Self-Organization of Nodes using Bio-Inspired Techniques for Achieving Small World Properties

Authors:

Rachit Agarwal (Telecom SudParis, Paris)
Abhik Banerjee (Nanyang Technological University, Singapore)
Dr. Vincent Gauthier (Telecom SudParis, Paris)
Prof. Monique Becker (Telecom SudParis, Paris)
Prof. Chai Kiat Yeo (Nanyang Technological University, Singapore)
Prof. Bu Sung Lee (Nanyang Technological University, Singapore)

Outline

- Motivation and Objective
- Algorithm Outline and background
  - Small World
  - Small World in Wireless network
  - Flocking
  - Region Formation
- Algorithm
  - Region Formation
    - Centroid Finding
  - Beamforming using Flocking Analogy
- Results
- Conclusion and Future work

Motivation and Objective

Motivation

- Can average path length be reduced for better performance?
- Can connectivity be increased?
- Can network nodes Self-Organize?
- Can the configuration be done in distributed way without the global knowledge of network?
- Is there a need of external infrastructure?

Objective

- In a wireless network, how to minimize average path length while increasing the connectivity and keeping the clustering coefficient intact in a distributed way without the global knowledge of network.

TELECOM SudParis

Algorithm Outline

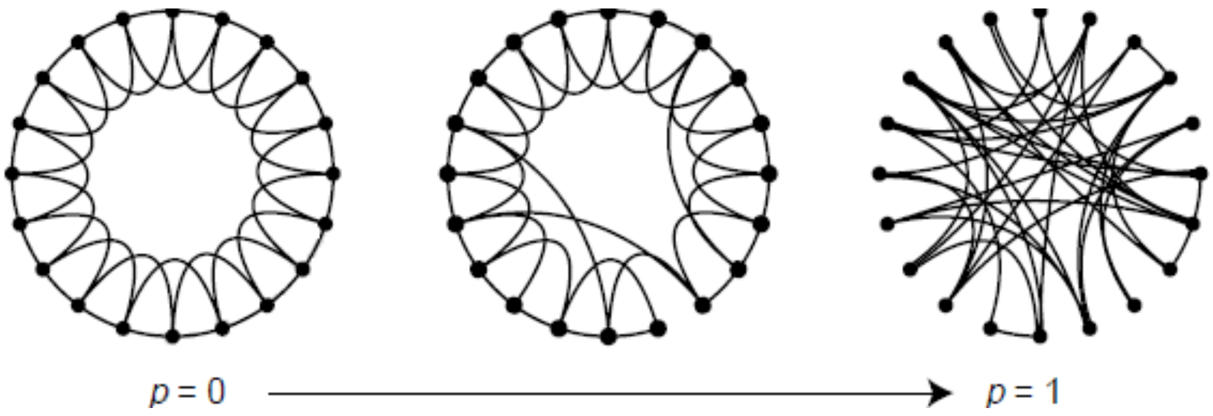
- **We propose to use**
  - Small world networks [1]
  - Beamforming
  - Inspirations from nature

  to achieve our goal.
- **Small world concept proposes the idea of introduction of long range links.**
- **In wireless networks beamforming helps us to achieve long links.**
- **Inspirations from nature to make the algorithm distributed and use only local information.**

[1] D.J. Watts, S.H. Strogatz, “Collective dynamics of ‘small-world’ networks”, Nature 393 (6684) (1998) 440–442

Small World

- **Watts et at [1] rewired links in a regular graph with a probability p.**
  - When p was small they observed, reduction in average path length while clustering coefficient was almost intact.

