# AN ALTERNATIVE PARADIGM FOR ROUTING IN WIRELESS AD HOC NETWORKS

John A. Stine
The MITRE Corporation
McLean, VA 22102

## ABSTRACT

We propose a new paradigm for routing in ad hoc networks based on the collection and dissemination of node states. This paradigm assumes nodes have location awareness and can measure the received signal strength of incoming transmissions. Thus, nodes can discover the pathloss in their environment. This information along with other information relevant to the node is combined into a node's state that is disseminated throughout the network. This state information not only supports all nodes discovering the network's topology but provides the very information that makes network management, network engineering, traffic engineering, and spectrum management feasible. The contribution of this summary is a brief description of how the node state routing (NSR)[1] paradigm enables these management and engineering capabilities.

## 1. INTRODUCTION

Research and development efforts in ad hoc networking have striven to make ad hoc networks similar to wireline networks in the interest of reusing concepts and protocols that have been developed for the same. Specifically, routing protocols use the concept of a link as the basis of understanding topology and the interaction of nodes. The link, however, is only an abstraction of a state of a wireless network and does not describe a physical entity as it does in wireline networks. The full collection of links in the ad hoc network cannot coexist simultaneously as they would interfere with each other. We proposed an alternative paradigm that attempts to capture the true physical interdependence among the nodes in [Stine and de Veciana 2004]. This alternative uses node states to understand topology. Section 2 of this summary provides an abbreviated description of how protocols are built using this paradigm. Section 3 describes how this paradigm supports advanced network management, network engineering, traffic engineering, and spectrum management capabilities. Section 4 describes our future research in this area.

## 2. NODE STATE ROUTING (NSR)

NSR has two routing constructs, nodes and wormholes. The node construct is modeled as a point in space. The wormhole construct is modeled as a directed path between two points in space. Nodes and the end nodes of wormholes are connected through wireless links. Links are inferred from the node states. The basic algorithm used to select which routing constructs to use in a route considers the cost of sending a packet to a construct (i.e. the cost of using a link) and the cost of using the construct. These costs are derived from the states of the nodes and the wormholes. Some potential states are listed in Table 1.

Table 1. Example Node States

| STATE | DESCRIPTION |
|---|---|
| **Address** | MAC address of the node or the wormhole. |
| **Propagation map** | A data structure for articulating pathloss in different directions. |
| **Cost** | A cost that is assigned to using a node or a wormhole that is considered when assigning a metric to a link. |
| **Configuration** | Describes the radios and connections the node has indicating an ability to participate in additional networks. |
| **IP Addresses** | IP addresses that are used by the node. It includes multicast addresses. |
| **Direction** | Current direction of node movement. Used to predict future topology |
| **Infrastructure** | This field identifies if the node provides access to another network (.e.g WIN-T) or a special service. |
| **Location** | The location defines where the node or where the wormhole's endpoints physically exist in the network. |
| **Load** | A measure of the quantity of traffic being handled by the node or wormhole. |
| **Time Stamp** | This is the time that the reported state was measured. We assume time is synchronized in the network. |
| **Velocity** | Current velocity as measured by the node. Used to predict future topology. |

In NSR, nodes discover the pathloss to their neighbors and disseminate this as a pathloss in a direction with no explicit mention of the neighbor. Wormholes provide this pathloss information for both end nodes. Efficient methods to articulate pathloss in multiple directions are proposed in [Stine and de Veciana 2004]. Topology and routes are discovered as follows:

1. Infer connectivity between a pair of nodes if the pathloss between them is less than a threshold. Since each node state provides a pathloss, we use the worst of the two to ensure symmetric links.
2. Weight the inferred links using node state information.
3. Calculate a routing table using Dijkstra's algorithm.

Inferring connectivity using node states at first appears awkward since the data to make the inference of a link seems so tenuous. However, this is an artifact of the network being dynamic and existing in a dynamic environment. Observing and reporting the presence of links just hides this variability and fails to capture the interactions that should be considered to make good routing decisions. Node states provide a better mechanism to capture an ad hoc network's state. As a result, not only can rout-

[1] Patent pending

ing protocols consider node and environment interactions but the state information can simultaneously support other network functions.

## 3. EXPLOITING NODE STATE INFORMATION

Most any information that a node can observe can be articulated as a node state. This provides great flexibility not only in how to calculate routes but also in how to manage and control the network. In routing, the node states are combined in algorithms to generate metrics for the inferred links. Algorithms can be designed to support any number of objectives including minimum hop, reliability, energy conservation, route stability, load balancing, and trust. An advantage of NSR is that multiple metrics and in turn routing tables can be created using the same node states using just one data dissemination process. The routing tables can be applied selectively based on characteristics of packets, conditions in the network, or the requirements of users.

Management and control of networks is typically accomplished using protocols that track the state of the network through self reporting by network components and the persistent pinging of distant components by the network management station. In ad hoc networks, the additional network capacity required to track the state of the network could render the protocol a liability as capacity is already limited and normally challenged by the routing protocol. In the case of NSR, however, the routing protocol itself is the state dissemination mechanism and there is no requirement to implement another. The more interesting aspect of using the node states of NSR is that they can be used to understand the use of the radio frequency media in a spatial sense.

In wireline networks, users at network management stations react to problems by attempting to reconfigure the network. