PhD. Dissertation Proposal

Network Awareness in Wireless Sensor Networks

- for Intelligent Organization and Efficient Routing

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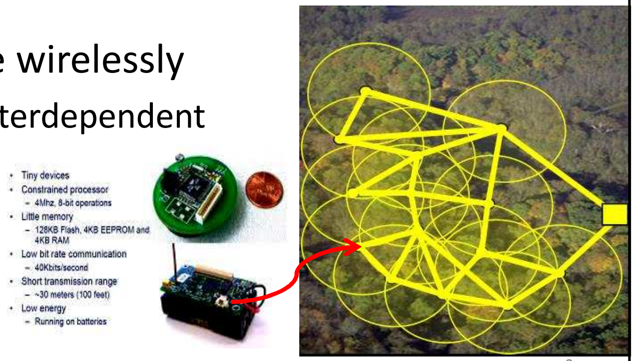
Introduction - Wireless Sensor Networks (WSNs)

- Large networks: 1000 to 10000 of nodes
- Sense- pressure, temperature, velocity, humidity, etc.
- Communicate wirelessly
  - Nodes are interdependent
- Constraints:
  - Memory
  - Energy
  - Processing



http://smarterplanet.tumblr.com/post/162351140/wireless-sensor-networks-blog-archive-timeless

2

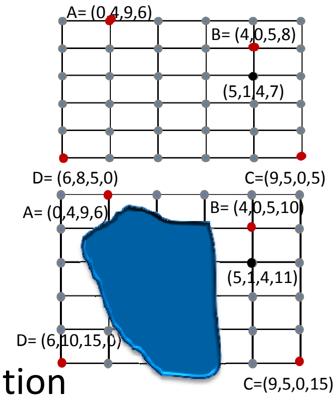
Background

- Initially unstructured networks
- Why structuring/organization required for WSNs?
  - For some applications organization is required
  - Efficient/improved data dissemination
- Self organization schemes-
  - Localization- GPS/RSSI
    - Requires additional hardware
    - Accuracy issues
  - Clustering
  - Virtual Coordinate Systems

3

Virtual Coordinate Systems - VCS

- *Ordinate*:
Relative position
in terms of # hops,
w.r.t. an anchor node
  - Ex: A,B,C,D anchors



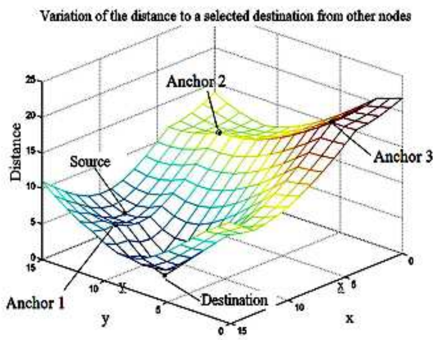
- Norm 2 based distance evaluation
- Geographic information not required
- Physical voids do not exist in Virtual Domain
- No additional hardware

4

Issues in VCS

- **<u>Optimal</u>** number of anchors and their placement is unknown
  - Affects routing performance
    - Local minima problem
  - Identical coordinates issu

- Furthest apart anchors
  - No appropriate scheme available to achieves this



Problem Statement

To develop and characterize techniques and algorithms to achieve reliable and efficient information exchange via self-organization of large WSNs

1. Self organization of wireless sensor networks based on efficient approaches

3. Structuring sensor networks by self learning approaches

2. Methods of extracting topology map, without the need for physical information

4. Making the nodes aware of the network and sensed phenomena

6

Tasks

1. Self organization of wireless sensor networks based on efficient approaches

- Regaining lost directionality of VCS
- Directional VC based routing and anchor placement
- Efficient representations of VCS

2. Methods of extracting topology map, without the need for physical information

- Techniques for generating topology maps
- Topology preserving map based routing
- Boundary detection without localization

7

Tasks (Contd.)

3. Structuring sensor networks by self learning approaches

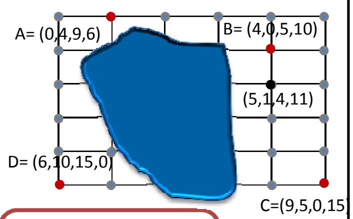
- VCS and topology preserving map through learning
  - Reliability, convergence of learning etc.
- Effect of sleeping cycles, node failures and adding new nodes

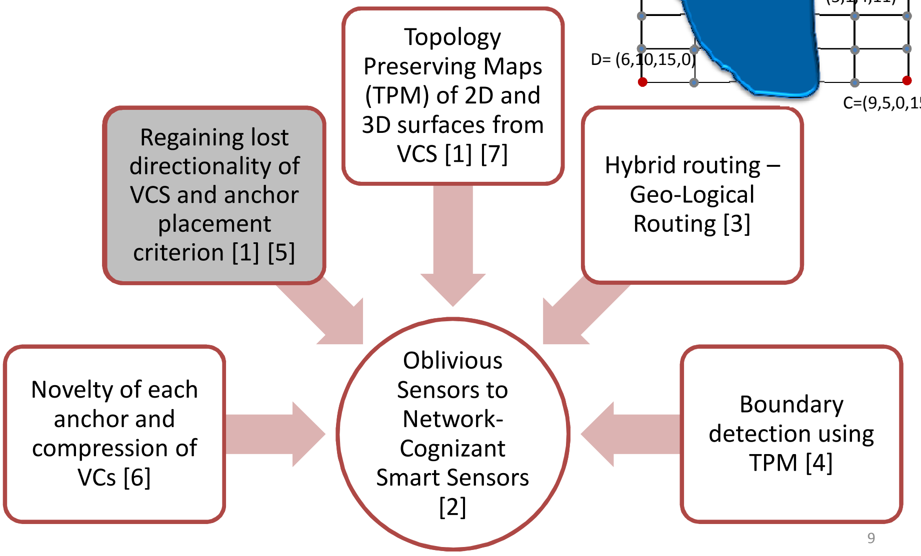
4. Making the nodes aware of the network and sensed phenomena

- Making nodes aware of the network and events/sensed phenomena
  - Accuracy, complexity
  - Cost effective implementation