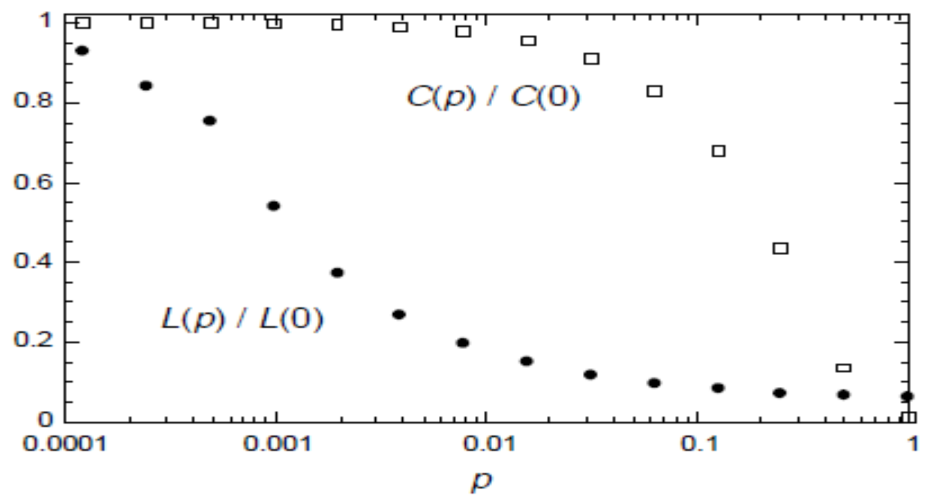


[1] D.J. Watts, S.H. Strogatz, "Collective dynamics of 'small-world' networks", Nature 393 (6684) (1998) 440–442

Small World (cont..)

Small World Properties [1]

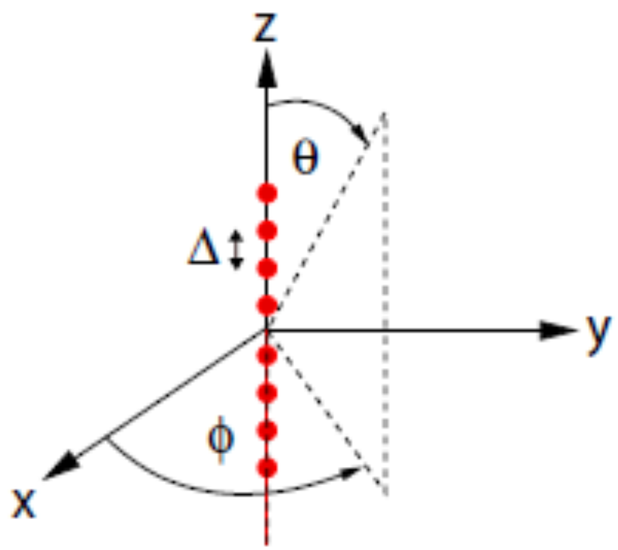
- Reduction in average path
- Relatively less change in clustering coefficient

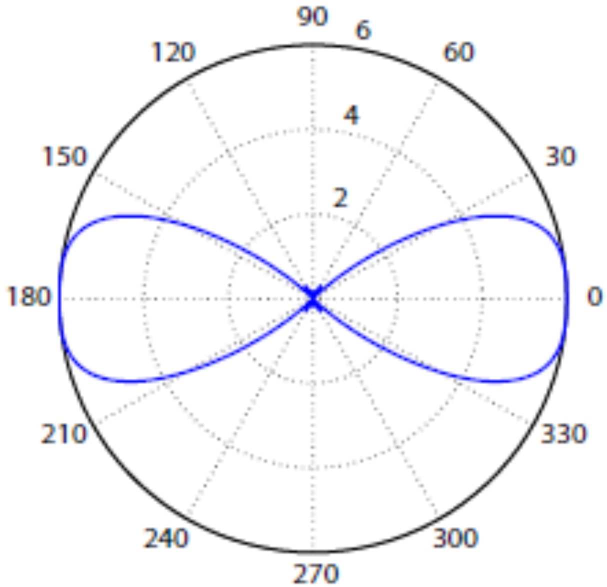


[1] D.J. Watts, S.H. Strogatz, "Collective dynamics of 'small-world' networks", Nature 393 (6684) (1998) 440–442

Small World in Wireless Networks

- **In wireless networks, rewiring of links can be achieved by beamforming, [2].**





[2] A. Banerjee et al., "Self-Organization of Wireless Ad Hoc Networks as Small Worlds Using Long Range Directional Beams"

Small World in Wireless Networks (cont..)

- **To successfully achieve small world characteristics in wireless networks**
  - Identification of nodes that beamform
  - Identification of beam properties is must
- **However, challenges for achieving small world characteristics in wireless networks are marked by**
  - Spatial nature
  - Limited power
  - Lack of global knowledge
  - Unidirectional paths

Flocking

Flocking (cont..)

Helps in

- Identify nodes that beamform
  - Node orients itself
- Reduce avg. path length, maintain clustering coefficient
  - Remain close to the group
- Connect unconnected components
  - Moving away from the neighborhood to avoid collision

Region Formation

- **The message complexity increases with network size.**
  - Divide the network into logical regions to limit the message complexity.
- **Limiting the set of nodes that beamform.**
  - Reduces number of asymmetric links.

