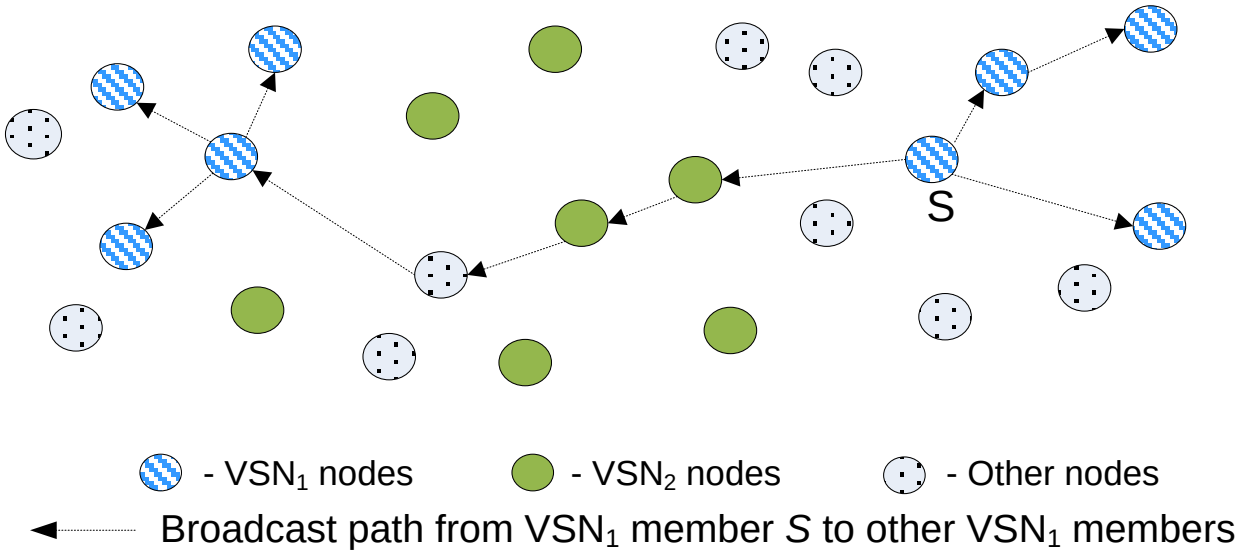
- Virtual Sensor Networks (VSNs)
- VSN formation
- Performance analysis
- Summary & future work

Dedicated Wireless Sensor Networks

- Sense the physical world at a far greater temporal and spatial granularity
- Nodes are limited in sensing, processing, and communication capabilities
- Severe power constraints
- Cost
- Homogeneous nodes



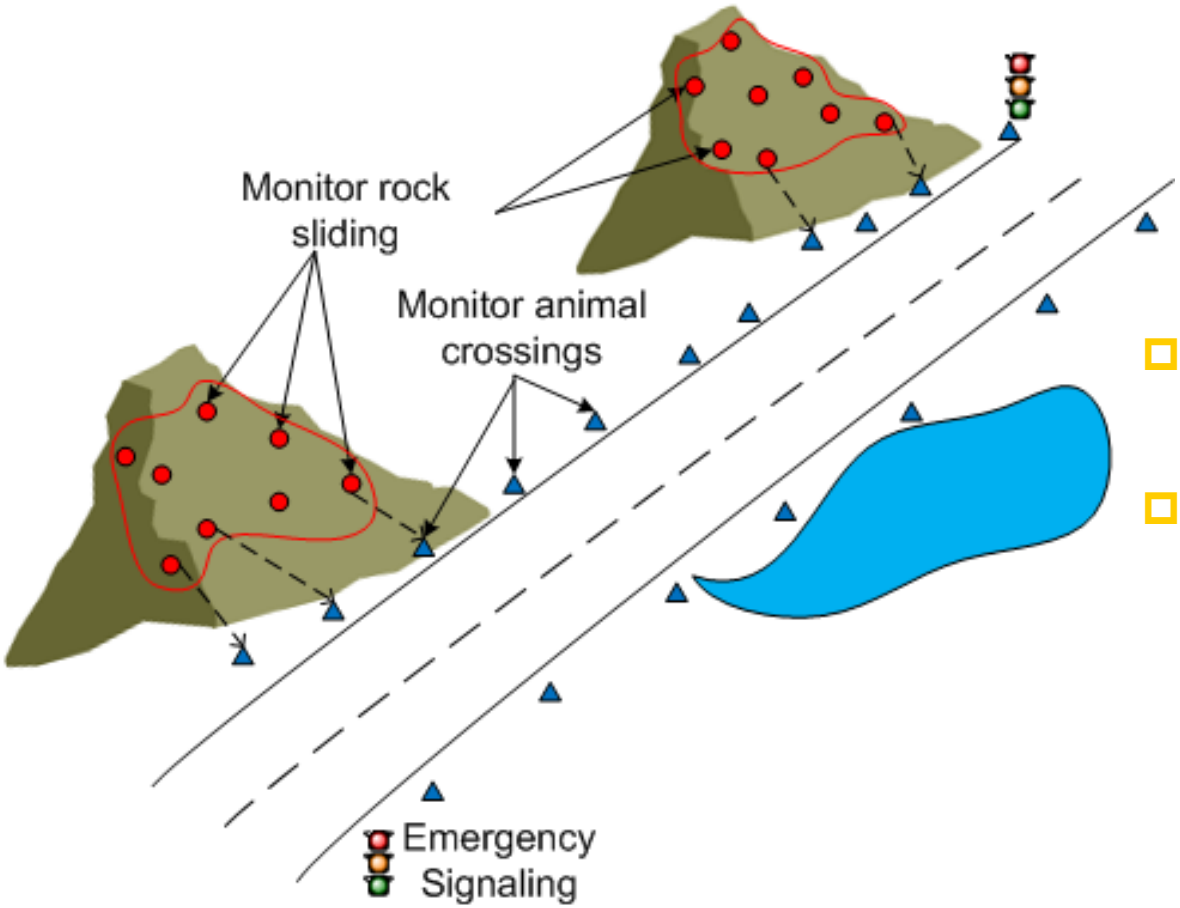
Virtual Sensor Networks (VSNs)



Jayasumana, Han, & Illangasekare, "Virtual Sensor Networks," 2007

- Formed by a subset of nodes dedicated to a certain task/application
- Other nodes provide support to create, maintain, and operate
- Multiple VSNs on a single WSN
- Heterogeneous

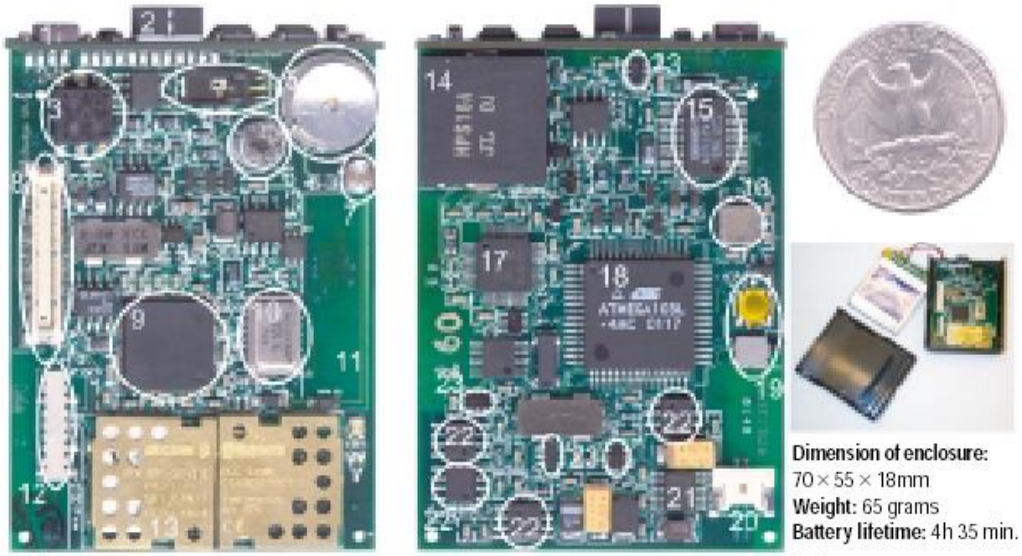
Example 1: Geographically overlapped applications



- Heterogeneous nodes
- Relay each others data

Example 2: Multi-functional sensor networks

- One physical sensor network for different functions
  - Each node equipped with multiple sensors
    - SmartKG iBadge platform
  - Multiple applications
    - Smart neighborhood systems

