

Managing Connectivity in Wireless Ad Hoc Networks

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Abstract

Wireless ad hoc networks commonly have a significant amount of change and unpredictability in their network topologies. Routing algorithms designed for wireless networks overcome this with little interaction requirements from an administrator, making the process as transparent and automated as possible. However, there exist scenarios where wireless network administrators would benefit from real-time analysis and management of such networks. One such scenario is in automated field robotics, where robot nodes communicate wirelessly and are directed to tasks by an administrator.

Because of issues with basic connectivity in wireless networks, such networks require significantly more advanced solutions for manageability than their wired counterparts. The research presented here identifies some of the key issues in managing wireless ad hoc networks, and describes a protocol for managing connectivity for such a network as a whole. A simulation software solution has been built based on this protocol as a demonstration and proof-of-concept tool, which will also be detailed.

Keywords: automated wireless ad hoc networks, signal loss map

Introduction

- Wireless ad hoc networks are difficult to manage due to their variable infrastructure.
- An administrator needs a minimum of:
 - Knowledge of network topology.
 - Knowledge of network environment.
 - Ability to make changes to the network.
- Wireless networks are affected by signal propagation.

1. Introduction

Wireless ad hoc networks are difficult to manage because of their variable infrastructure. While access restrictions enforcing which wireless devices can connect to a network can be managed through various key-based encryption protocols and access lists, little research has been done to date which focuses on managing connectivity in wireless ad hoc networks. Wireless networks face the challenge of basic connectivity. Ensuring all nodes are connected cannot be guaranteed, especially if the administrator has no ability to monitor and manage the network. In order to manage the network as a whole, an administrator needs both knowledge of the network topology, the network environment, and the ability to make changes to the network. These 3 factors provide the minimum components required for manageability of wireless ad hoc networks.

Fixed-infrastructure wired networks have a known topology. Their topology can be planned and diagrams can be drawn up as required. The topology of wireless ad hoc networks is often, however, in constant change. The connectivity between nodes usually cannot be planned. Rather, it is an area that a management system could represent.

The ability to organise an automated wireless network would be further aided if knowledge of the network environment is available. Wireless signals propagate to differing maximum distances depending on environmental conditions (weather, wireless clutter, etc) and environmental structure (buildings, landscape, etc). An administrator would benefit greatly from having access to signal propagation maps, logical maps which delineate the communication strengths between nodes over varying locations. Such maps assist the administrator by informing them of how signals between nodes are likely to propagate over areas.

Finally, a network's manageability is largely based on the power to change the network. In a wireless ad hoc network, change means positioning nodes so that a better, more connected network can be created. While this only applies to automated networks where administrators have the power to guide nodes to specific locations, from an architectural point of view this ability is an important one in managing wireless nodes. While not all networks will be able to make proper use of the feature, other networks will. Therefore, it too will be included in this design.

Architecture Design

- Network topology information shared between all nodes.
 - neighbors of each node
- Network information is broadcast periodically.
- Each node equipped with:
 - Wireless interface (e.g. IEEE 802.11b)
 - Location-providing device (e.g. GPS)

2. Design

Wireless ad hoc networks in principle do not have any fixed infrastructure. There are no fixed base stations or specialty nodes which form the hub of communication. Instead, all nodes are equal, capable of routing packets as the routing algorithms designate, and free to roam to any location. From a manageability point of view an administrator should therefore be able to connect and manage the network through any node. The administrator's access is through a wireless interface connecting to the network similar to any other node.

The design we have chosen for this architecture is based on all nodes sharing knowledge equally with each other. The network topology is known by all nodes, with changes propagated to each node as they occur. An administrator connecting to the network is seen, by the network, as a regular node. It therefore receives all information updates as they occur. As network updates aggregate all information each node broadcasts, updates are sent periodically. This collates information received into more efficient forms and reduces network overhead.

Each node's minimum hardware requirements are a wireless interface and a location-providing device. The wireless interface (such as an IEEE 802.11b wireless card) allows each node to communicate with surrounding nodes in the network. The location-providing device (such as GPS) allows an administrator to view the positions of all nodes in the network. It is also a requirement for signal loss map development, as will be detailed later.