Algorithm

Steps

- Identify Regions
  - Find centroid node of all the regions
- Apply Flocking rules
  - Identify beamforming nodes
  - Identify beam properties

TELECOM SudParis

Region Formation

To form regions

- Lateral Inhibition [5,6] is used.
- Each node initially declares itself as the head
- The neighbors depending on degree and hopcount inhibit themselves from being heads.
- The max size of the hopcount is limited to a fixed value.
- Once the nodes in a region are defined, centroid node of the region is identified.

Each node around the head has an associated hopcount, we call it as gradient.

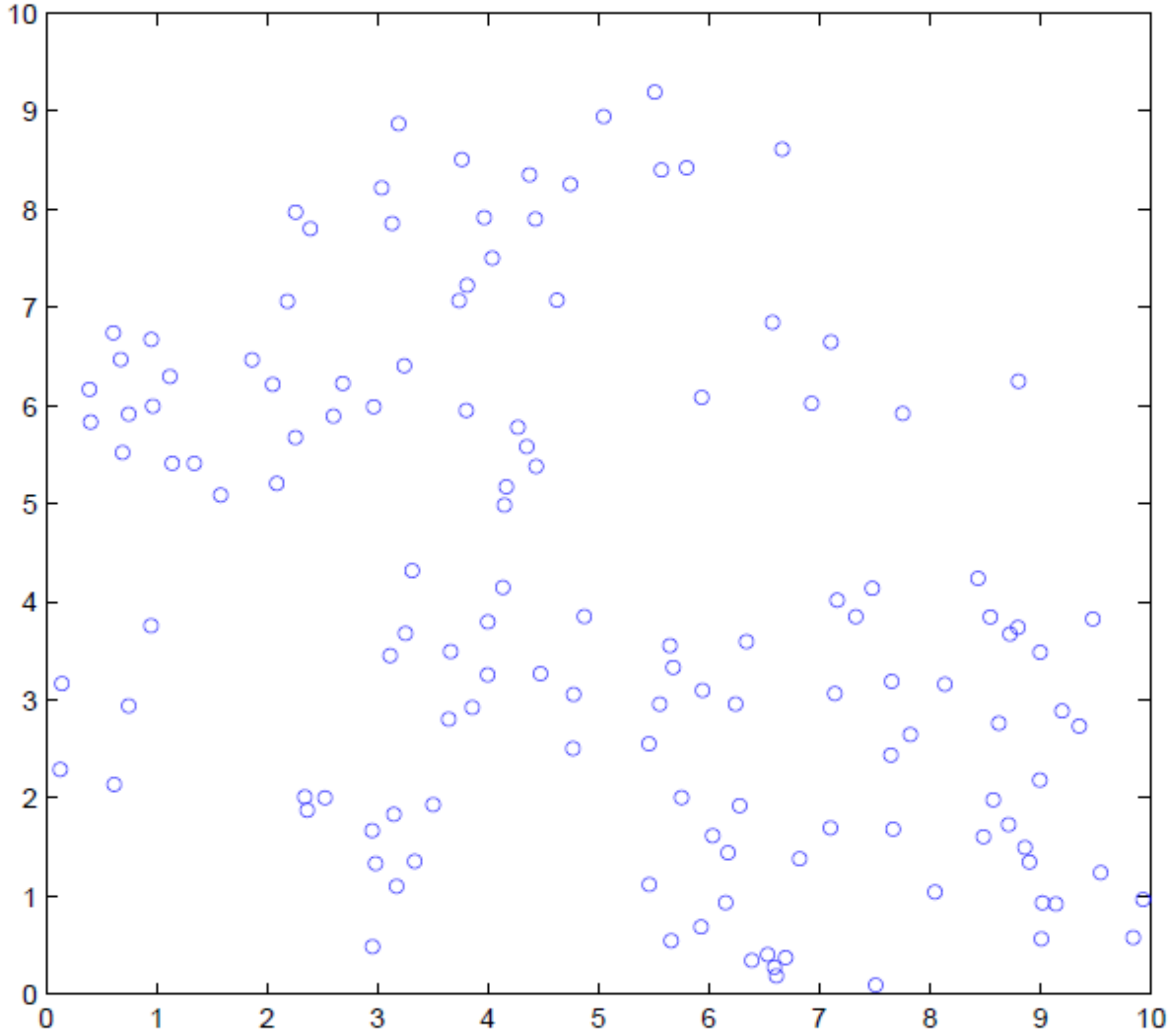
[5] R. Nagpal, D. Coore, "An algorithm for group formation in an amorphous computer", In Proceedings of the 10th International Conference on Parallel and Distributed Systems (PDCS'98), Las Vegas, NV, October 1998.
[6] Afek, Y., Alon, N., Barad, O., Hornstein, E., Barkai, N., and Bar-Joseph, Z, "A Biological Solution to a Fundamental Distributed Computing Problem.", Science, vol 331, pp. 183-185, 2011.