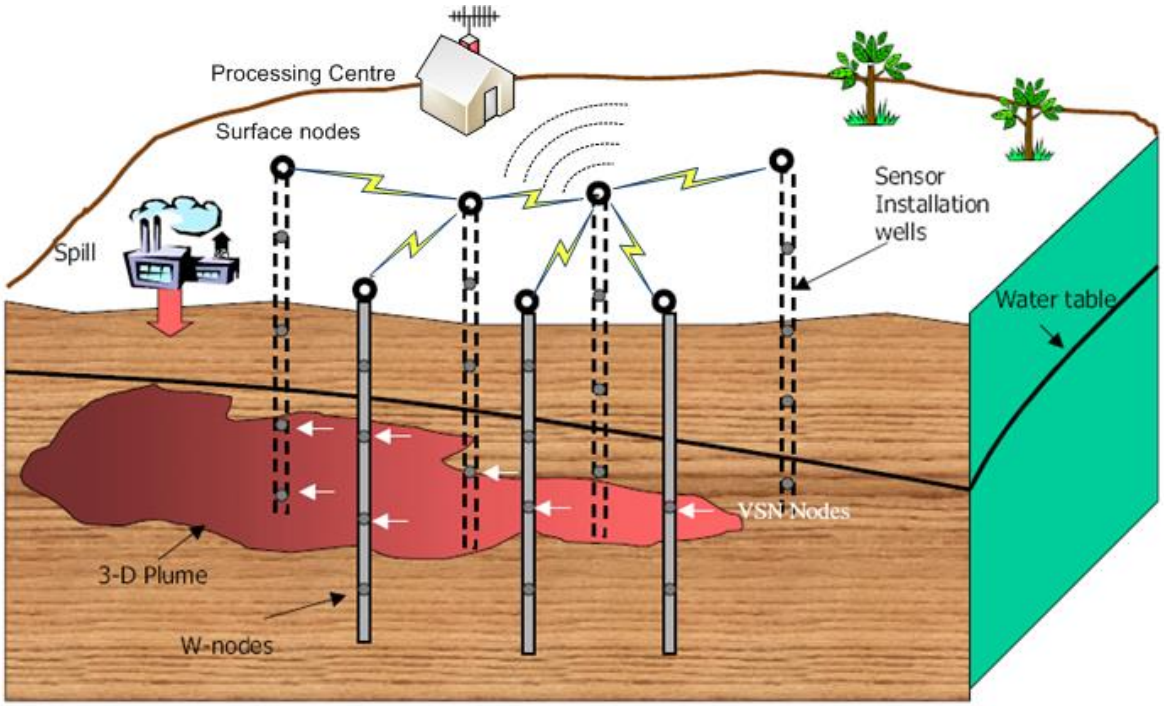


47 × 68 × 7 mm (1.85 × 2.78 × 0.28")

1. Accelerometer forx, y-axis
2. Magnetic field sensor
3. Pressure sensor
4. Humidity sensor
5. Ultrasound tranceiver
6. Microphone
7. Light sensor
8. Connector (SW download)
9. DSP
10. RFM radio (for localization)
11. PCB antenna for RFM radio
12. Blue tooth antenna
13. Blue tooth module
14. Loudspeaker
15. ADC magnetic field sensor
16. Accelerometer for x-axis
17. Codec chip
18. Microcontroller
19. Switches (Power, Reset)
20. Battery connector
21. Power supply
22. Battery monitors
23. Switches to functional units

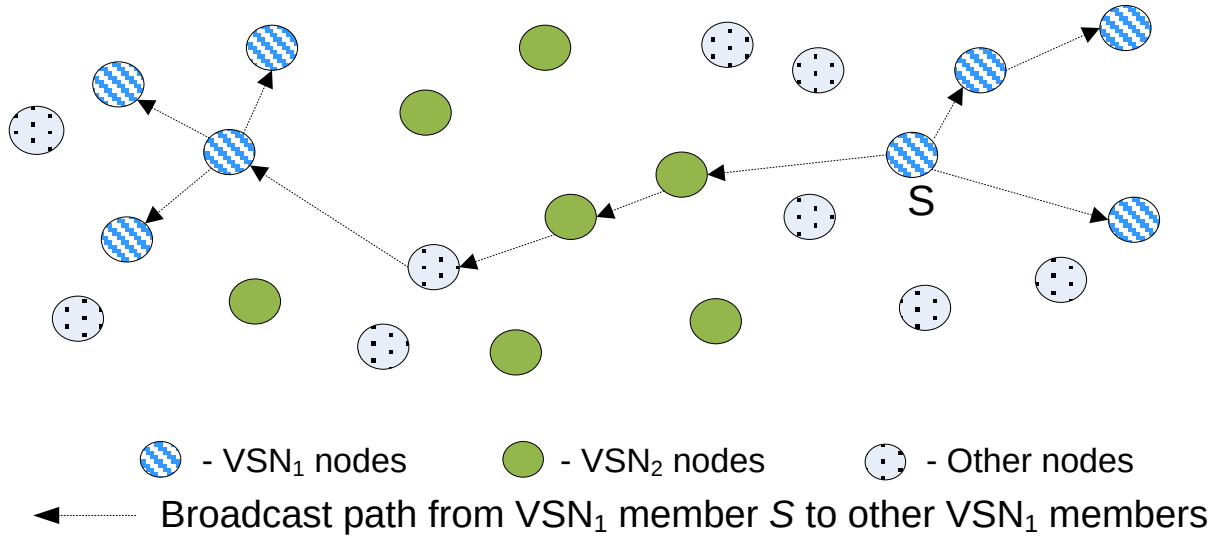
Example 3: Dedicated applications

- Some dedicated applications can benefit from the VSN concept as well
  - May involve dynamically varying subset of sensors & users



Jayasumana & Illangasekare, 2005

Virtual Sensor Networks (VSNs)



Jayasumana, Han, & Illangasekare, "Virtual Sensor Networks," 2007

- Better resource efficiency through collaboration and resource sharing
- Supports collaborative, resource efficient, and multipurpose WSNs
- We are proposing a cluster tree based approach for VSN formation

VSN support functions

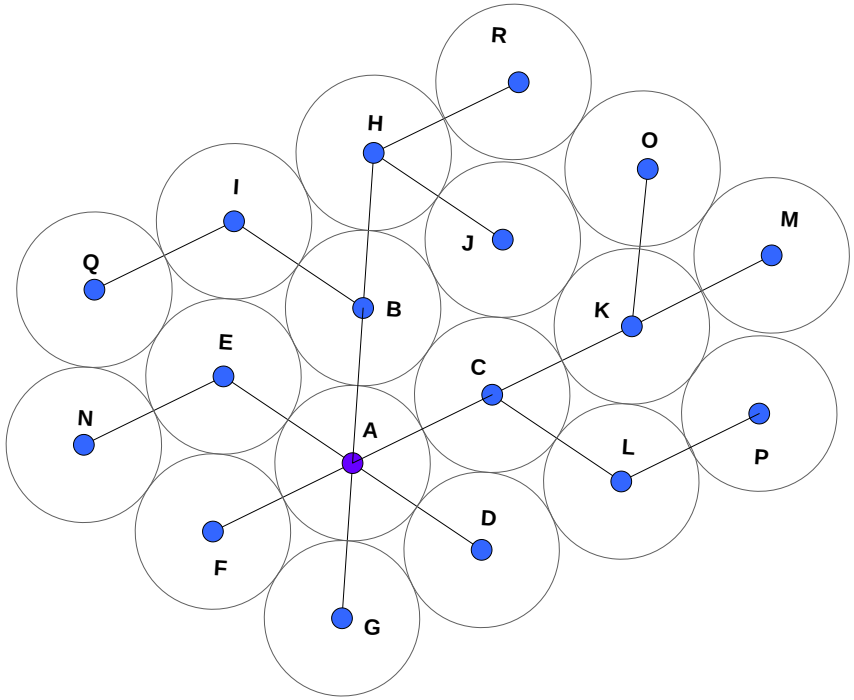
Function	Usage
Form_Discover_VSN(msg)	Nodes that detect a relevant event for the first time
Unsubscribe_VSN(msg)	Unsubscribe if no longer need to be in a VSN
Unicast_VSN(destination, type, data) *Muticast_VSN(type, data)* *Broadcast_VSN(data)*	VSN communication

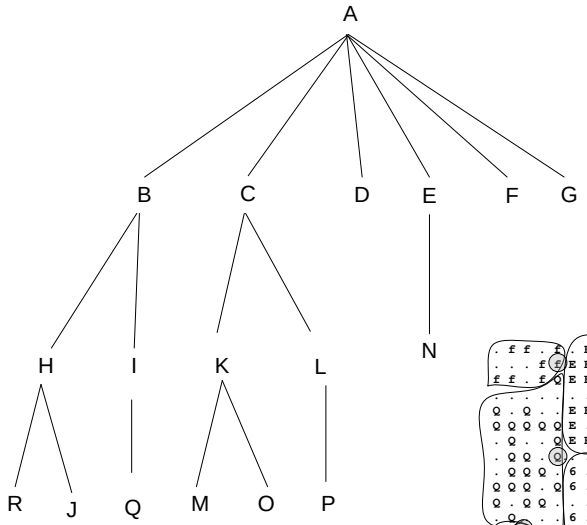
- Additional functions are required to handle splitting and merging phenomenons

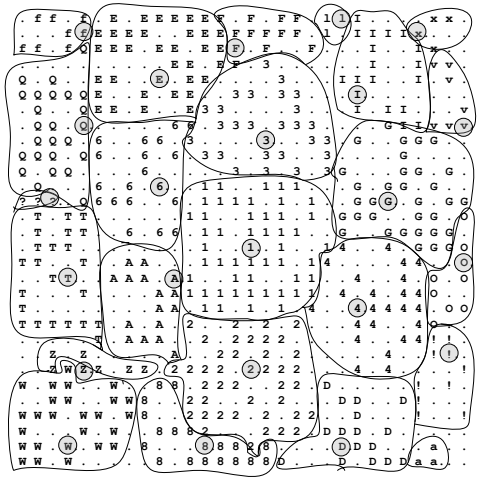
VSN message delivery

- Alternative strategies for node-to-sink and node-to-node communication
  - Random routing
    - Rumor routing – *Braginsky and Estrin, (2002)*
    - Ant routing – *Hussein and Saadawi (2003)*
  - Geographic routing
  - Hierarchical routing
- Need some sort of an addressing scheme
- Imposing some structure within network is more attractive
  - E.g., Cluster tree – IEEE 802.15.4, GTC
  - GTC – Generic Top-down Clustering algorithm

