Discrepancy: The Neglected Description of Wireless Sensor Networks (and its Applications)

Goce Trajcevski
Dept. of Electrical Engineering and Computer Science
Northwestern University
Evanston, Il 60208
goce@eecs.northwestern.edu

1. Introduction and Motivation

Routing is one of the most thoroughly investigated problems in Wireless Sensor Networks (WSN) settings [1]. A particular aspect of the problem is the, so called, *multipath routing*, which has two complimentary motivations:

1. Increasing the reliability/robustness of the packets delivery to a particular destination [2,3]
2. Balancing the load among the available relay-nodes [4,5,6] which, in turn, contributes towards the better balancing of the residual energy in the network, thereby prolonging its overall lifetime.

Typically, in multipath settings, the following contexts are considered [5,6]:

1. Single vs. multiple sources.
2. Single vs. multiple sinks.
3. Non-intersecting vs. braided paths.

Clearly, the quality of the routing protocol, as part of the overall Quality of Service (QoS), will depend on the overall *connectivity* of a given network, which is determined by the network topology [7], and the parameter that is often used when reporting experimental observations regarding the benefits of a particular approach is the *density* of the network.

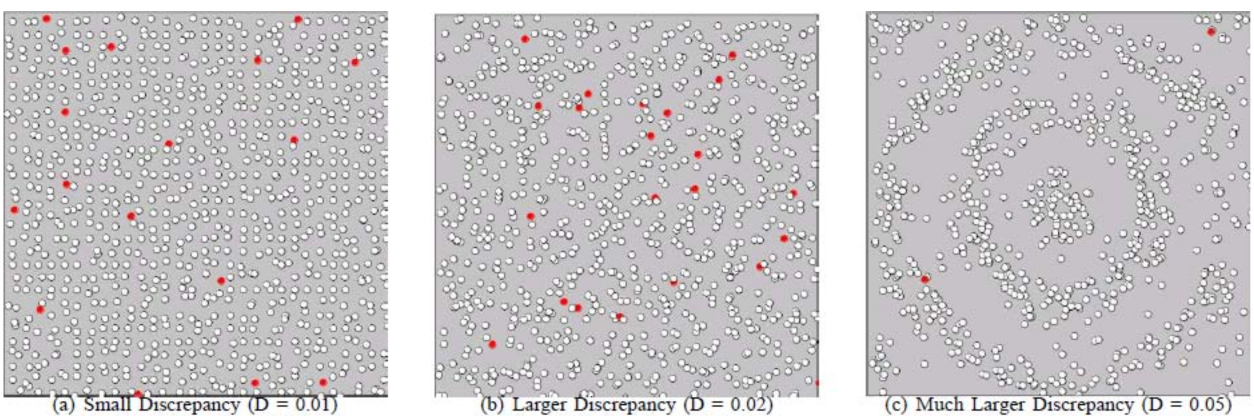

Figure 1. Deployments with Different Discrepancy Values

We postulate that there is another measure that can be used to describe the properties of a particular deployment – the *discrepancy* of a given network. As an illustration, consider Figure 1 above. It illustrates three deployments, all of which have the same density (in terms of the number of nodes in the geographic area of interest), however, their deployments are quite different which, in turn, could have different impact on the routing algorithms.

Formally, given a d-dimensional unit cube $Cd = [0, 1)^d$, the discrepancy of a discrete n-point set $S \subseteq Cd$ is a measure which specifies how much does the distribution of the elements of S deviate from the uniform one [8]. The discrepancy of S from the uniform distribution R, is defined as:

$$D(S,R) = nA(R) - |S \setminus R|$$

We note that, while the results pertaining to various properties of the discrepancy of a given discrete set in the one-dimensional case (d = 1) abound, the results in two dimensional case are much more recent and for three (and higher dimensions) they are scarce. Part of the reason is a specific twist of the "dimensionality curse" – namely, in 2D it is not straightforward to define what is a "good" uniform distribution (e.g., points located on the vertices of a square grid vs. triangular-mesh [8]) and it is the case that certain 2D sets that have relatively small discrepancy for the grid-case, need not exhibit the same for the triangular-mesh case.

2. Discrepancy and Multipath Routing (Results and Goals)

Quite a few routing protocols in WSN literature have adopted the, so called, Field-based approach, where the next-in-line relay node is selected based on a trajectory of a given field-line[1] [9.Mother]. A common drawback of those approaches is that, whenever there are no nodes available to serve as next-hops along the selected field-line, they select node along a different field-line and carry on the transmission along that one. This, in turn, limits the flexibility of the routing protocol in the subsequent selections – namely, in sub-regions where the local-density of the nodes permits, the protocols do not revert to the originally-selected field-lines.

We have demonstrated that, increasing the discrepancy-awareness of the multipath routing protocols adds an extra level of adaptability when selecting the next-hop node from a given source towards a given sink. The detailed experimental observations are available in [10.TR].