Task Design

- Each node maintains a list of tasks it will perform.
- Each node also stores a list of all other nodes' task lists.
- Task information from all nodes can be used in predicted routing algorithms, to determine when other nodes will become or cease being communication neighbors.
- Each travel task details:
 - Start time
 - End time
 - Start location
 - End location
- Management interface allows adding and viewing of future tasks for any node in the network.

2.1 Task Design

Wireless ad hoc networks can be made up of autonomous or non-autonomous nodes. Our research focuses on autonomous networked nodes, as such a network is more likely to require management. Non-autonomous nodes act independent of an administrator's wishes, and as such the administrator may be limited to an analytical role. In autonomous networks, however, nodes (such as robotic nodes) can be directed to locations to perform tasks. While our research does not focus on specific tasks performed at locations, it does provide mechanisms to direct nodes to specific locations to travel to at various times. These "tasks" are therefore travelling tasks, where a node is directed to move itself to some location at a given time.

Each node maintains a list of tasks it will complete, along with its current location (provided by GPS, for example). The current position of a node is broadcast with each packet as a requirement of the Signal Loss Map solution, described later. The task list itself is broadcast to each node at periodic intervals as a Task Packet, so that each other node is aware of its neighbors' actions. While this is primarily aimed for an administrator to log into the network and receive information on the current actions of all nodes, it may also be utilised by routing algorithms as a form of predictability. In other words, if nodes are aware of their neighbors future movements, routing algorithms can use this information to predict handoffs and routing topology changes.

The administrator may add or remove tasks and transmit the updated list of tasks immediately to the destination node as a Task Update Packet. Both the Task Packet and the Task Update Packet have the same structure. These packets detail a table of future movement tasks the administrator commands a node to follow. The table is made up of the 4 fields, start time, end time, start location and end location. The start and end times are the times when travel should begin and end (with the node's speed adjusted accordingly). The start and end locations are physical coordinates where the node is to travel between. As the design of the tasking model in this work is specifically to demonstrate node movement management, it has been kept as simple as possible.

Signal Propagation Map

- Represent logical signal propagation topology over physical areas.
- Created and constantly updated in real time by nodes themselves.
- Each node maintains its own map, but periodically broadcasts its changes to all nodes.

signal loss = 2.0 (forest)	signal loss = 1.0 (outdoor area)	signal loss = 1.0 (outdoor area)
signal loss = 2.0 (forest)		signal loss = 5.0 (office)
		signal loss = 5.0 (office)

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2.2 Signal Loss Map Design

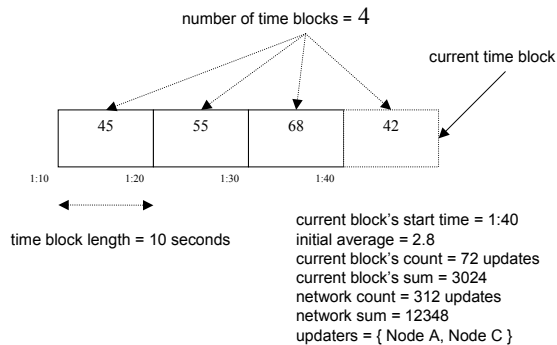
The predicted propagation of signals over physical areas is a requirement for any wireless management system. Wireless transmission capabilities in an unknown or known environment are, however, near impossible to predict with perfect accuracy [1]. Not only do different locations have different communication capabilities, but environmental conditions may change those capabilities over time. Foreign nodes operating on the same channel, radio-frequency interference, environmental noise and even landscape may change radically over time, affecting any recorded or estimated measurements of signal loss.