8

Contributions

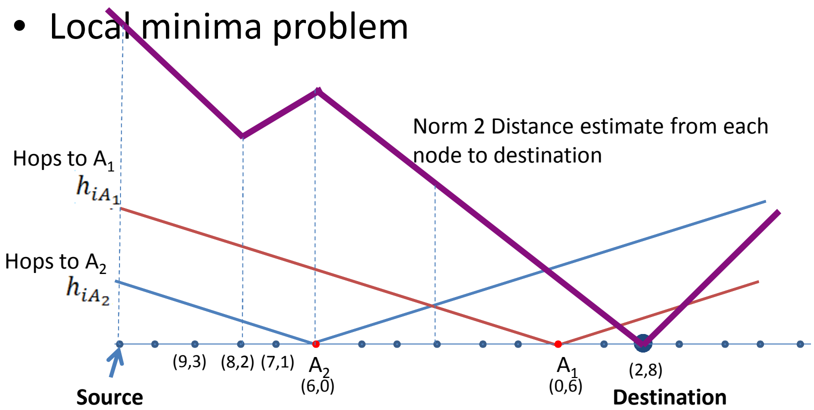




9

Regaining Lost Directionality of VCS

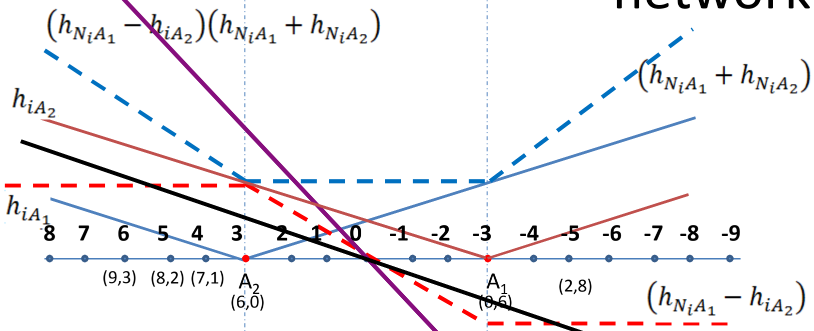
- Local minima problem



- Transformation to regain the directionality

10

Directional Transformation in 1D network



$$f(h_{N_iA_1}, h_{N_iA_2}) = \frac{1}{2h_{A_2A_1}}(h_{N_iA_1} - h_{iA_2})(h_{N_iA_1} + h_{N_iA_2})$$

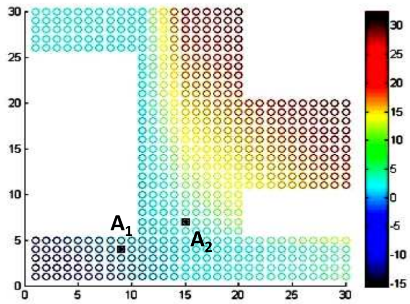
Unit vector in A_1 A_2 direction $\vec{\boldsymbol{u}}_{\boldsymbol{A_1A_2}}$

Vector representation :

$$\vec{\boldsymbol{f}}(\boldsymbol{h}_{\boldsymbol{N_iA_1}}, \boldsymbol{h}_{\boldsymbol{N_iA_2}}) = f(h_{N_iA_1}, h_{N_iA_2})\vec{\boldsymbol{u}}_{\boldsymbol{A_1A_2}}$$

11

Directional Transformation in 2D network

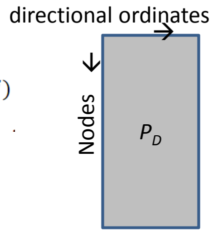


2D extension

$$f(h_{N_iA_1}, h_{N_iA_2}) = \frac{1}{2h_{A_2A_1}}(h_{N_iA_1} - h_{iA_2})(h_{N_iA_1} + h_{N_iA_2})$$

12

Angle Between Two Directional Ordinates



- Two directional ordinates $P_D^{(i)}$ and $P_D^{(j)}$
- Angle between i^{th} and j^{th} ordinate

$$\Phi_{ij}=\Phi_{ji}= \cos^{-1}\left(\left(P_D^{(i)}\right)^T P_D^{(j)} / |P_D^{(i)}||P_D^{(j)}|\right)$$

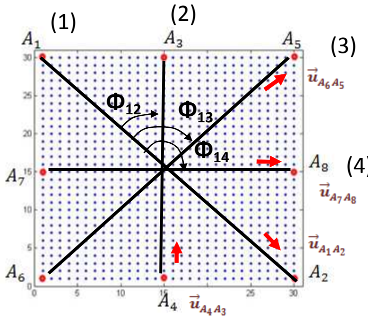
where $|P_D^{(i)}| = \sqrt{\left(P_D^{(i)}\right)^T P_D^{(i)}}$

Example:

Φ_{12} 46.22^0

Φ_{13} 90^0

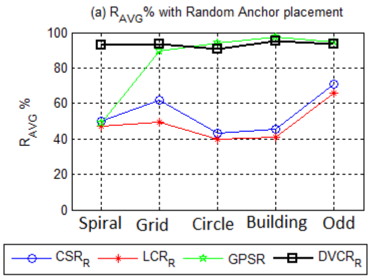
Φ_{14} 133.77^0



Directional Virtual Coordinate Routing

- Step 1: DVCS Greedy Forwarding till a local minima
  - Why local minima in DVCS?
- Step 2: How to overcome a local minima
  - Next node is selected, based on a rough estimation of hop distance
- Can design different routing schemes using DVCS

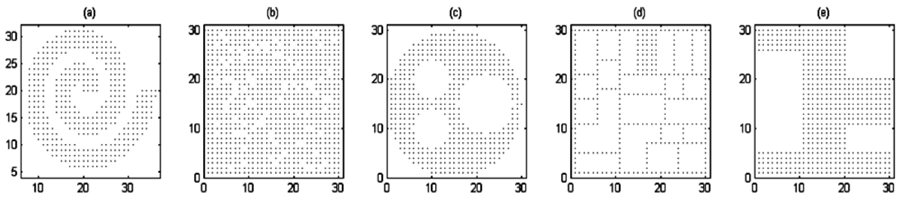
14



		Random 5 anchors		
		CSR	LCR	DVCR
Spiral	$R_{AVG}\%$	49.97	46.9	**92.7**
Grid	$R_{AVG}\%$	61.89	49.7	**93.7**
Circle W holes	$R_{AVG}\%$	43.5	39.7	**90.5**
Building	$R_{AVG}\%$	45.7	40.8	**95.4**
odd NW	$R_{AVG}\%$	70.7	66.0	**93.7**