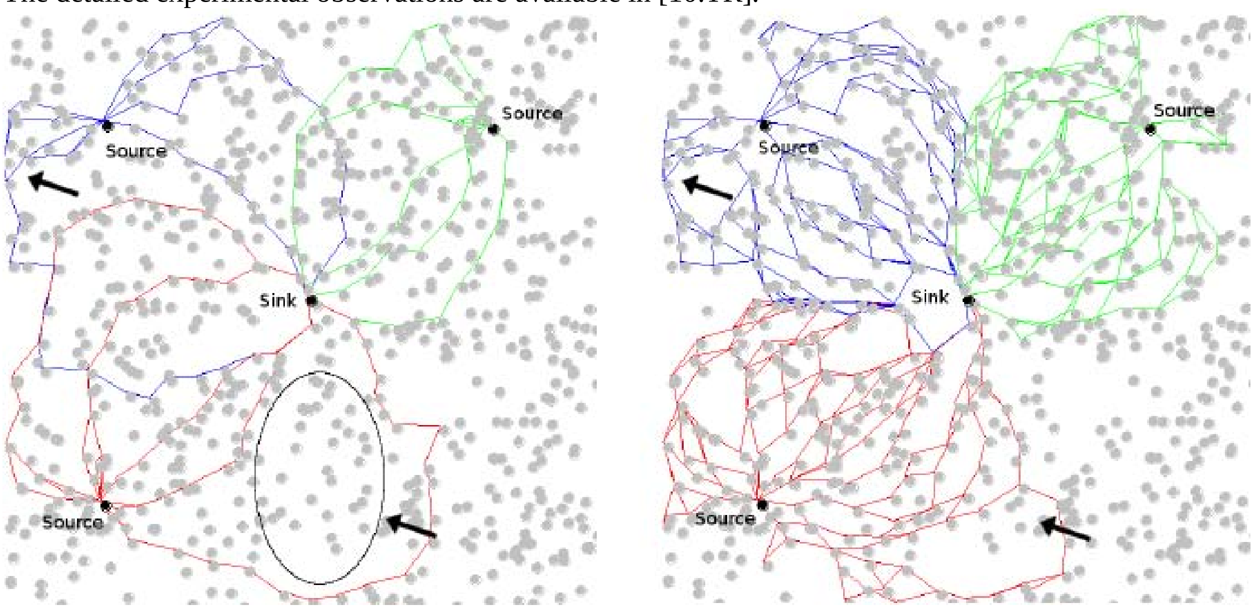

Figure 2. The Effects of (Un)Merging Different Multipath Routes

Figure 2 illustrates the increase in number of paths in a scenario in which 3 different sources are simultaneously transmitting the data to a given sink. The left portion demonstrates the effect of merging different paths, whereas the right portion illustrates the benefits in terms of "un-merging" previously merged paths, whenever possible. As can be seen, this results in a lot more routes which, in turn, means that the energy expenditures due to routing will be more evenly distributed throughout the network. This, in turn, yields a higher balance of the residual energy which can help in increasing the overall WSN lifetime.

DESIDERATA Currently, our research is focusing on developing energy-efficient distributed algorithms that a WSN can use to determine its own discrepancy, where the challenging question is

[1] The lines of the field typically correspond to the gradient of (the potential of) that field.

how that information can be dynamically maintained, and at different levels of granularity. In addition, our methodology works under assumption that a given WSN has a uniform distribution of the starting energy-reserves – and we are investigating how to incorporate the energy-map as part of the discrepancy description.

References

1. K. Akkaya and M. Younis. A survey on routing protocols for wireless sensor networks. *Ad Hoc Networks*, 3(3), 2005.
2. A. Manjhi, S. Nath, and P.B. Gibbons. Tributaries and deltas: Efficient and robust aggregation in sensor networks. In *ACM International Conference on Management of Data (ACM SIGMOD)*, 2005.
3. Hany Morcos, Ibrahim Matta, and Azer Bestavros. M2rc - multiplicative-increase/additive-decrease multipath routing control for wireless sensor networks. In *SenSys*, 2004.
4. Y. Ganjali and A. Keshavarzian. Load balancing in ad hoc networks: Single-path routing vs. multi-path routing. In *INFOCOM*, 2004.
5. W. Luo, W. Liu, and Y. Zhang. Performance optimizatin using multipath routing in mobile ad hoc and wireless sensor networks. *Combinatorial Optimization in Communication Networks*, 2, 2005.
6. G. Parissidis, V. Lenders, M. May, and B. Plattner. Multi-path routing protocols in wireless mobile and ad hoc networks: A quantitative comparison. In *NEW2AN*, 2006.
7. C. Bettstetter. On the minimum node degree and connectivity of a wireless multihop network, 2002.
8. J. Matousek. *Geometric Discrepancy: an Illustrated Guide*. Springer-Verlag, 1999.
9. S. Toumpis. Mother Nature Knows the Best: A survey of recent results on wireless networks based on analogies with physics. *Computer Networks, 52(3)*, 2008.
10. G. Trajcevski, O. Ghica, R. Shubotz, M. Zuniga, P. Scheuermann, M. Hauswirth. *Discrepancy And Multipath Routing in Wireless Sensor Networks*, Technical Report NWU-EECS-09-18