Cluster tree formation with Generic Top-down Clustering (GTC) algorithm



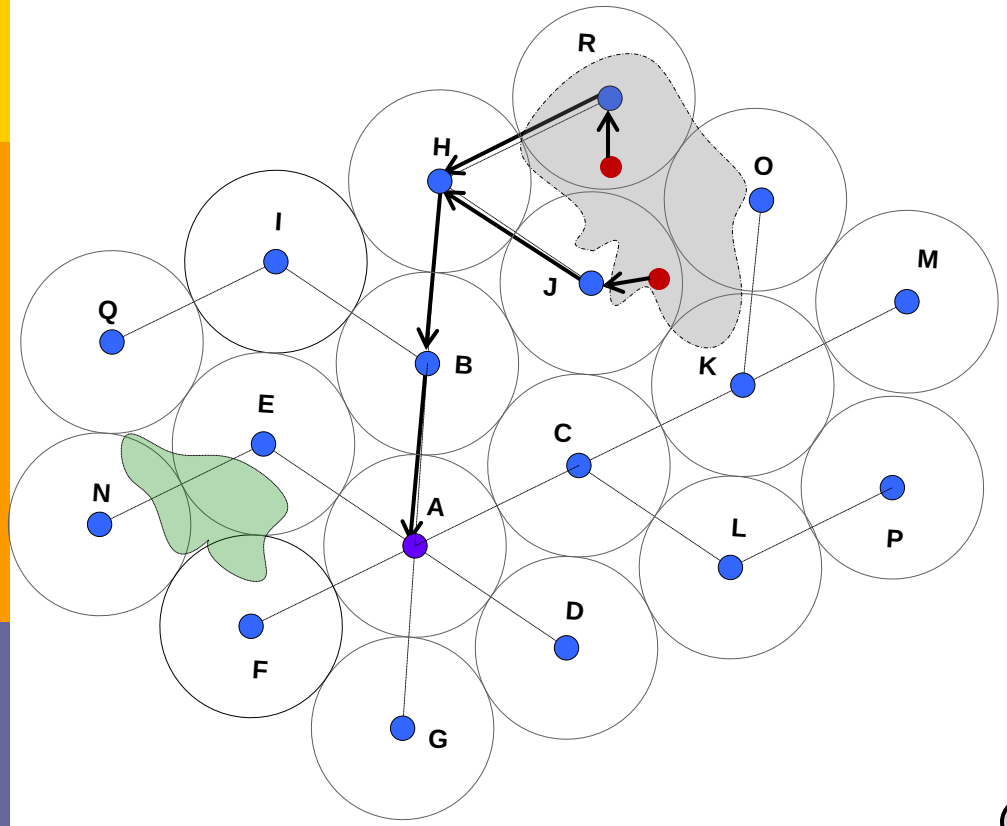


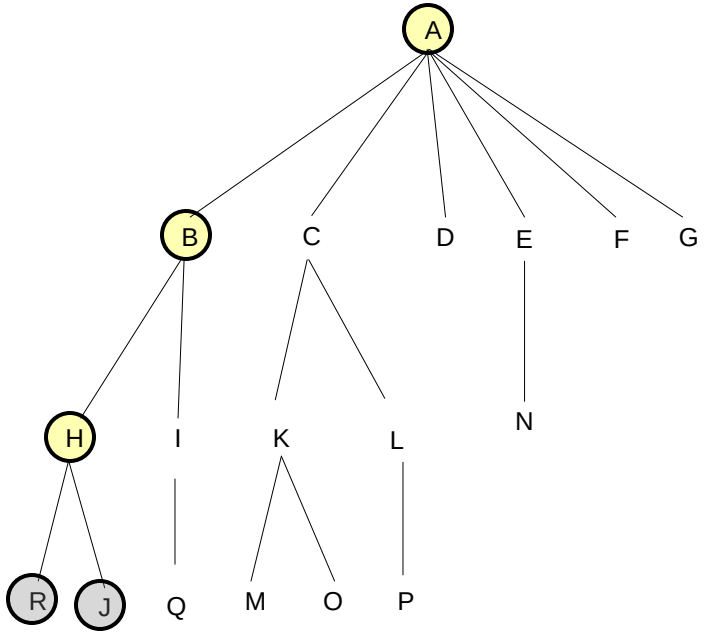


Bandara & Jayasumana, 2007

- Hierarchical addressing scheme is developed to facilitate in-network communication

Cluster tree based self-organization of VSNs

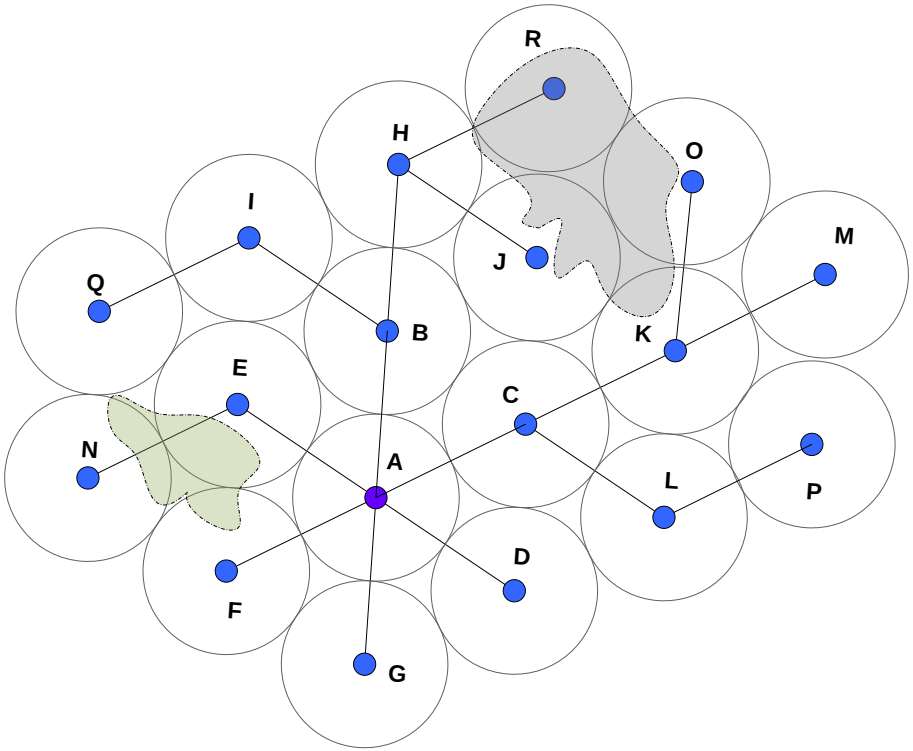


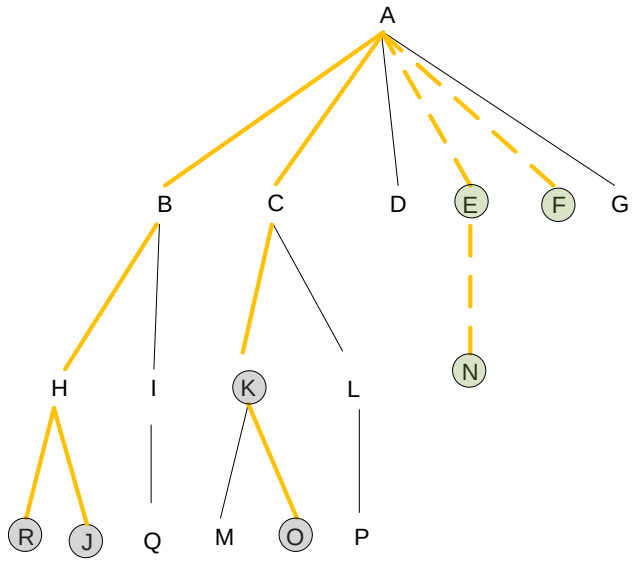


Cluster heads in VSN

Cluster heads that facilitate VSN

Self-organization of VSNs (cont.)





Cluster heads belong to plume 1

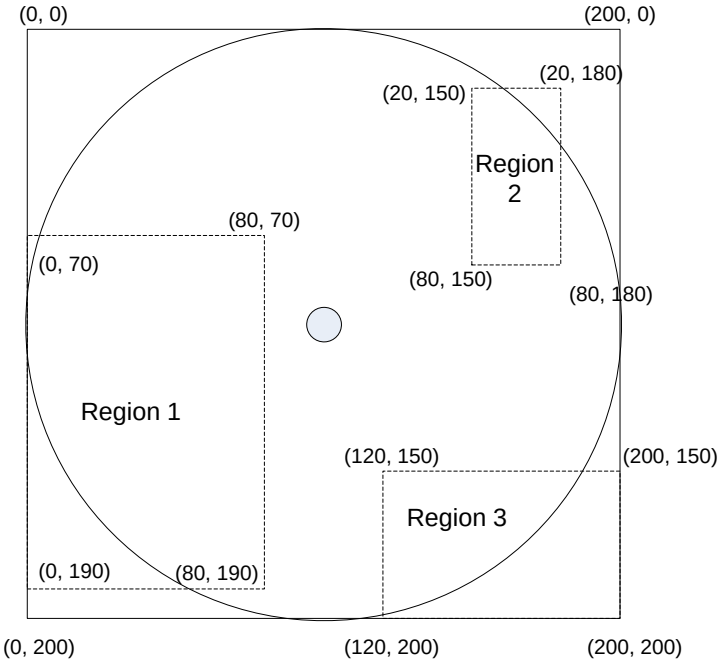
Cluster heads belong to plume 2

Virtual tree belong to plume 1

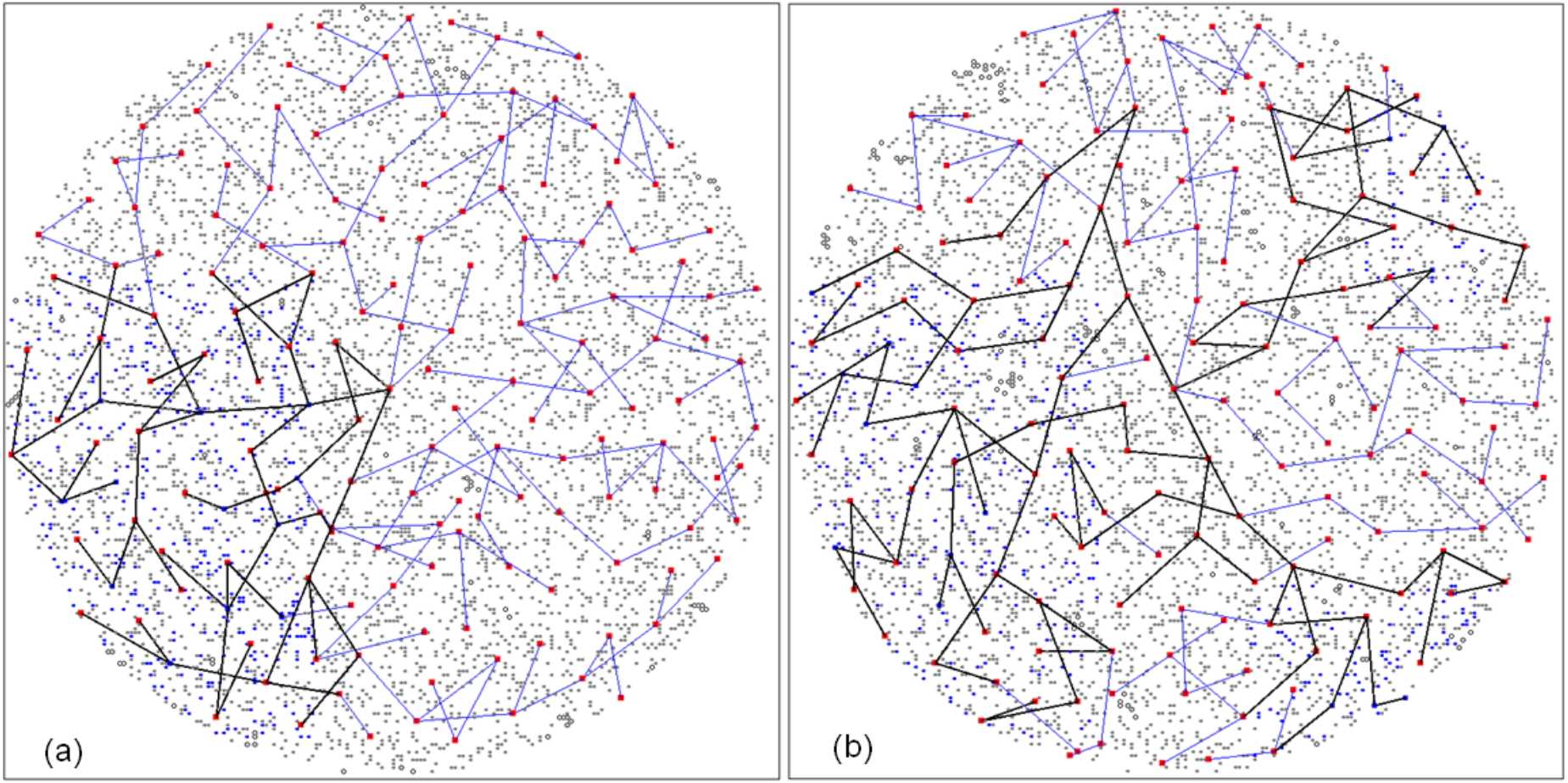
Virtual tree belong to plume 2

Simulator

- Discrete event simulator was developed using C
- 5000 nodes in a circular region with a radius of 500m
- 500 nodes detect the phenomenon in all the regions



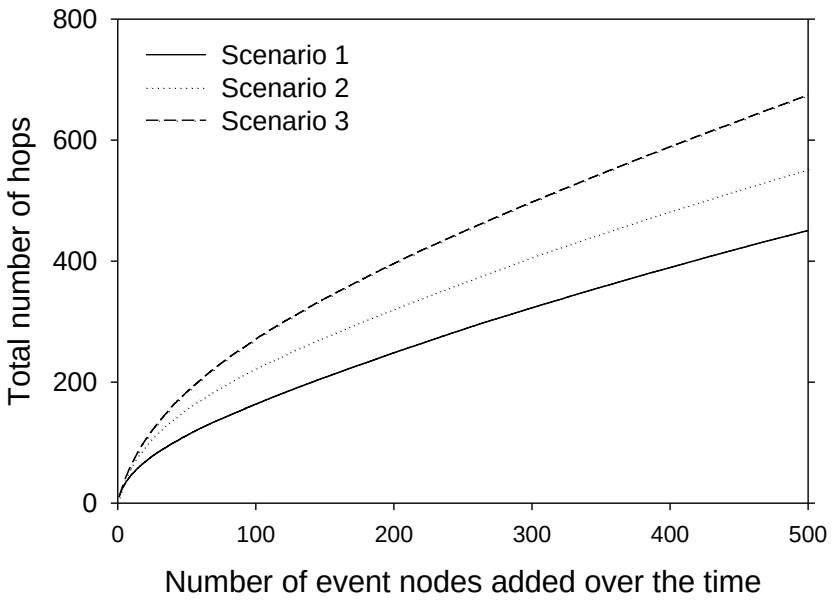
Performance analysis – Self-organization of VSNs



(a) Scenario 1, (b) Scenario 2

P_T= *-12dBm*

Performance analysis – VSN formation overhead



- Scenario 2 - Cost of discovering two VSN members with Rumor routing

No hops per agent	Probability of successful delivery
350	0.51
600	0.84
1000	0.91

- Scenario 2 - 896 hops are required if CH-to-CH communication is multi-hop

- Cluster tree based VSN formation guarantees that all VSN members identify each other
- Lower overhead

Summary & future work

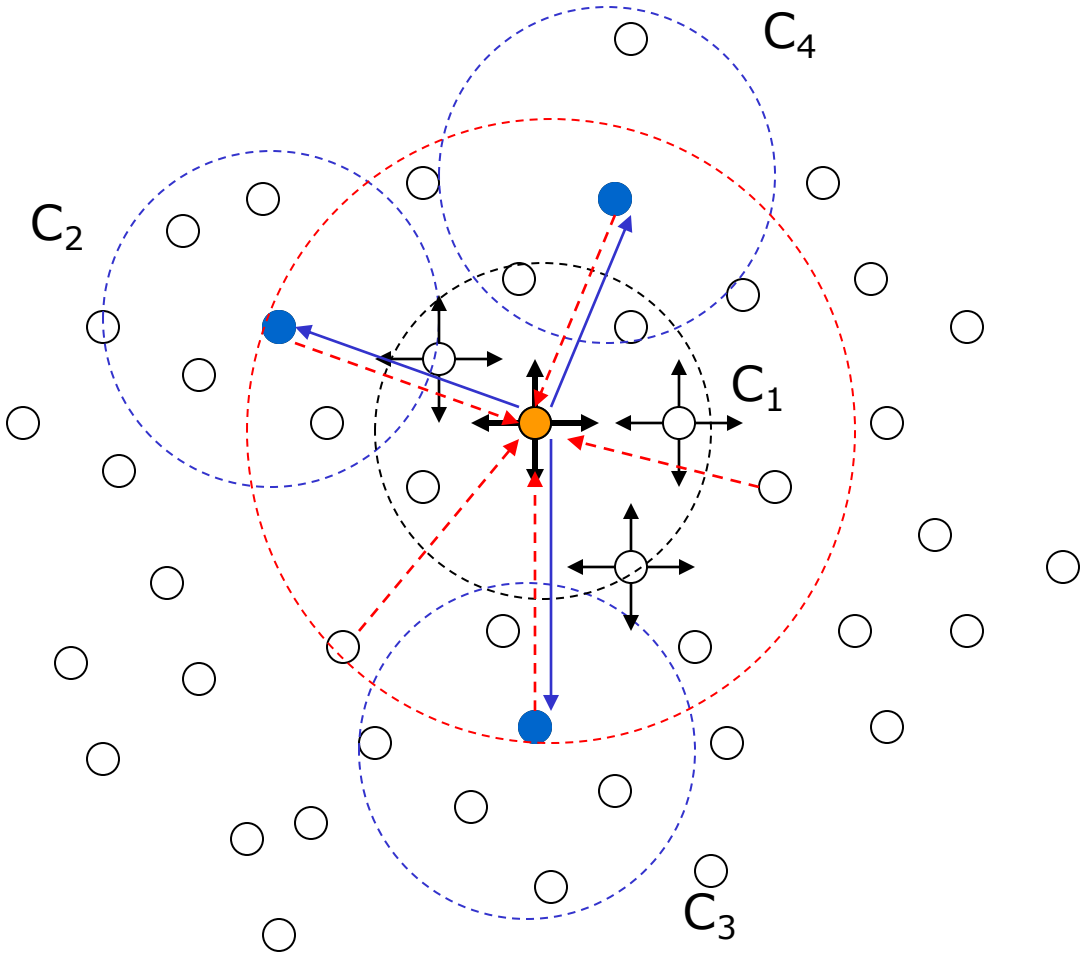
- Cluster tree based VSN formation scheme
  - Efficient
  - Reliable
  - Addressing scheme

- Future work
  - VSN management functions to detect multiple VSNs
  - Merging 2 VSNs together
  - Splitting a VSN into 2 VSNs

Questions ?

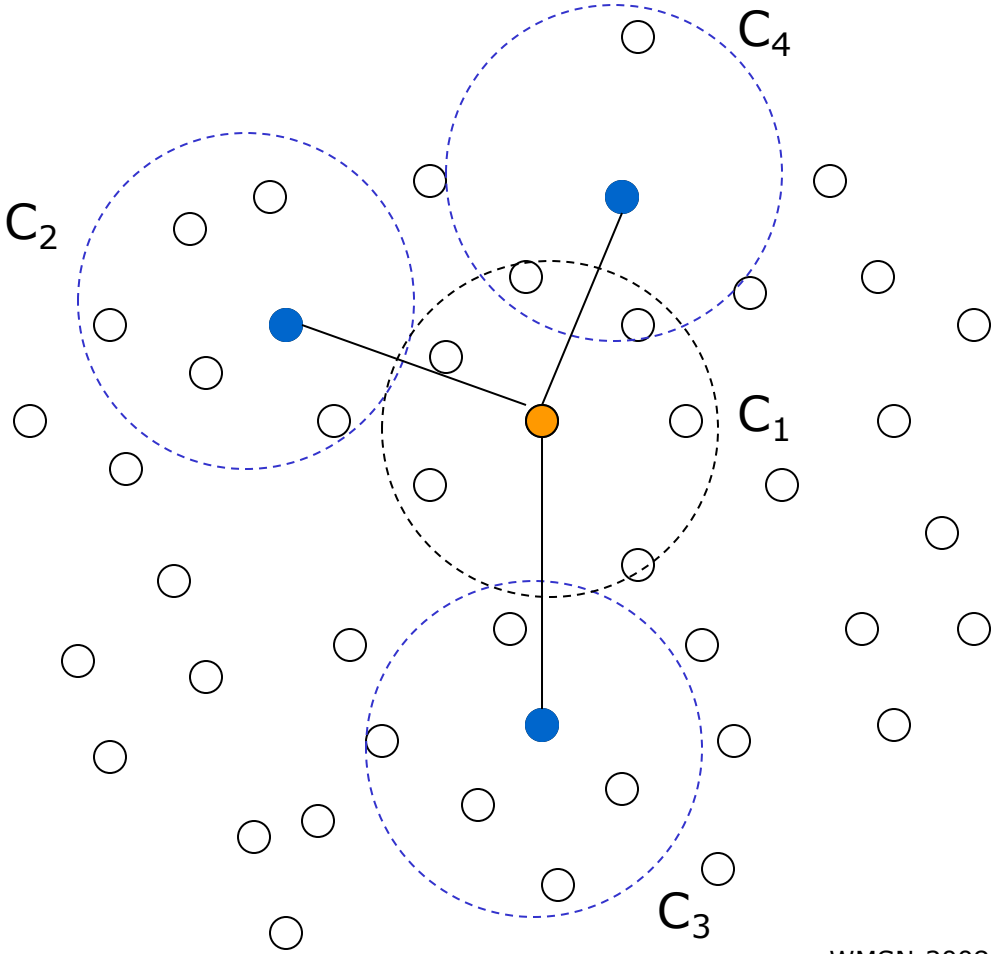
Thank You…

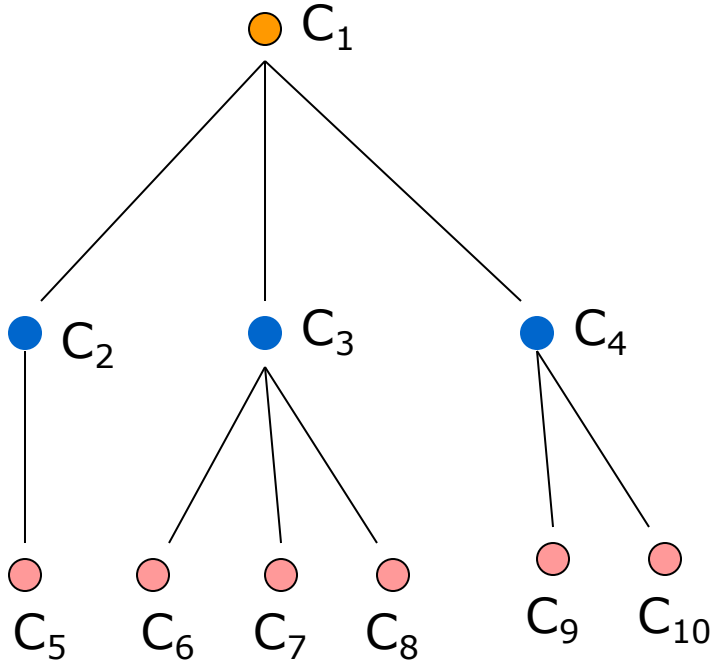
Generic Top-Down Cluster & cluster tree formation (GTC) algorithm



GTC - Cluster tree formation

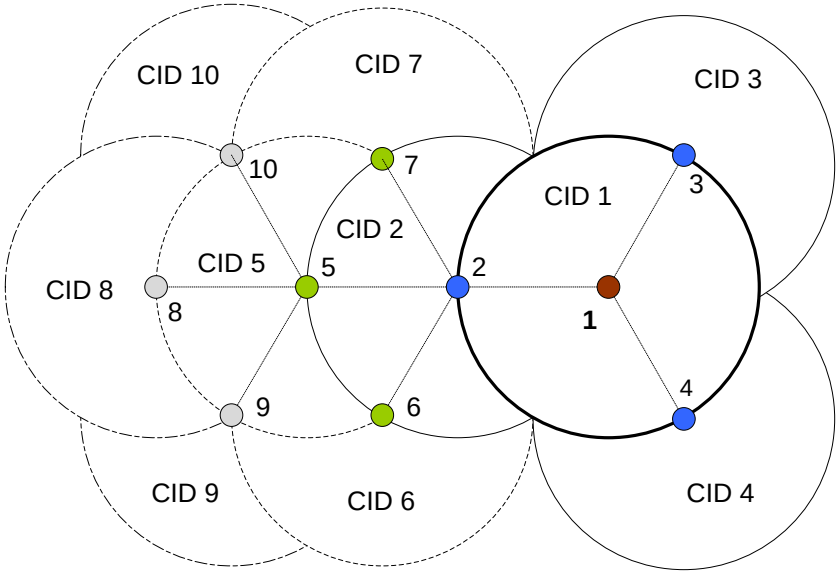
- Cluster tree is formed by keeping track of parent & child relationships





GTC algorithm (cont.)

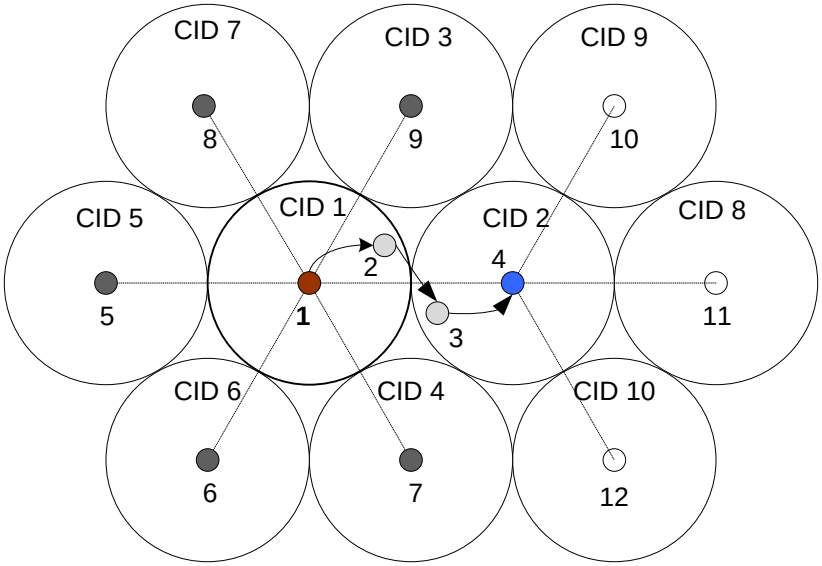
- SHC – Simple Hierarchical Clustering
- HHC – Hop-ahead Hierarchical Clustering



SHC clusters

$hops_{max} = TTL_{max} = 1$

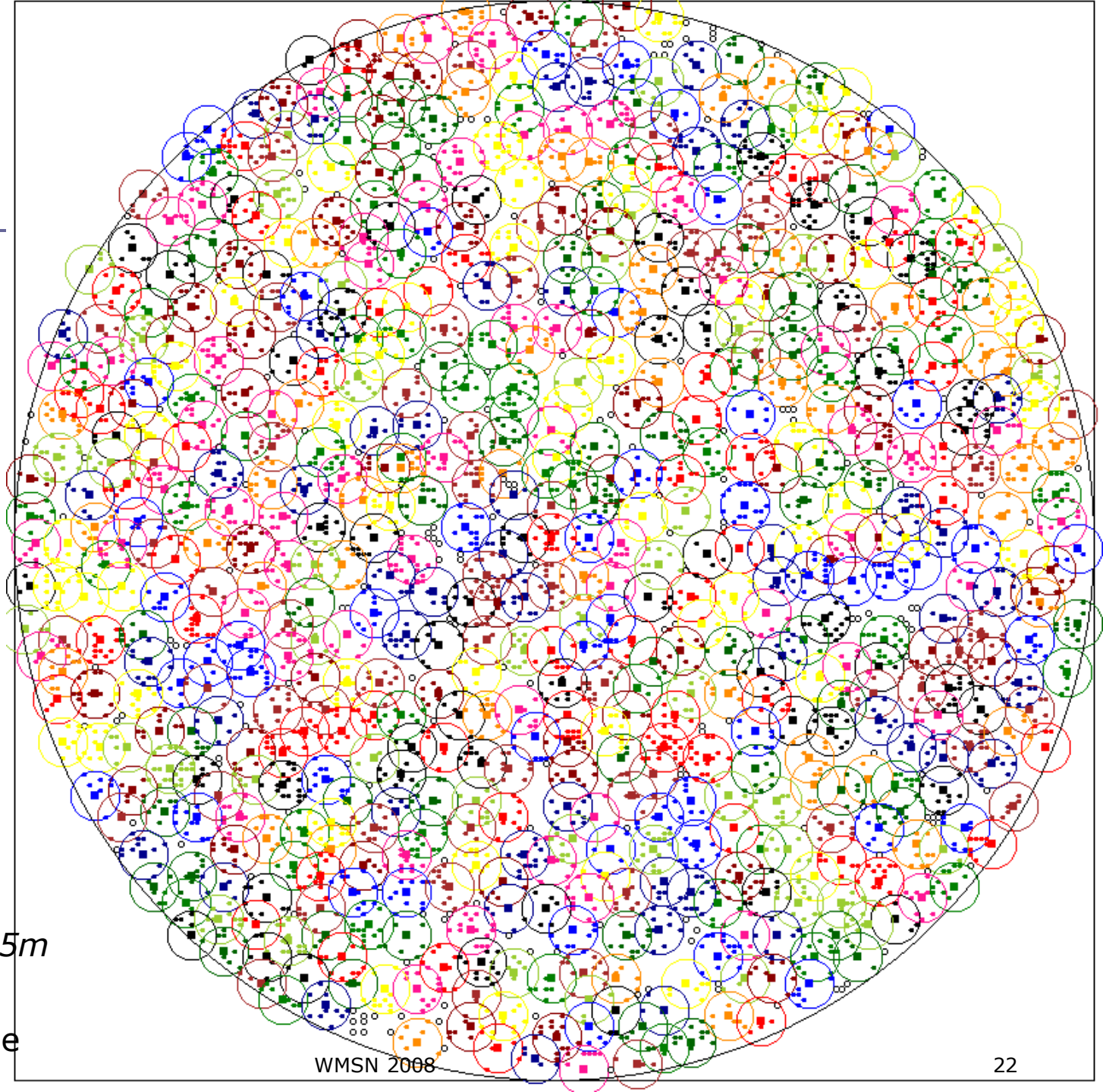
Similar to IEEE 802.15.4 cluster tree



HHC clusters

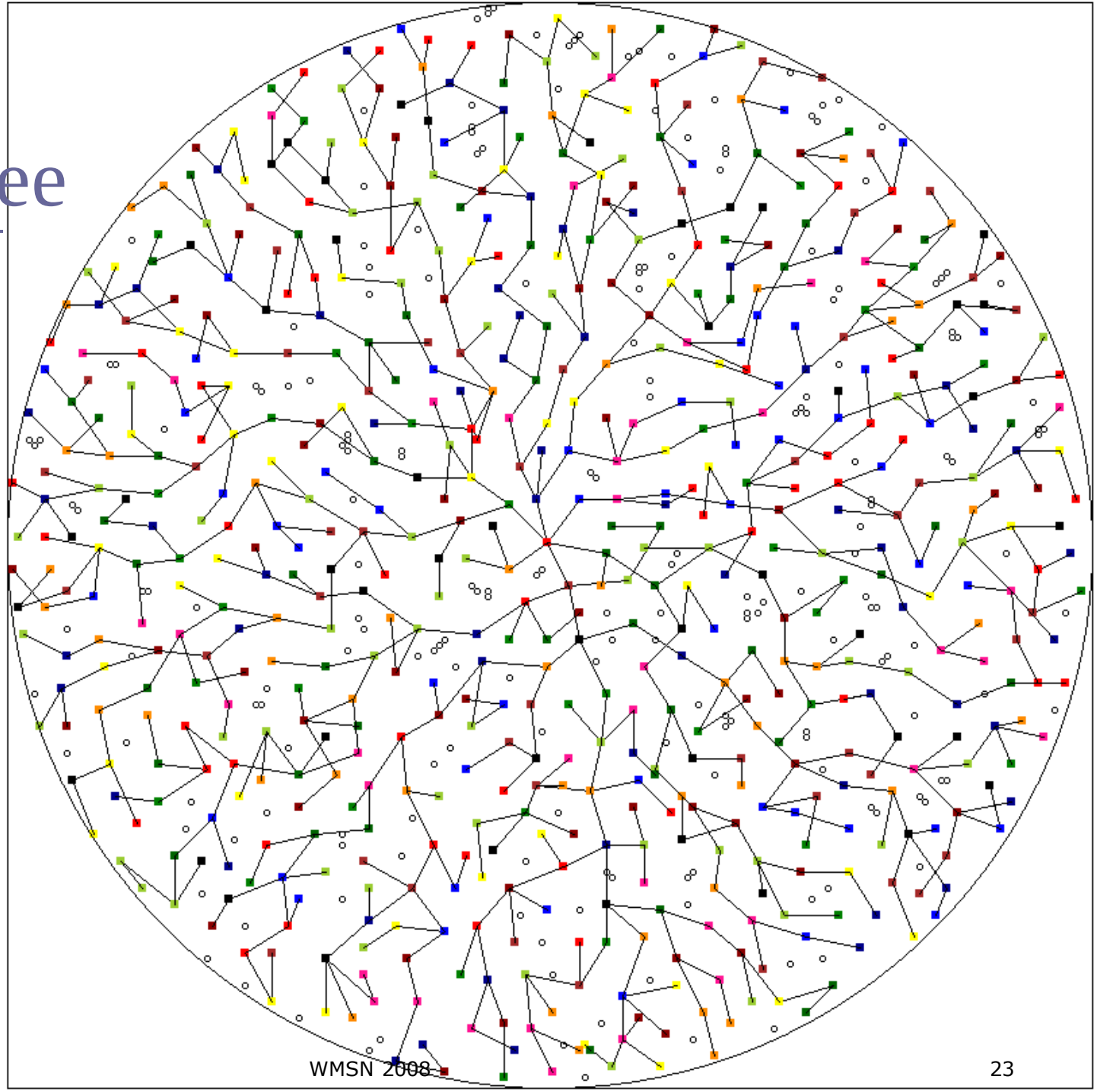
$TTL_{max} = 2 \times hops_{max} + 1$

Clusters

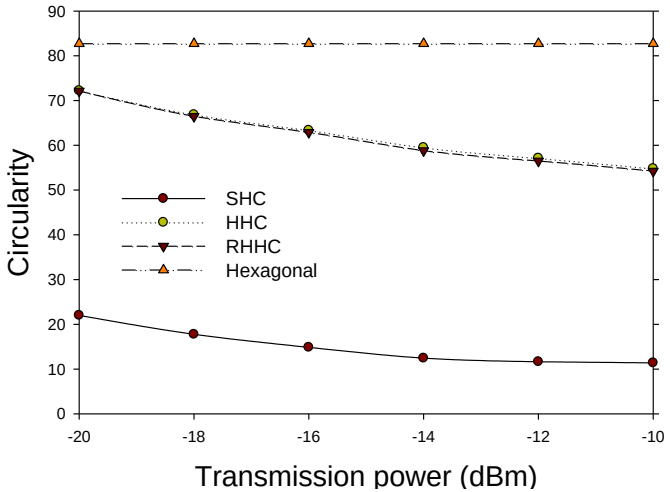


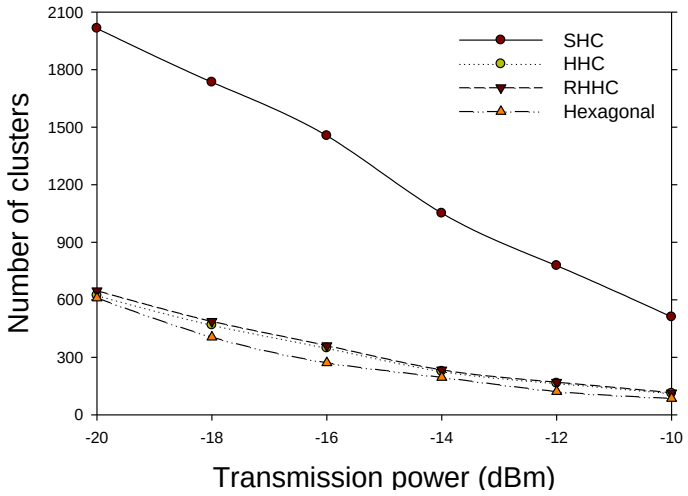
- HHC
- 5000 nodes
- Grid - *201×201*
- Grid spacing – *5m*
- *R = -20dBm*
- Root node in the middle

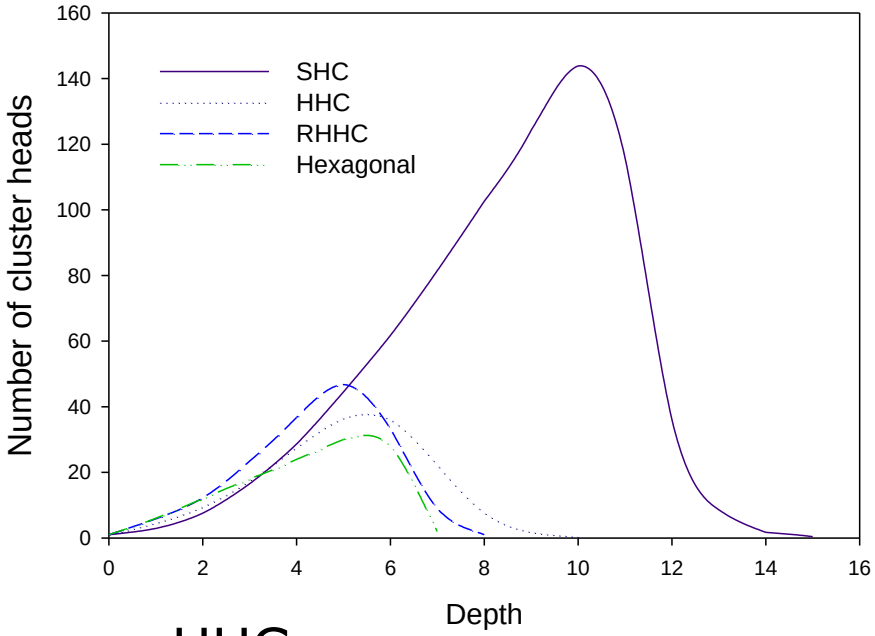
Cluster tree



Performance analysis

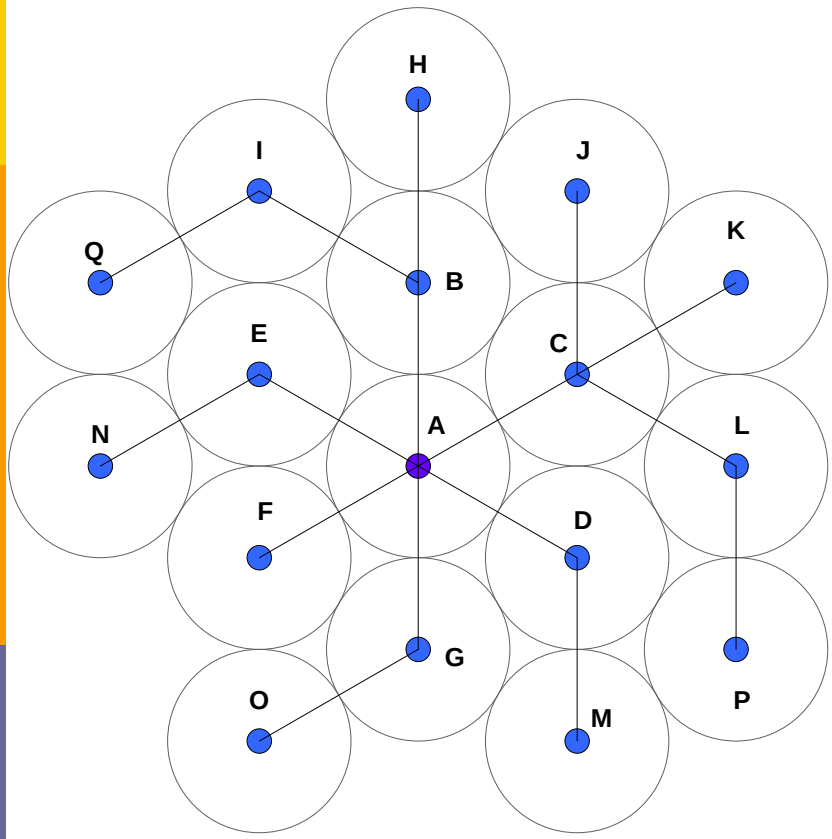


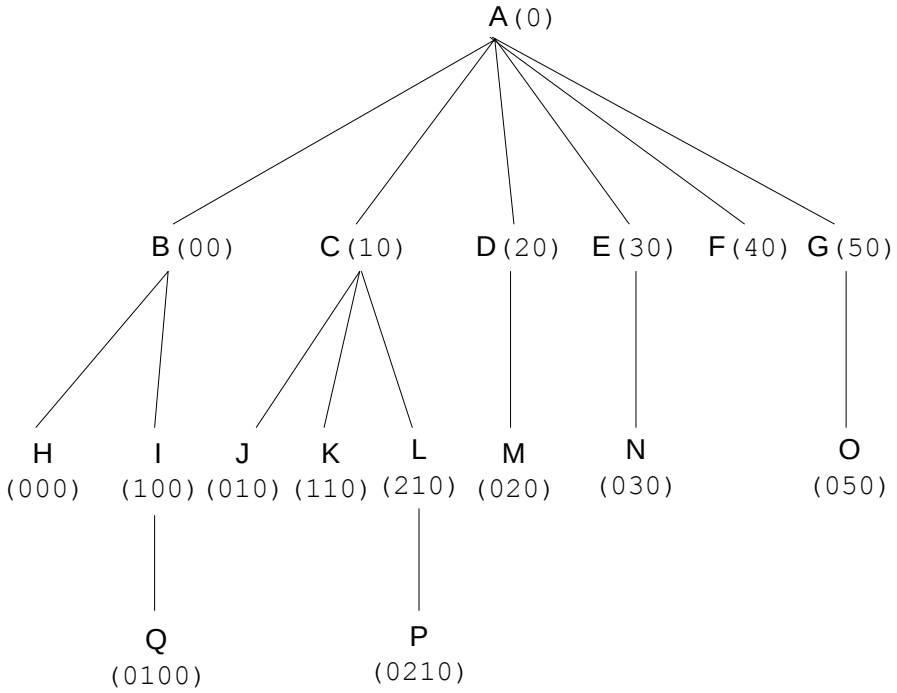




- HHC
  - Uniform clusters
  - Better circularity
  - Lower number of clusters
  - Lower depth
  - Message complexity *O(n)*