To overcome these challenges, a signal loss map is required. Signal loss maps represent the logical signal propagation topology over a physical area. They describe how signals are likely to propagate in various directions over various distances. Due to the constantly changing nature of the wireless environment, a perfect signal loss map is not possible to create with current technologies. However, various estimates may be developed to provide a map detailed enough for use in management or in predicted routing protocols. Our previous research [5] presented a new concept in creating and maintaining a map capable of representing signal loss, known as the "Communication Map". This Communication Map is an expandable map of non-overlapping cells, each cell representing a common signal loss for the area it represents. The Communication Map is a map of average signal losses over areas of a physical topology. The Communication Map creates a logical view of a physical environment, without the aid of any physical topology information. The map is built entirely from signal information received from each node's wireless networking interface (e.g. an IEEE 802.11b wireless network device), and their location, provided by any form of location-providing device (for example, GPS).

Each node creates and updates its own map, but will periodically share it with all other nodes. A much larger coverage of the logical signal propagation topology can be covered if all nodes work together to build a more complete map. Sharing the map also aids the administrative node, as it too will receive a complete copy of the map as a whole. The administrator can then use this knowledge to position nodes where they will keep or increase connectivity.

Signal Loss Map Sharing

- Signal loss maps are not only broadcast from each node, but shared.
- Signal loss recordings are averaged in the latest time block
- Previous time blocks are broadcast for sharing.
- Previous time blocks are also used for each cell's overall averages
- A cell's average includes all nodes' averages, but only the cell's specific recordings are broadcast.



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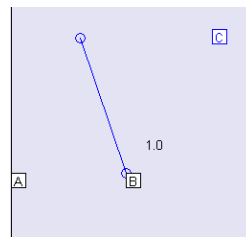
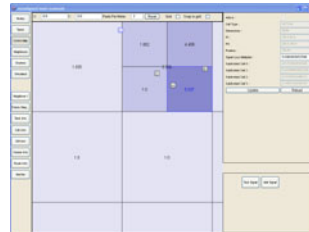
Signal loss maps are significantly more complicated to broadcast at periodic intervals. This is due to the fact that each node does not only contain their own map, like a list of tasks, but must also share the map. The maps are also in constant change, with each cell average being revised should a new signal be received passing through that cell. Therefore, the Communication Map was designed to be broadcast in segments. These segments are known as "time blocks", and detail a period of recorded averages for a cell.

A time block is a fixed period of time over which all signal loss recordings that occur during that period of time affect that average. The actual average signal loss of a cell is the average of the number of time blocks being kept. This idea is best understood using an example, referring to figure above. The length in time of each time block is 10 seconds, which means that each time block will keep the average signal loss of 10 seconds worth of updates. All updates that occur go in the latest block (the *current time block*), where the update is added to the current block's sum of signal loss values, and the current block's count value is incremented by 1, to reflect the additional packet that has now been recorded. The average of the current time block is simply the block's sum divided by the block's count of updates. If an update arrives at a time outside that time block (the current block's start time plus each time block's length), then a new time block is created to represent the current time block, and all other time blocks are shifted down one place. Older time blocks are used for two purposes. Firstly they average out recordings to overcome wireless signal instability. Secondly, they can be broadcast easily, and any node which misses a single packet can receive missing time blocks in the next update.

Each Time Block stores several important fields. The *start time* is the period for which this time block takes effect. The *initial average* is the average returned when no values have yet been recorded, but where an average may be required. The *initial average* is always set to the average of all time blocks before the latest time block was created. The current block's *count* and *sum* are used when sharing the map with other nodes, and represent the averages this node itself received and calculated. The network *count* and *sum*, on the other hand, contain all averages, both locally recorded and those obtained from the network as a whole. These are the values used to calculate the average for this cell, and represent the average that the network as a whole produces. The *updaters* field is a set of network addresses of nodes which have already updated this Time Block, so that no node contributes more than once to the Time Block. This is important as maps may be passed often due to map sharing not being an acknowledged process. Repeated updates may therefore contain some of the same Time Blocks. The *updaters* field solves this potential problem by ensuring each Time Block from a neighbouring node is counted only once.

Signal Loss Map Usage

- The administrator can view the overall network signal loss map.
- The map can be overlaid by node positions and future task paths.
- Connectivity estimates can be drawn between any two points on the map.