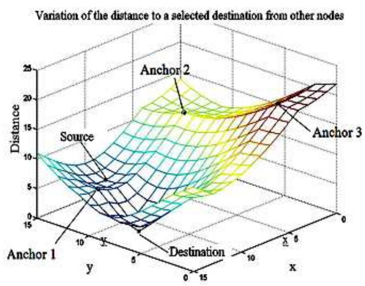
R_{AVG} % of CSR, LCR, GPSR and DVCR with 5 randomly placed anchors in spiral, 30 by 30 node grid with 800 nodes, circle with 3 holes, building, and odd networks

- 5 random anchors, TTL(Time-to-Live) is 100



Anchor Placement Scheme

- Performance of VCS is affected by anchor placement
- Boundary nodes/furthest apart nodes as anchors
  - Costly localization
- Nodes at corners are better th
  - Alleviate local minima issue
  - Less identical coordinates
- Distributive identification



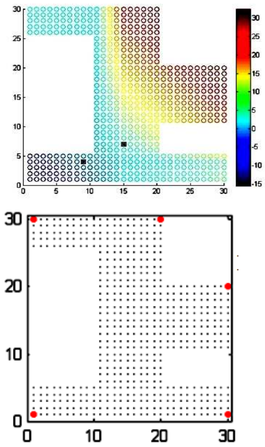
Extreme Node Search

- *Extreme* nodes are identified as anchors

Step 1- Two nodes are selected randomly and generate VCS
Step 2 - Nodes will generate DVCS using (1) locally
Step 3 - Check where ordinate is a local minimum/maximum by each node

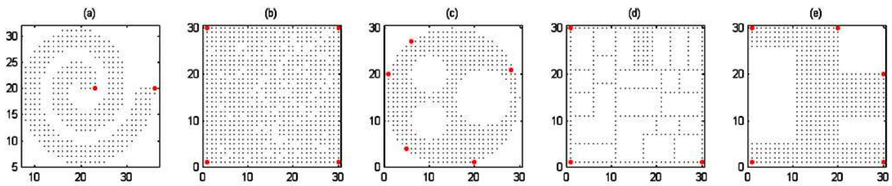
If $f(h_{iA_1}, h_{iA_2}) < f(h_{jA_1}, h_{ij})$; $\forall\, n_j \in K_h(\boldsymbol{n}_i)$
n_i is an anchor
End
OR
If $f(h_{iA_1}, h_{iA_2}) > f(h_{jA_1}, h_{ij})$; $\forall\, n_j \in K_h(\boldsymbol{n}_i)$
n_i is an anchor
End

Step 4 – Local minima/maxima nodes generate the VCS



Scatter plot of DVCS ordinate under highlighted anchors to identify corner nodes for anchors.

Performance Improvement in Routing

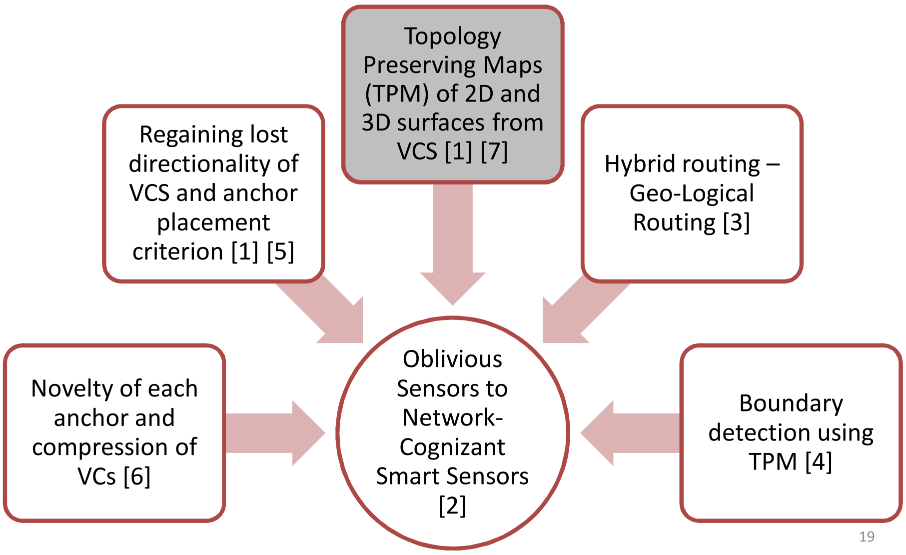


R_{AVG}% OF DVCR, CSR, LCR AND GPSR

		Random 5 anchors			With new anchor placement			GPSR
		CSR	LCR	**DVCR**	CSR	LCR	**DVCR**	
Spiral	R_{AVG}%	49.97	46.9	**92.7**	61.66	67.3	**95.9**	49.1
Grid	R_{AVG}%	61.89	49.7	**93.7**	87.55	52.9	**99.0**	89.5
Circle W holes	R_{AVG}%	43.5	39.7	**90.5**	84.02	75.5	**96.9**	93.8
Building	R_{AVG}%	45.7	40.8	**95.4**	80.14	59.5	**99.5**	97.3
odd NW	R_{AVG}%	70.7	66.0	**93.7**	99.92	93.0	**100**	94.4

18

Next…



19

Topology Preserving Maps from VCS (Cntd.)

- No localization → Cost effective
- No additional hardware required
- Overcome the disadvantages in VCS
- Opens up various opportunities to develop new WSN algorithms

20

2-D Topology Preserving Maps

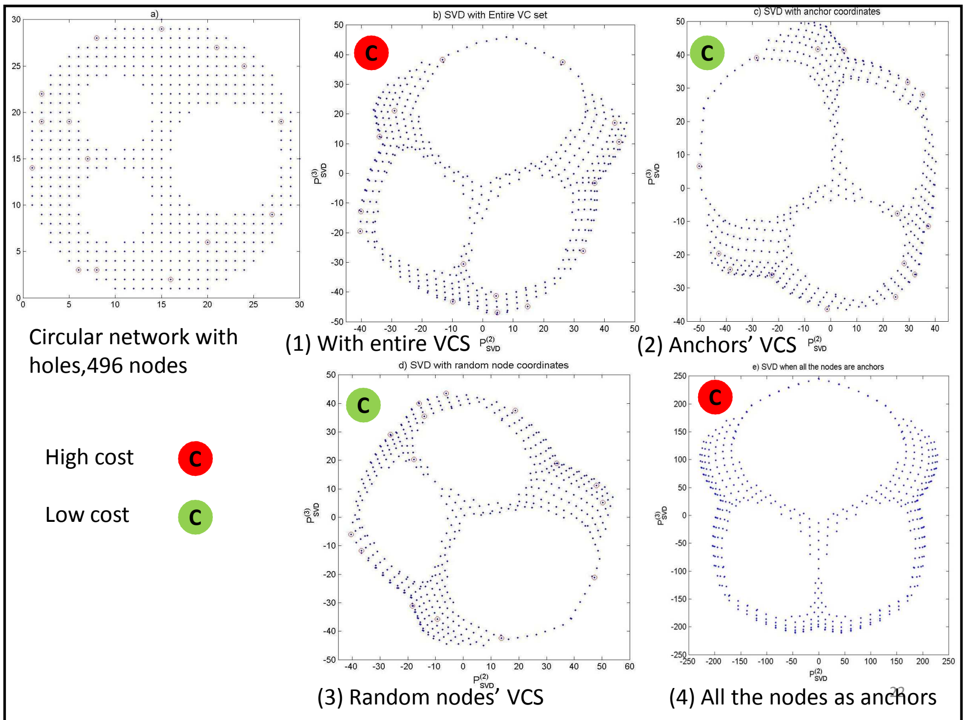
- No location information

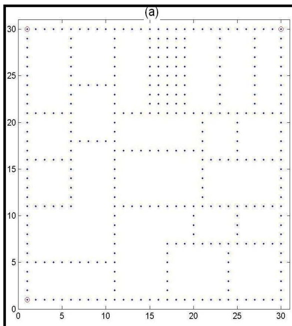
- N nodes, M anchors $\quad \boldsymbol{P = U\, S\, V^T}$
- VCS of N nodes, N x M matrix

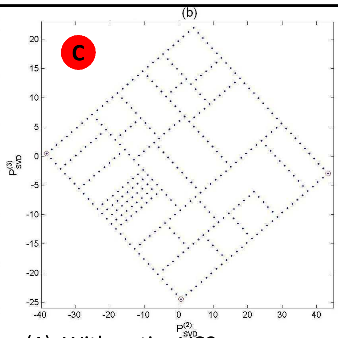
$$\boldsymbol{P_{SVD} = US = PV}$$

- Topological coordinates (TCs),

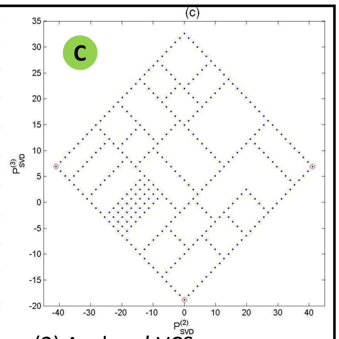
$$\boldsymbol{[X_T\ Y_T] = [P_{SVD}{}^{(2)}\ P_{SVD}{}^{(3)}]}$$







(1) With entire VCS

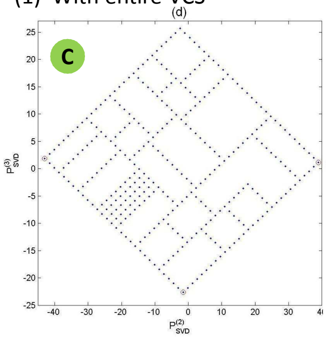


(2) Anchors' VCS

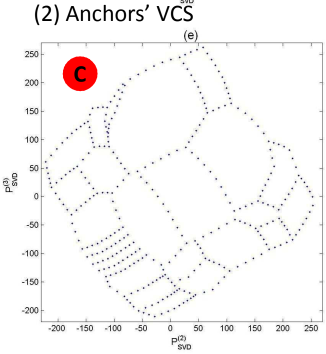
343-node Network in a building

High cost C

Low cost C



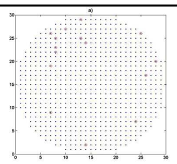
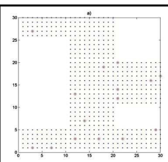
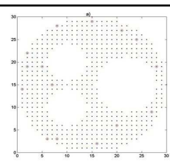
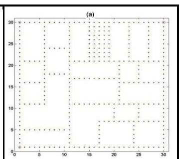
(3) Random nodes' VCS



(4) All the nodes as anchors

Performance Evaluation (Cntd.)

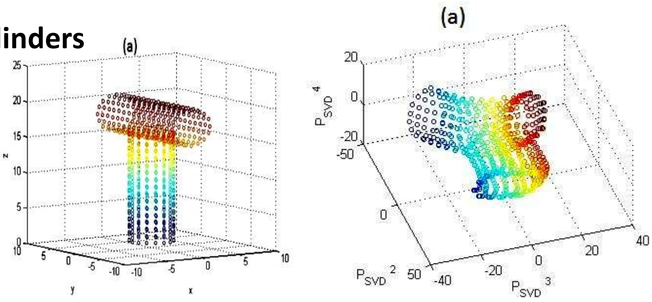
$$\text{Topology Preservation Error} = \frac{\#\text{ out of order pairs}}{\text{Total }\#\text{ possible pairs node network}}$$

Network				
With entire VCS	0.90%	1.68%	0.36%	0%
15-Anchors' VCS	0.83%	1.59%	1.07%	0%
10-Random nodes' VCS	0.21%	1.50%	0.49%	0%

3D Topology Preserving Maps

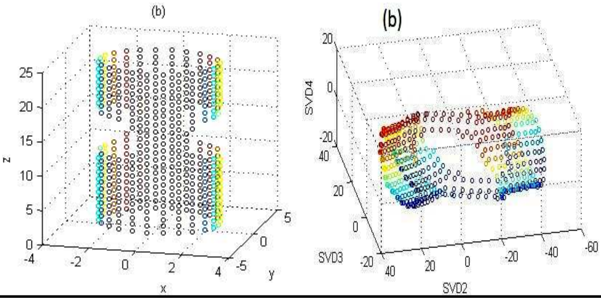
Two Perpendicular Cylinders

Each cylinder has a radius 2.54 units, height 16 units, and is covered with a grid of 512 nodes, each with a communication range of 1.
20 random anchors.

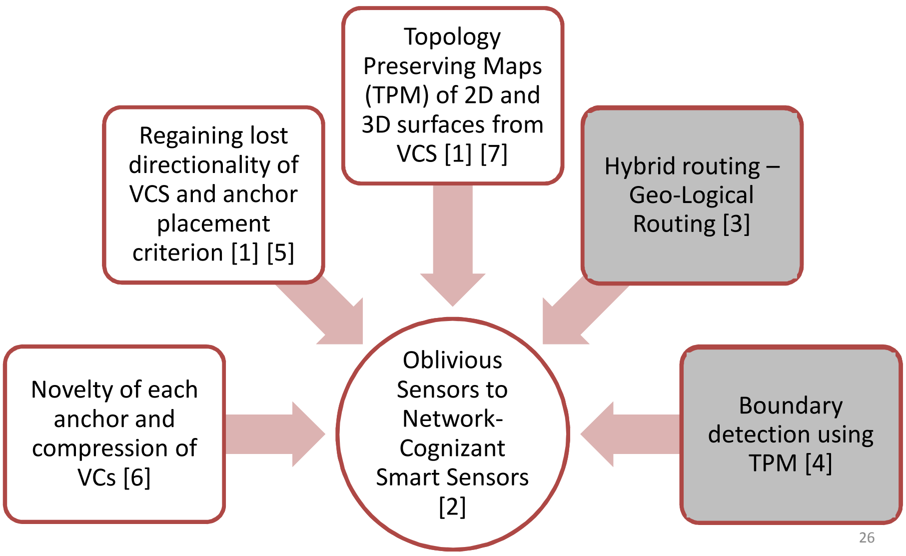


Cylinder with a Hole

Cylinder of radius 2.54 and height 24 with a hole through it is covered with 490 nodes, each with a communication range of 0.5.
15 randomly placed anchors



Next…

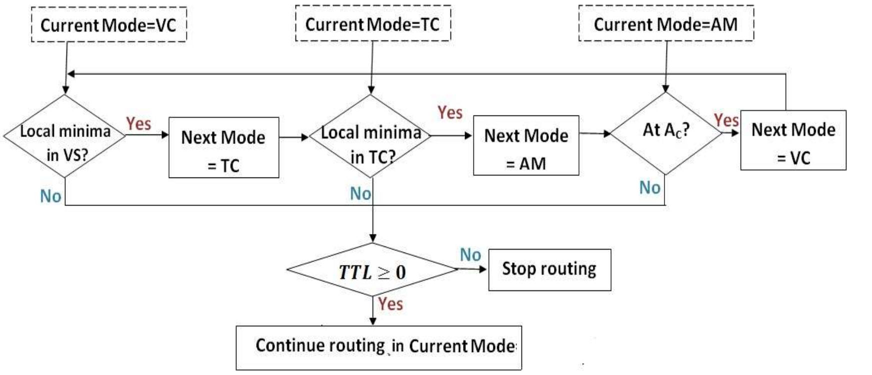


26

Geo-Logical Routing Algorithm

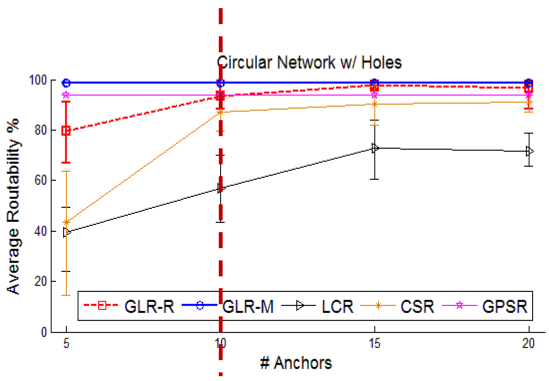
- Hybrid routing scheme

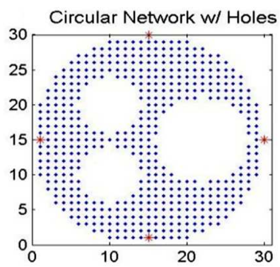
TC - Topology based Coordinates
VC - Virtual Coordinates
AM - Routes toward closest anchor



***TTL*: time-to-live of a packet**

Applications: Geo-Logical Routing



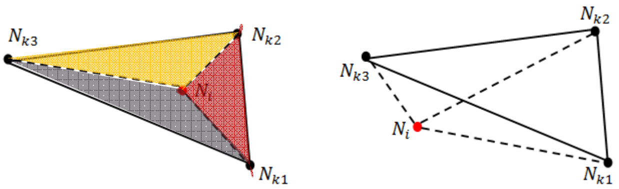


Avg. Routability GLR-M	98%

28

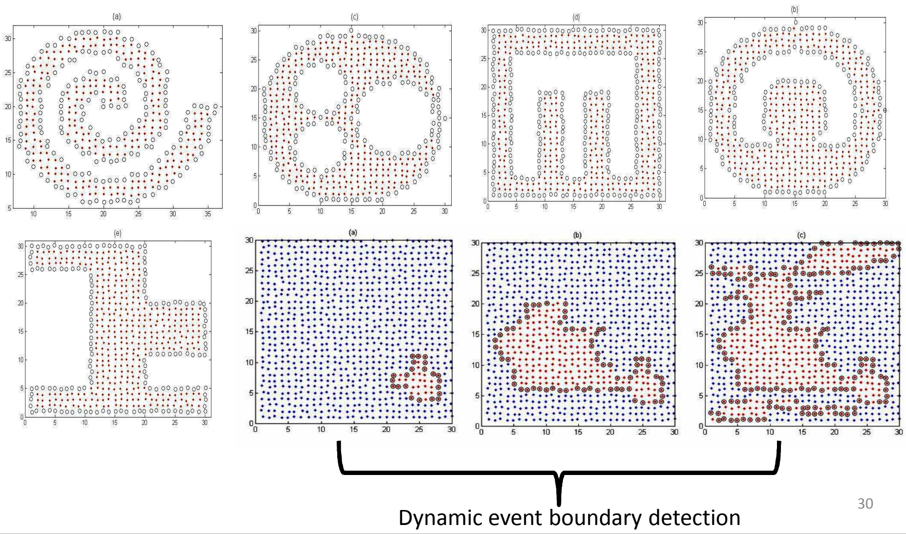
Boundary Detection Algorithm

- If N_i has two or less neighbors→ N_i is a boundary node
- If N_i has three or more neighbors:
  - Neighbor triplet N_{k1}, N_{k2}, N_{k3}
  - N_i is a internal node if at least one triplet exists such that $\Delta N_{k1}N_{k2}N_{k3} > \Delta N_i N_{k2}N_{k3} + \Delta N_{k1}N_{k2}N_i + \Delta N_{k1}N_i N_{k3}$



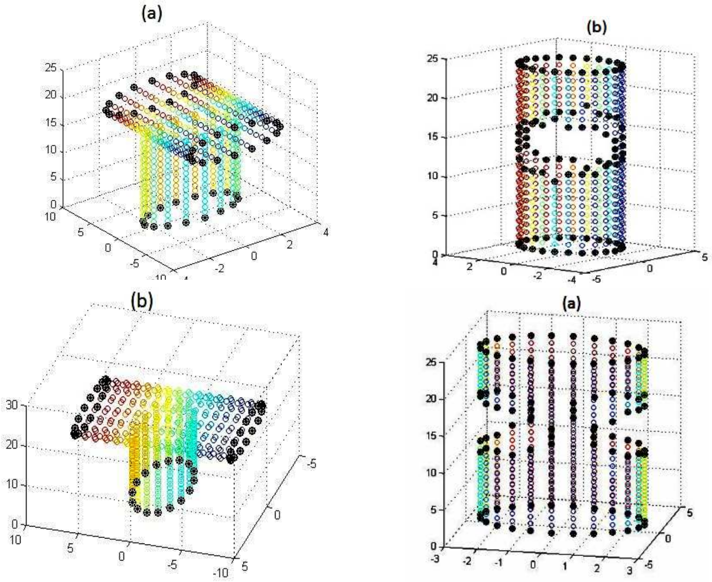
29

2D Network/Event Boundary Detection



30

Boundary Detection in 3D Surfaces



31

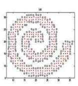
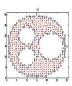
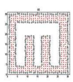
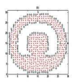
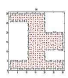
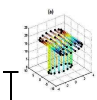
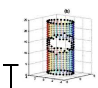
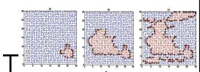
Performance Analysis

% accuracy of boundary identification (A%)

$$= \frac{\text{\# nodes that are correctly identified}}{\text{Total number of Boundary nodes}} \%$$

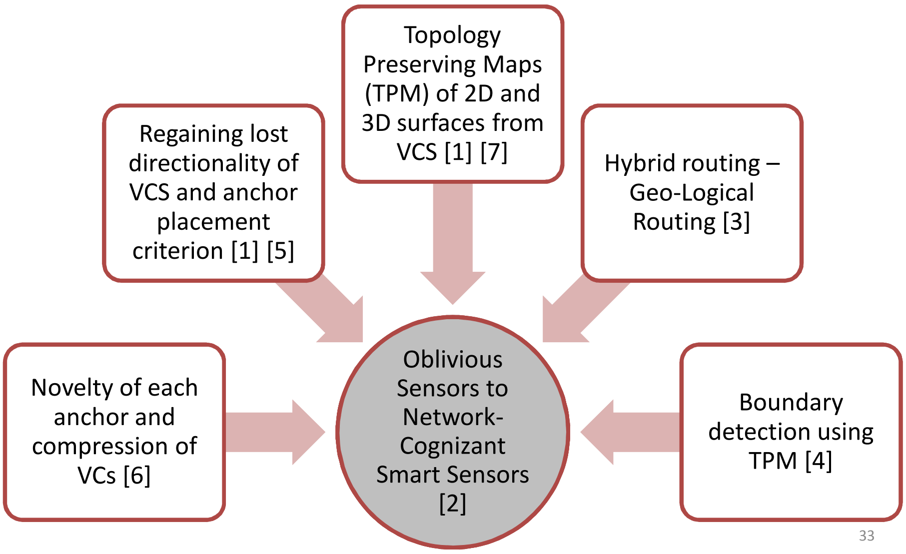
% Error in boundary identification(E%)

$$= \frac{\text{\# nodes that incorrectly identified}}{\text{\# nodes that are correctly identified}} \%$$

								
A%	100	100	100	100	100	100	100	90 (avg)
E%	0	0	0	0	0	0	0	0

32

Next…



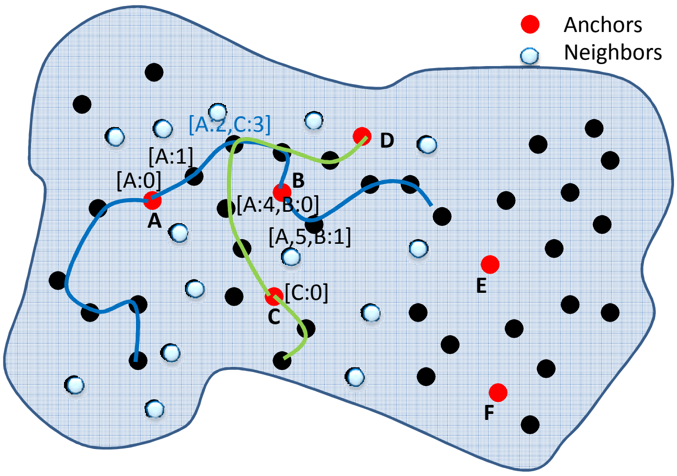
33

Oblivious Sensors to Network-Cognizant Smart Sensors

- Random routing is required in both structured and unstructured network
- So far, random messages haven't been used for learning
- Two stages-
  - Virtual coordinates from random routing
    - No initial flooding required
  - Virtual coordinates to Topological coordinates
    - No initial cost

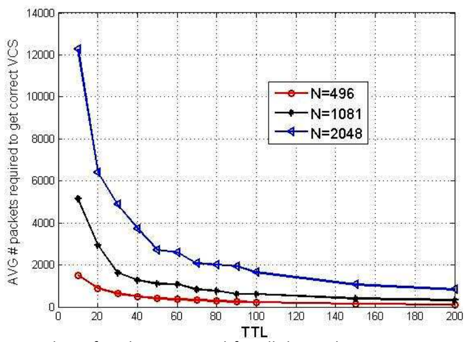
34

VCS Generation From Random Routing

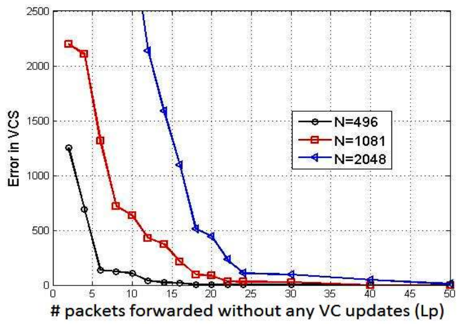


35

Termination Criterion of VCS Generation



Number of packets required for all the nodes to generate error free VCS averaged over 10 different configurations as TTL varies. Network has 10,20 and 40 anchors respectively for N=496 , 1081 and 2048.



