

A Study of Connectivity Metrics for Wireless Ad Hoc Networks

by

Samuel C. Nelson

A Proposal Submitted to the Honors Council

For Honors in Computer Science

15 October 2005

1 Introduction

Imagine the following scenario: A chemical plume is quickly emerging over a metropolitan area from the result of an accident or a terrorist attack. Emergency response helicopters fly over the area dropping thousands of tiny battery-powered sensors, called smart dust. They are about a cubic millimeter in size and have the ability to form a massive wireless ad-hoc network; that is, automatically create and maintain connections to one another, forming a web of wireless communication. Each of these sensors then collects data pertaining to its surroundings and, via the network the sensors created, relays that information to a collection point outside of the chemical plume. The response team now has real-time, constantly updated information about different densities, positions, velocities, etc of each section of the plume.

Now imagine that some subset of these sensors, or nodes, gets destroyed. The network is obviously not as well connected as it previously was, but is it connected enough to continue? Is the connectivity now so bad that the data obtained is untrustworthy? How many more nodes should be deployed to restore connectivity? Currently, there is no easy answer to these critical questions. One efficient way to study these networks is by computer simulation. Simulation is an invaluable tool, since it gives us the power of repeatability, controllability, and the ability to scale the number of nodes. Wireless ad-hoc network simulators are very novel, and therefore at the heart of much research. “Connectivity is one of the most important properties of a wireless ad hoc network” [2]. A metric (a number or rating) to properly measure network connectivity at any given time in a simulator is extremely important, since it will allow scientists to properly quantify network fragility, or health. In this thesis, I propose to comprehen-

sively study and compare the current connectivity metrics being used, expose their strengths and weaknesses in different situations, and formulate a recipe for creating a connectivity metrics designed specifically for different wireless ad-hoc network scenarios. This is important and relevant research, since it will help us assign numbers to, and quantify, how crippled a network can become in a given scenario.

2 Background

A graph is a mathematical construct, and is composed of a set of vertices and edges. A graph is connected if there is a set of links one could follow to get from any node to any other node [4]. Metrics currently used to determine the connectivity of a mathematical graph is an obvious first choice for determining connectivity in wireless ad-hoc network simulators, since graphs are used to represent the network. Furthermore, much is known about the properties of these metrics, and computational algorithms used to estimate them. For instance, work has recently been done allowing scientists to find the number of nodes needed, given a certain node density, to almost surely obtain a very connected graph [1]. An attempt to calculate the set of links one would need to eliminate between two nodes in order to disconnect the nodes (which would seem like a good indication of connectivity), is also very slow to implement [4]. In our searches, we have found sparse literature comparing current graph theoretic metrics to each other, in relation to wireless ad-hoc network simulators. It will be extremely beneficial for scientists to have comparisons of cost benefit ratios for different metrics.

There are, however, issues with practically applying these metrics. One is computational complexity. For instance, there exists a shortest path algorithm,

attributed to the mathematician Dijkstra, that when applied to all nodes results in a complexity too slow to be practical for very large networks [3]. While these metrics give a good estimate of connectivity, they are far too slow for practical simulation use. Secondly, many connectivity metrics are only suitable for certain scenarios, and wouldn't be ideal for others. Since the nodes foundationally rely on neighboring nodes to provide them with communication means, small changes to a single part of the network can cause quick and severe damage to the network connectivity. Therefore, metrics suitable for simulation of these networks must be able to quickly update in order to register changes in the graph. It is clear from the current literature on wireless ad-hoc network connectivity, that comparison for current metrics, discovery of strengths and weaknesses of these metrics, and the construction of new metrics, is greatly needed.

3 Project Description

This project will study connectivity metrics for wireless ad-hoc networks. The first half of the study will be comprised of comparing connectivity metrics that are currently being used in today's simulators. Therefore, a complete and thorough investigation of which metrics are applicable will be necessary. Next, they must be compared to each other in terms of the time it takes to estimate the metric with an algorithm, the amount of memory the algorithm uses, accuracy, and precision. This will consist of textual and visual (i.e., plots) comparison. We will then derive conclusions as to which metrics are most fitting, given a certain type of network or scenario.

The second half of the study will explore the advantages and disadvantages of the current metrics, as well as attempting to give a construction for a more fitting

set of metrics. This will include actual results from a simulator, and will compare them to what we would expect to happen in a given, simplified scenario. The connectivity metrics will be put under stressful conditions to test their limits. Graphs with extremely high and extremely low number of links (defined as the density of a graph), will be used to test these metrics and determine how they respond in terms of the factors mentioned before.

As a conclusion to these results, it will be apparent that a new, and more suitable, set of connectivity metrics be designed. Topics will be explored, such as computational complexity, which will allow us to give a construction for this new metric. This new metric will then be thoroughly compared with the old metrics, as well as tested under the same strength/weakness testing that was done on the old metrics. In the end, we hope to have a new, versatile metric that is specifically designed for wireless ad-hoc network scenarios.

4 Methodology

The Simulator for Wireless Ad-hoc Networks (SWAN) is a working simulator that Professor Perrone and I are currently modifying and using for our research. Our familiarity with this simulator makes it an ideal place to run the comparison experiments for the first section of the thesis. After collecting and implementing into SWAN the connectivity metrics, we will be able to run massive amounts of simulations and use the results to compare how the metrics fared against each other for many different scenarios. SWAN will give us the ability to stage arbitrary scenarios (some of which will be very stressful on the metrics). We will also utilize Hive, a cluster computer on campus that will allow us to run numerous simulations simultaneously.

Next, we will either use SWAN, or create a program, which will allow for simple graph input and changes, and measure the change in connectivity. Since the graphs will be basic, we know how the connectivity should respond to the changes, and we will discover different strengths and weaknesses of the current metrics. Throughout all of the simulations run up to this point, we will compile a database of the best features of each metrics, and attempt to construct a new metric, or set of metrics, that will be ideal for a given scenario. This new metric will most likely be a specific combination of the best parts of each current metric. Finally, we will re-run the comparison tests in SWAN for the new metric, and attempt to discover strengths and weaknesses of it. The results of this test will allow us to both refine the metric and open up a new research area.

5 Conclusion

Wireless ad-hoc networks are a new and quickly growing technology that is sparking research interest worldwide. Currently, very little is known about performance and failure-response pertaining to large-scale wireless ad-hoc networks (greater than 10,000 nodes). Before any system like this could effectively be used, there must be measures of scientific and thorough testing to qualitatively assess each section of the procedure. The literature that addresses the issue of network health in wireless ad-hoc networks is extremely sparse, and the concept of network health is the subject of much current research. By comparing and exposing flaws in current connectivity metrics, as well as giving a recipe for more adequate metrics, researchers will be able to obtain clearer and more precise experimental results. The ultimate goal of this research is to make advances towards understanding the fundamental mathematical properties of wireless ad-hoc networks.

References

- [1] Christian Bettstetter. On the minimum node degree and connectivity of a wireless multihop network. International Symposium on Mobile Ad Hoc Networking Computing, pages 80–81–91, New York, NY, USA, June 09 - 11 2002. ACM Press.
- [2] Gruia Calinescu and Peng-Jun Wan. Range assignment for high connectivity in wireless ad hoc networks. In *ADHOC-NOW*, pages 235–246, 2003.
- [3] Alan Gibbons. *Algorithmic Graph Theory*. Cambridge University Press, Cambridge, 1985.
- [4] H. Ozaki S. Tsukiyama, I. Shirakawa. An algorithm to enumerate all cutsets of a graph in linear time per cutset. *Journal of the ACM*, 27(4):619–632, 1980.