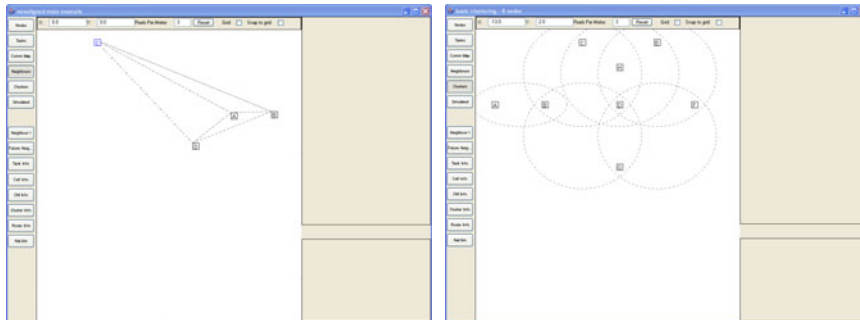


One of the most important sources of information for administrators of wireless networks is a detailed view of the network environment. In having access to a signal loss map, an administrator can make better informed decisions on the placement and actions of nodes and network structure. In the simulator we have created, the administrator has access to this information as obtained from the network. Signal loss maps are broadcast and updated periodically to all nodes attached to the network, whether they be automated nodes or administrator nodes (such as a management laptop accessing the network). The administrator can view this map, as well as overlay on top of the map any other topology information, such as current node positions, future task paths, or current network connectivity.

The management interface provided in our simulator also gives the administrator the ability to estimate connectivity between locations. Before decisions are made on where nodes may be placed, the administrator can draw connectivity lines on the map, which indicate whether nodes at two locations should be able to communicate, given the current signal loss map. This, along with estimated loss in db, distance, and other details are all provided at the drag of a mouse on the map, in the hope of greatly increasing the productivity of network managers.

Neighbor Design

- Managing connectivity requires network diagrams:
 - direct-connectivity diagram
 - cluster diagram
- Such diagrams are easy to produce given a list of neighboring nodes from each node in the network



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2.3 Neighbor Design

Managing connectivity is best understood with network diagrams. Providing a view of the current connectivity between all networking devices is one of the fundamental design goals of the management interface we have created. From knowledge of each node's neighbors, both a direct-connectivity diagram and a cluster diagram can be drawn and updated in real time. The two figures above demonstrate this concept. The first figure demonstrates the basic connectivity diagram, drawing direct connections between nodes and their neighboring nodes. This view, like all views in our management interface, are kept up-to-date in real time, with nodes moving and connectivity joins and breaks drawn as they happen (after the delay of the administrator-controlled periodic broadcast setting). The second figure expands on this information to illustrate which nodes are all neighbors with each other, and thus forms groupings of these nodes. This information is not only beneficial to administrators, but can also be directly applied to clustering algorithms, should the routing protocols employed in the network implement clustering.

These neighbor views are accomplished with one final type of periodic broadcast. At regular intervals, all nodes inform all other nodes of a list of their neighboring nodes. A neighboring node is simply a node which can be currently reached directly over the wireless medium. Such a list is extremely bandwidth-optimised, detailing only a list of network ids for each node that is presently connected to a node. From this information the above diagrams can be derived.

Conclusion

- Our architecture aims to overcome shortcomings in managing wireless ad hoc networks.
- Primarily concerned with automated networks, though non-automated wireless networks may benefit.
- Future research is required to look at managing specific wireless ad hoc routing protocols.

3. Conclusion

The management architecture we have designed aims to overcome current shortcomings in managing wireless ad hoc networks. Our design is largely based around automated nodes, as there is greater opportunity for management in such networks. However, the signal loss maps and neighborhood connectivity diagrams can be applied to non-automated networks as well. All the views shown in the simulator we have created are designed primarily to aid administrators in managing connectivity in wireless ad hoc networks. Further research can explore management of various wireless ad hoc routing protocols in addition to the basic topology information we provide.

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