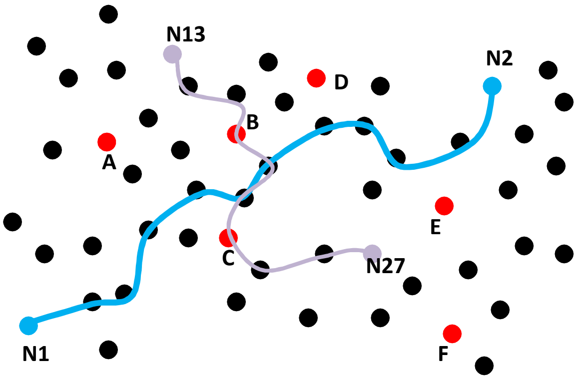
Error in VCS vs. number of packets forwarded by each node without any VC updates , averaged over 10 anchor placements.

- Can use VCS based routing

36

Topology Preserving Maps From Learning

- Network has VCS

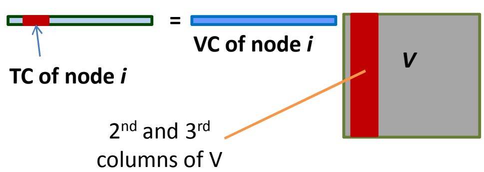


- Collect source and destination addresses

Topology Preserving Maps From Learning(Cntd.)

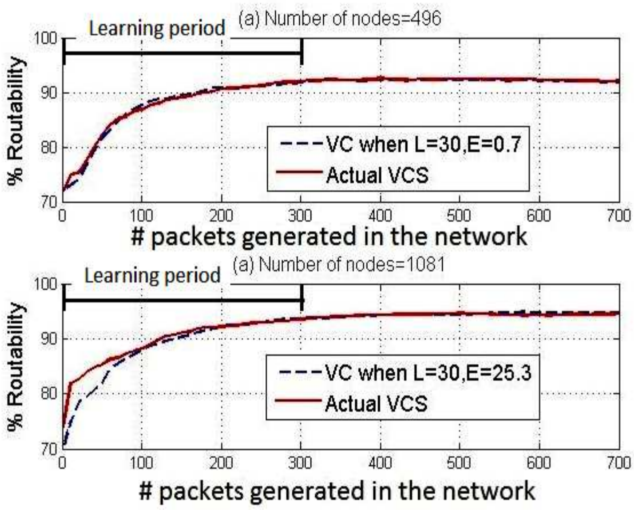
- Each node (i) generate basis V, thus can get topological coordinates → $Q \quad = U\, S\, V^T$

$$P_{SVD,i} = P_i\, V$$



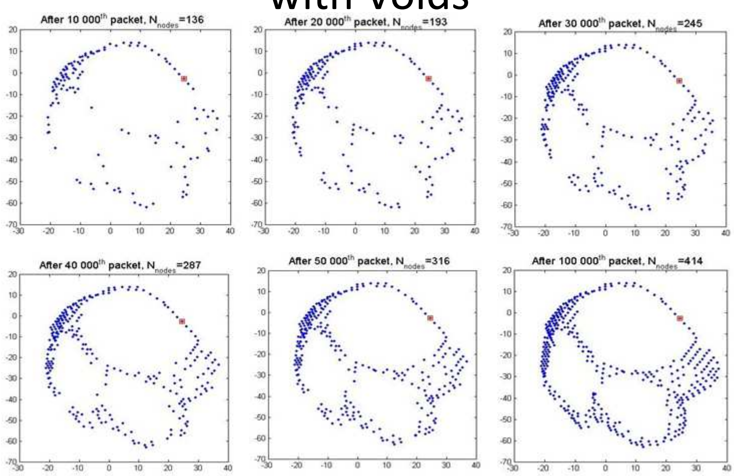
- Topological coordinates based routing
- Each node develop topology preserving map → network awareness

Performance Improvement-Routability



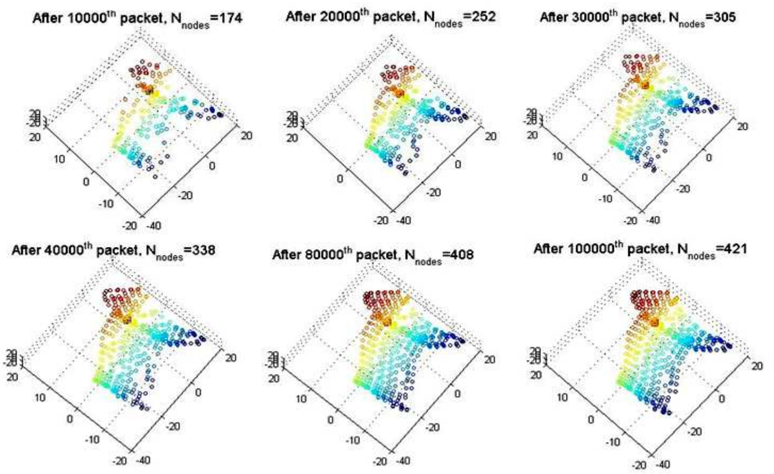
39

Topological Map at a Node- Circular Network with Voids



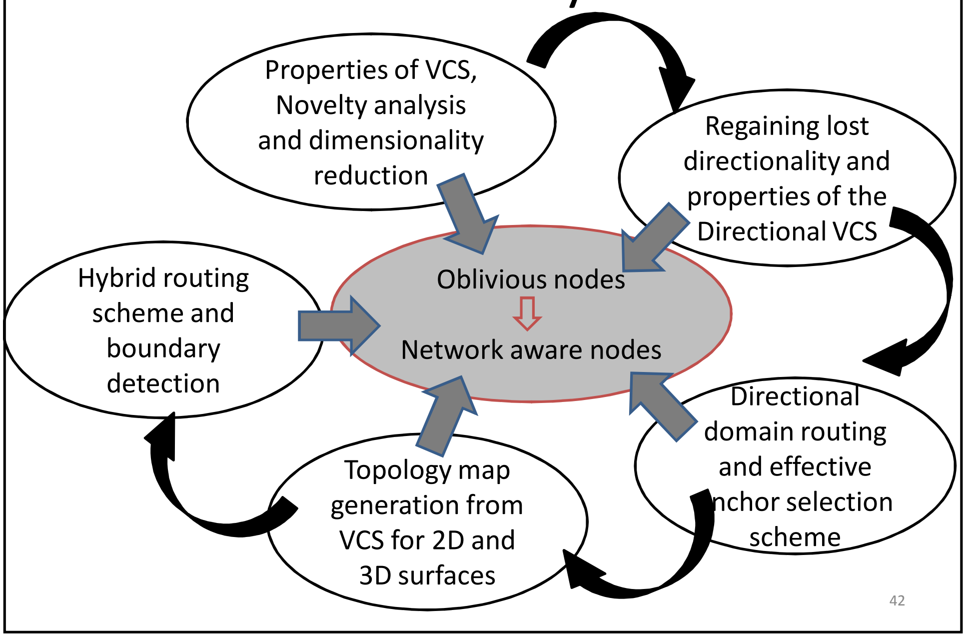
Topology preserving map development at a sample node (identified by color red). Number of anchors is 10 and total number of nodes is 496. TTL of a packet is 100.