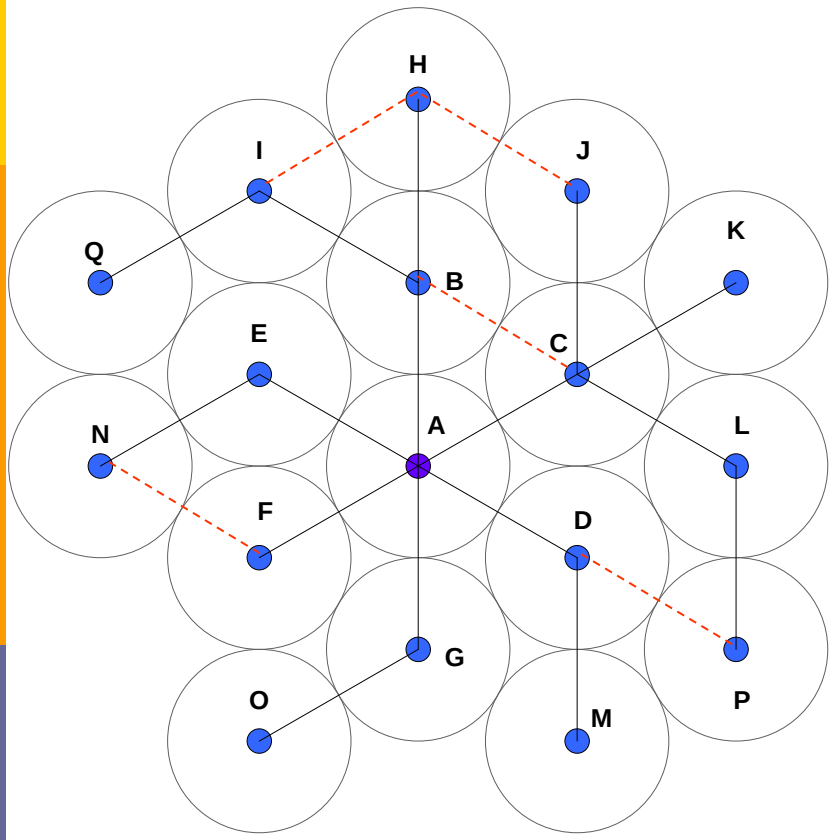
Hierarchical addressing

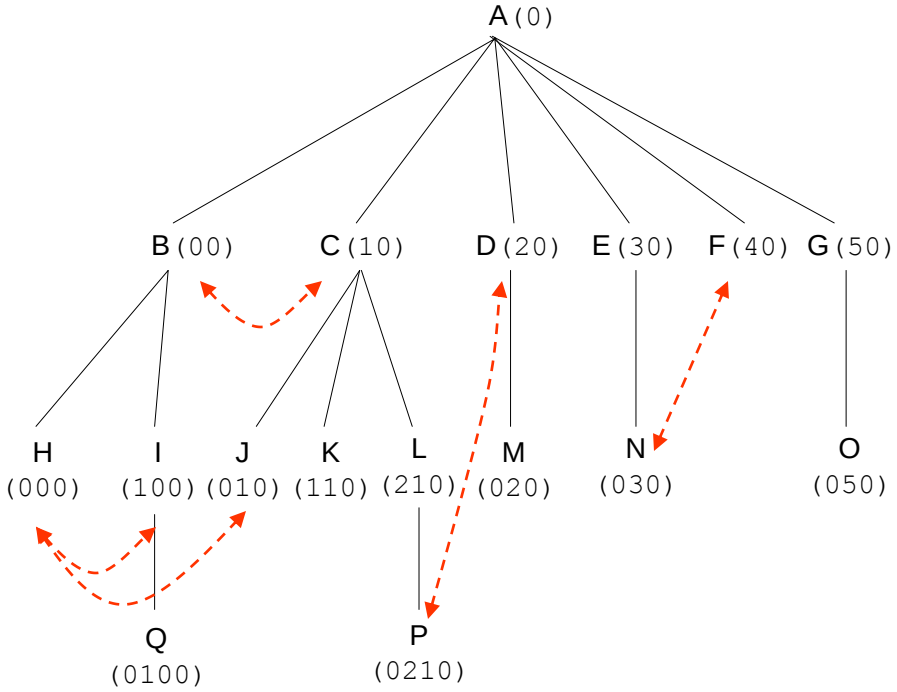




- Single point of failure at root node

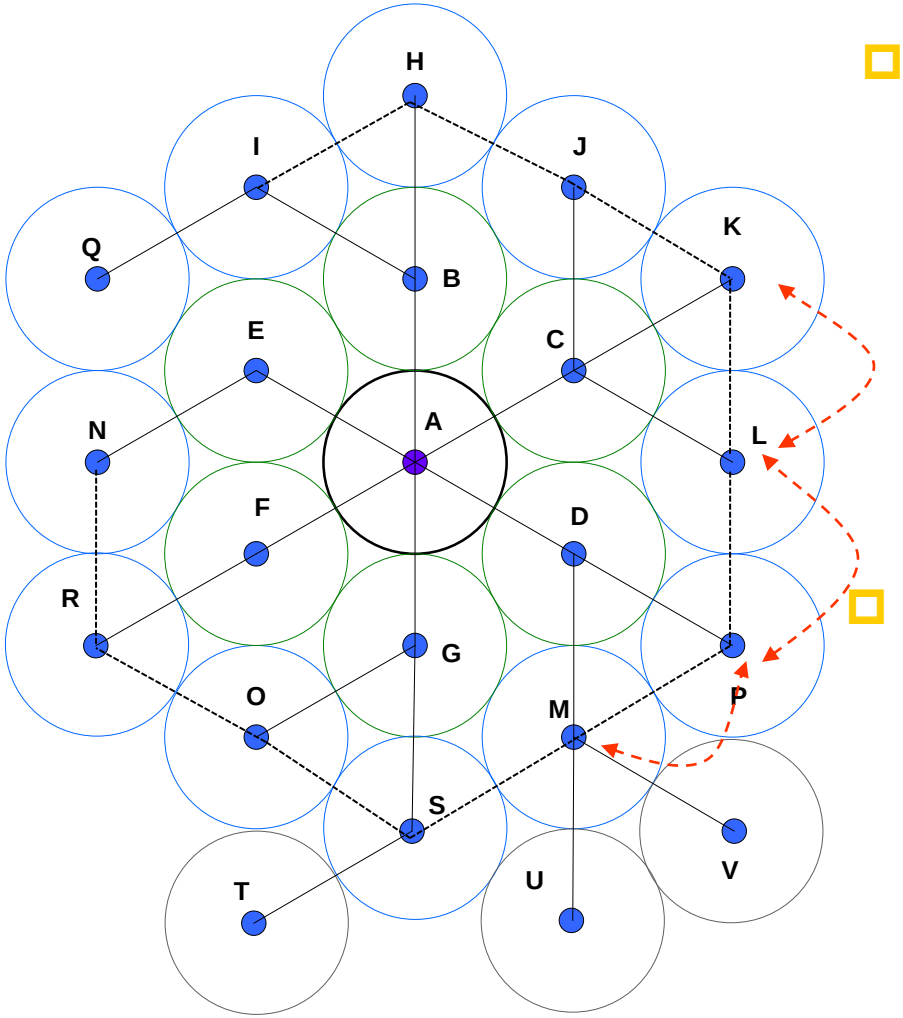
Cross-links based routing





- Routing through cross links
  - Reduce burden on the root node
- Use hierarchical addresses

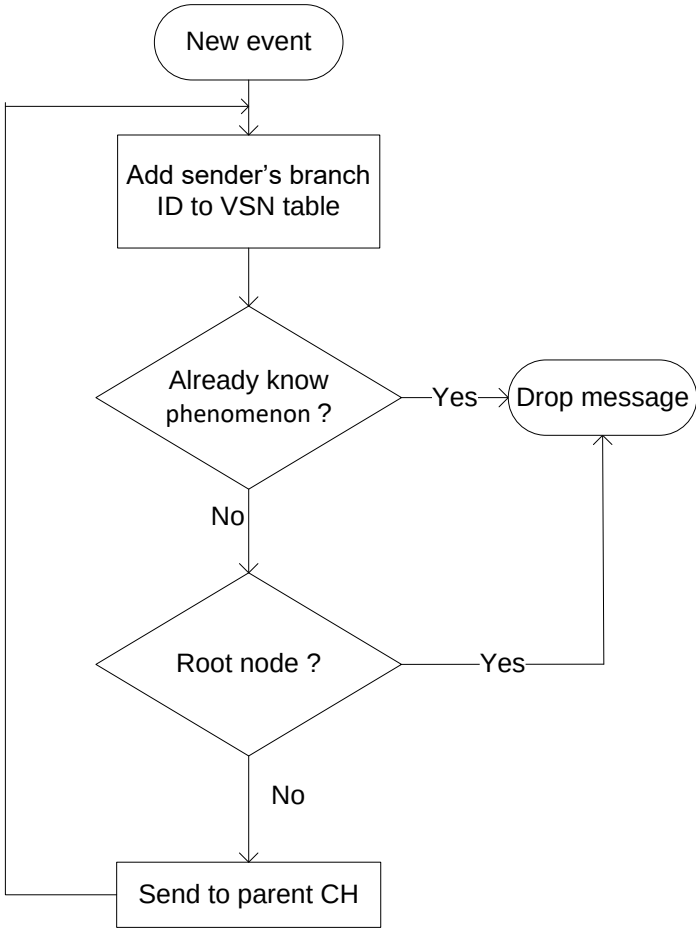
Circular path based routing



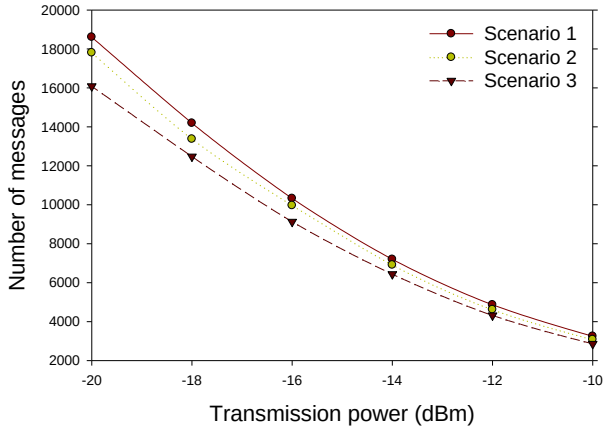
- Send message from U to K
  - Hierarchical routing - 5 hops
  - Cross links - 5 hops
  - Circular path - 4 hops
- Circular path
  - Connects clusters at the same depth
  - Reduce workload on root node
  - Use hierarchical addresses

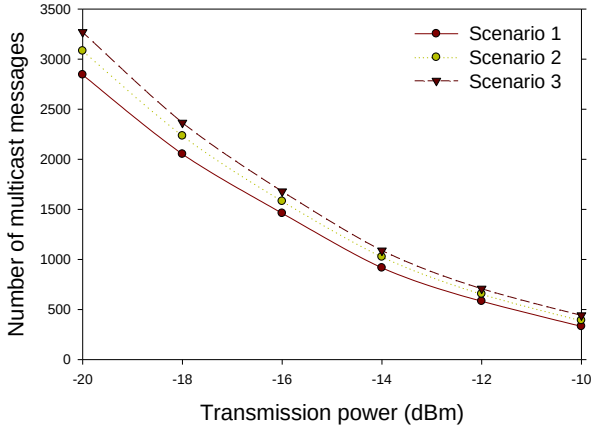
VSN formation algorithm

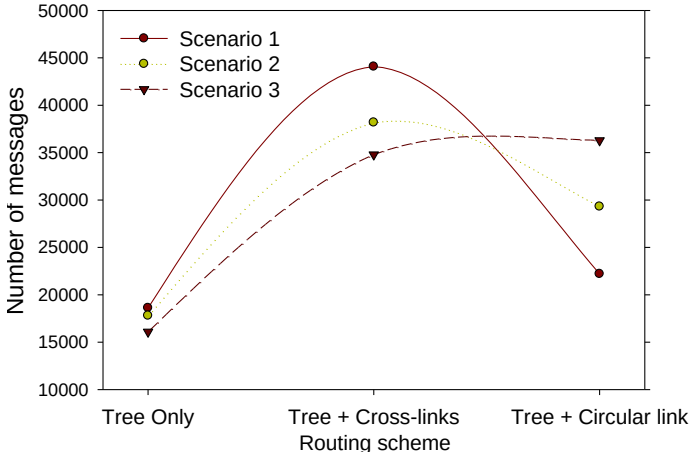
```
Handle_VSN_Message(msg)
      //Initially n = 0, m = 0
1     IF msg.source ∈ my.cluster_members
2       IF(msg.type ∉ my_data.VSNs)
3         my_data.VSNs(n) ← msg.type
4         n ← n + 1
5         Forward_To_Parent_CH(msg, my.parent_CH)
6       my_data.VSN_table(m) ← (msg.source,
                  msg.type)
7       m ← m + 1
8     ELSE
9       IF(msg.type ∉ my_data.VSN_table)
10        Forward_To_Parent_CH(msg,
                  my_data.parent_CH)
11      my_data.VSN_table(m) ← (child_CH, msg.type)
12      m ← m + 1
```



Performance analysis – Number of messages







- Cross-link and circular path base routing increase network capacity