Centroid Finding

- **Centroid node has highest closeness centrality among the nodes in the region.**
- **Centroid of a region is found using [7]**
  - Virtual coordinates are assigned to nodes in the region
  - Average of neighbor coordinates is shared
  - Process continues until nodes in the region have same average coordinates
  - The node having virtual coordinate same as average coordinate is termed as centroid node.

[7] T. Watteyne, I. Augé-Blum, M. Dohler, S. Ubéda, and D. Barthel, "Centroid virtual coordinates: A novel near-shortest path routing paradigm," Computer Networks, vol. 53, pp. 1697–1711, July 2009.

Region Formation and Centroid Finding



Beamforming using Flocking Analogy

The set of nodes that beamform are identified

- Alignment analogy:
  - The nodes which have more hopcount than their neighbors.

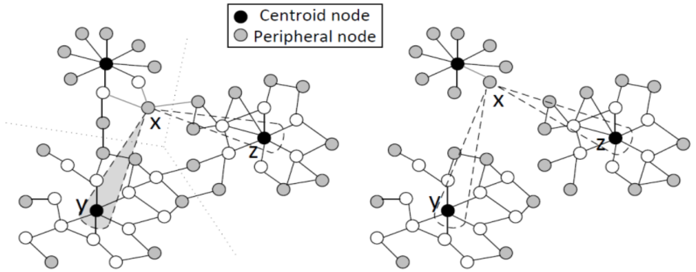
$$hopcount(i,k) \geq hopcount(N_i,k)$$

  - Where i is the node in the k^{th} region with N_i neighbors

These beamforming nodes beamform towards the centroid nodes

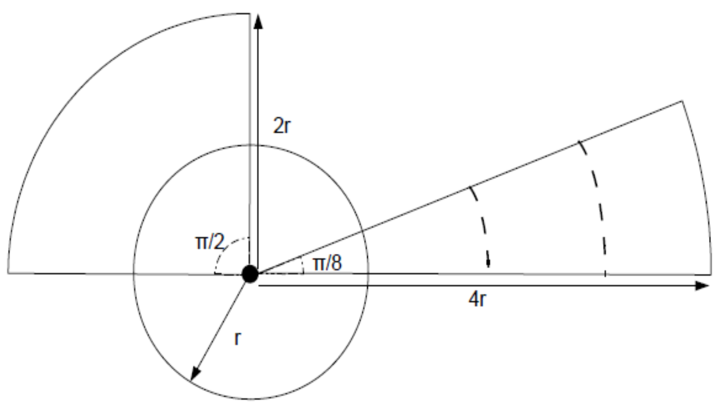
- Cohesion Analogy:
  - To increase the connectivity preference to other regions
  - Reduction in path length is more.

A peripheral node can be centroid node as well



Beamforming using Flocking Analogy (cont..)

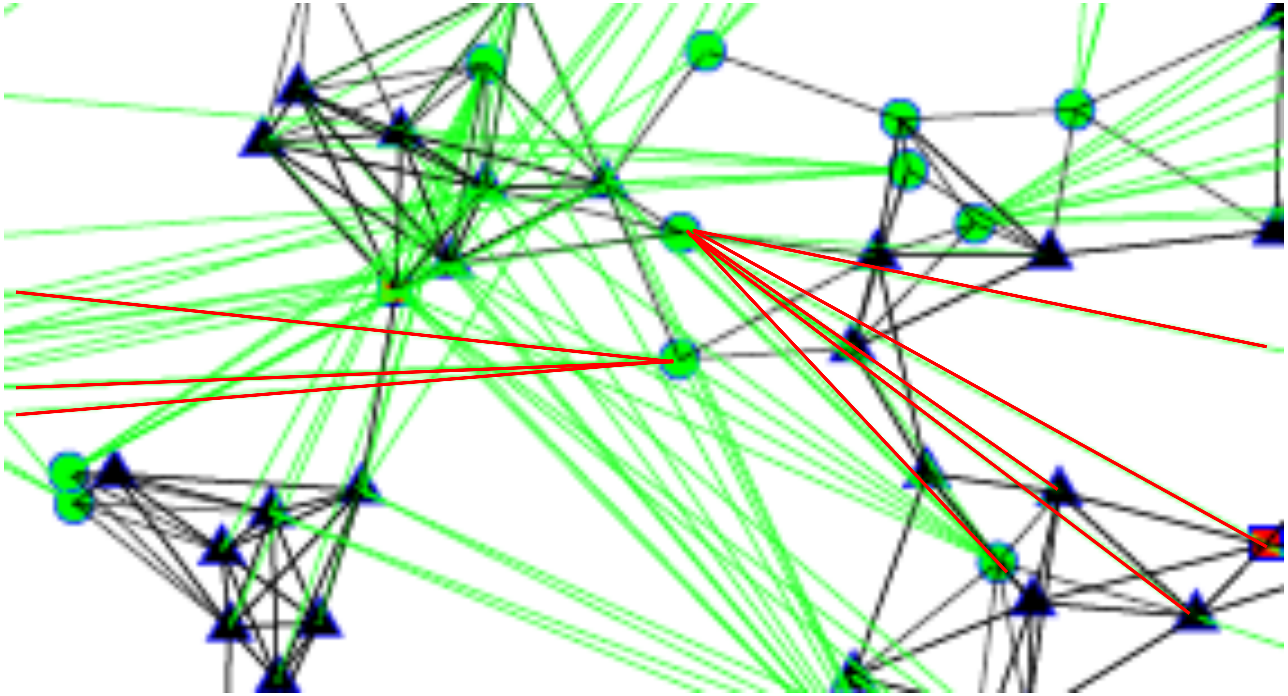
- **In-order to cover more area**
  - Separation Analogy:
    - Nodes orient their beams in different directions as their peripheral neighbor.
- **To beamform for theoretical purpose we use sector model as in [8] for antenna configuration**
  - Nodes randomly chose antenna elements to beamform
  - Same power as omnidirectional antenna



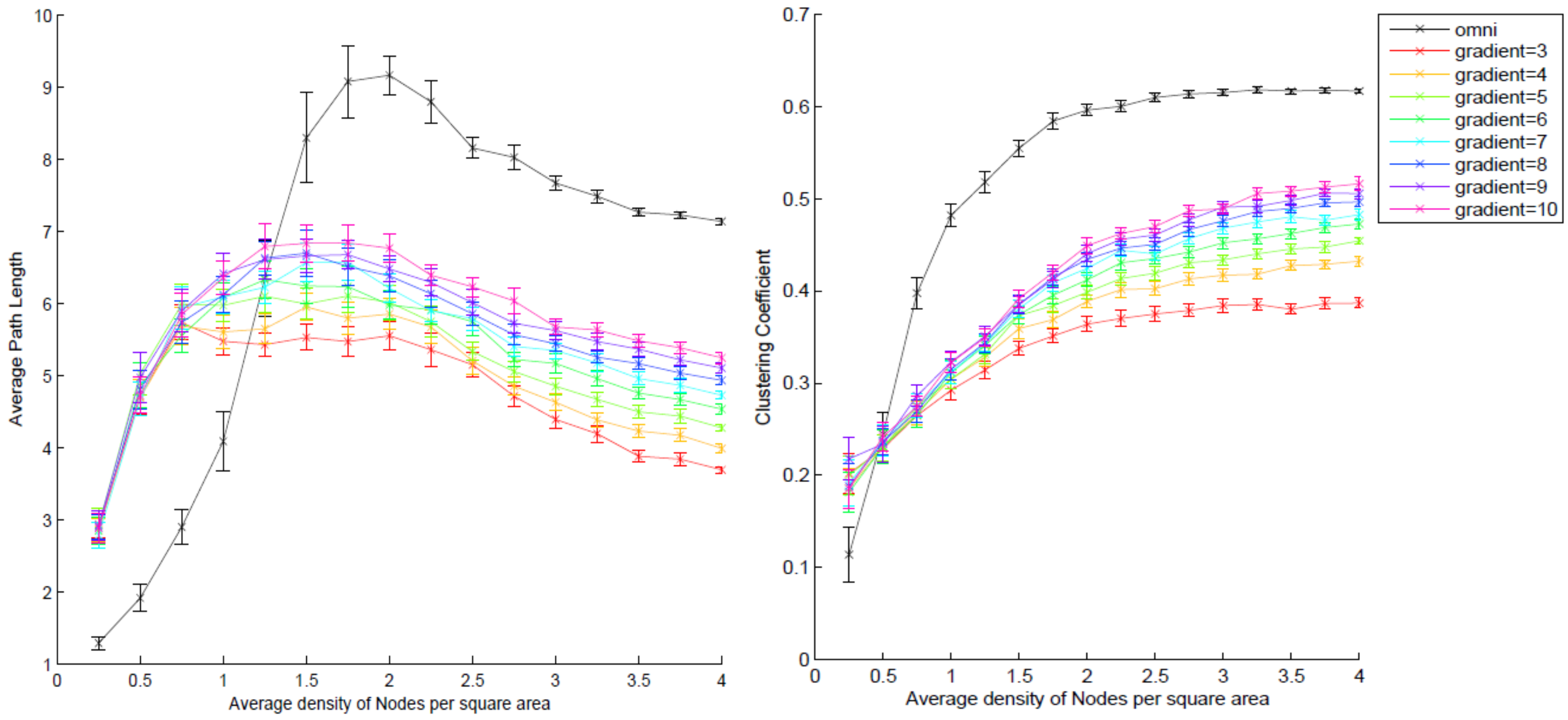
[8] Z. Yu, J. Teng, X. Bai, D. Xuan, and W. Jia, "Connected Coverage in Wireless Networks with Directional Antennas," INFOCOM, 2011