Topological Map at a Node: T-joint

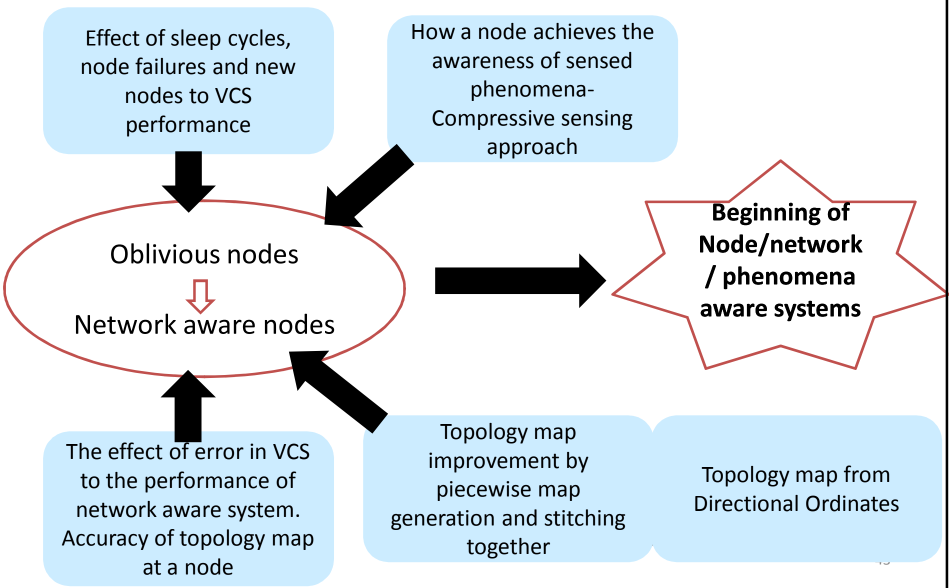


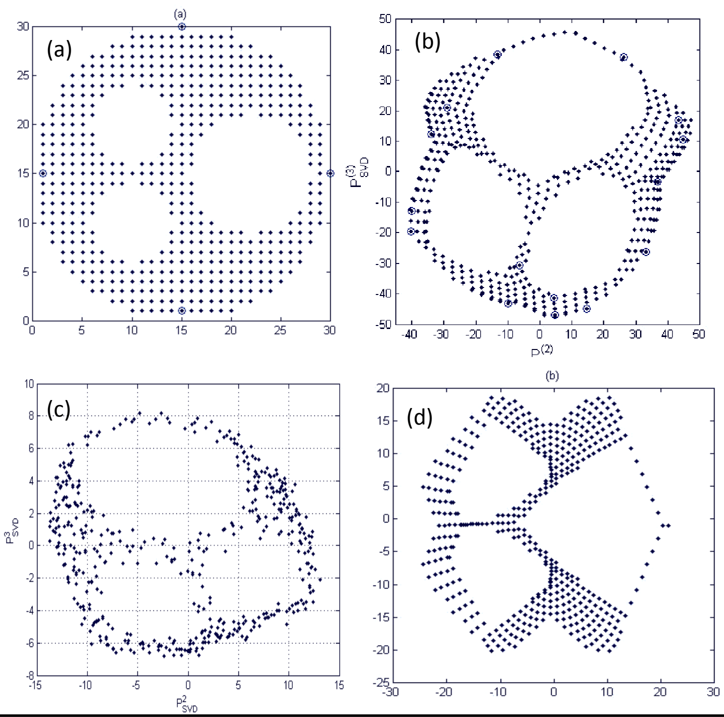
Topology preserving map development at a node of a 3D T-joint assuming it store the destination topology coordinate of every destination node that goes through it. Number of anchors is 10 and total number of nodes is 512.TTL of a packet is 100.

Summary



Future Plans





Topology map from Directional Ordinates

(a)Network with circular boundary and circular obstacles, with 496 nodes;

(b and c)Topology map via SVD based method with communication range =1 , and 3

(d) Topology maps obtained via Directional Virtual Coordinates with only 4 anchors

44

Publications

Suggestions

Questions

1. **D.C. Dhanapala** and A.P. Jayasumana, “Anchor Placement in WSNs – A Directional Ordinate Based Approach,” Proc. IEEE global communications conference (GLOBECOM 2011), Dec. 2011. (to be submitted)
2. **D.C. Dhanapala** and A.P. Jayasumana,” Clueless Sensors to Network-Cognizant Smart Sensors: Topology Awareness Via Self-learning in Wireless Sensor Networks” ACM SIGCOMM 2011, Toronto, Ontario, Canada, Aug. 15-19, 2011 (in review)
3. **D.C. Dhanapala** and A.P. Jayasumana, “Geo-Logical Routing in Wireless Sensor Networks,” Proc. IEEE global communications conference (GLOBECOM 2011), Dec. 2011. (to be submitted)
4. **D.C. Dhanapala,** S. Mehta and A.P. Jayasumana, “On Topology Mapping and Boundary Detection of Sensor and Nano-networks Deployed on 2-D and 3-D Surfaces,” Proc. 8th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON), June 2011. (Accepted)
5. **D.C. Dhanapala** and A.P. Jayasumana, “Directional Virtual Coordinate System for Wireless Sensor Networks,” Proc. IEEE International Conference on Communications (ICC 2011), June 2011. (accepted)
6. **D.C. Dhanapala** and A.P. Jayasumana, “Dimension Reduction of Virtual Coordinate Systems in Wireless Sensor Networks,” Proc. IEEE global communications conference (GLOBECOM 2010), Dec. 2010.
7. **D.C. Dhanapala** and A.P. Jayasumana, “Topology Preserving Maps From Virtual Coordinates for Wireless Sensor Networks,” Proc. 35th Annual IEEE Conference on Local Computer Networks (LCN 2010), Oct. 2010. (**Best paper award**)

45