Beamforming using Flocking Analogy (cont..)

- **Peripheral nodes sweep all the sectors**
- **Find centroid which is farthest**
- **Beamforms towards the farthest node**



Results



Average Path Length
Average density of Nodes per square area
Clustering Coefficient
Average density of Nodes per square area
omni
gradient=3
gradient=4
gradient=5
gradient=6
gradient=7
gradient=8
gradient=9
gradient=10

Conclusion and Future Work

Conclusion

- Beamforming and inspirations from nature can be used to achieve Small World Properties in Wireless networks.
- The knowledge of network is not needed for configuring the network.
- Connectivity can be increased.
- Small world properties are impacted by the size of the region used in our algorithm

Future Work

- The optimal size of regions to be identified.
- The effect of mobility of the nodes on the algorithm.
- Evolution of network

References

[1] D.J. Watts, S.H. Strogatz, “Collective dynamics of ‘small-world’ networks”, Nature 393 (6684) (1998) 440–442.

[2] A. Banerjee et al., “Self-Organization of Wireless Ad Hoc Networks as Small Worlds Using Long Range Directional Beams”.

[3] C. Reynolds, “Flocks, herds, and schools: A distributed behavioral model”, Comp. Graph. 21 (4), Pp. 25–34, 1987.

[4] I. Couzin, J. Krause, N. Franks, S. Levin. “Effective leadership and decision-making in animal groups on the move”. Nature, vol 433, pp. 513–516, 2005

[5] R. Nagpal, D. Coore, “An algorithm for group formation in an amorphous computer”, In Proceedings of the 10th International Conference on Parallel and Distributed Systems (PDCS’98), Las Vegas, NV, October 1998.

[6] Afek, Y., Alon, N., Barad, O., Hornstein, E., Barkai, N., and Bar-Joseph, Z, “A Biological Solution to a Fundamental Distributed Computing Problem.”, Science, vol 331, pp. 183-185, 2011.

[7] T. Watteyne, I. Augé-Blum, M. Dohler, S. Ubéda, and D. Barthel, “Centroid virtual coordinates: A novel near-shortest path routing paradigm,” Computer Networks, vol. 53, pp. 1697–1711, July 2009.

[8] Z. Yu, J. Teng, X. Bai, D. Xuan, and W. Jia, “Connected Coverage in Wireless Networks with Directional Antennas,” INFOCOM, 2011.

Questions?

Thank you for attention

rachit.agarwal@telecom-sudparis.eu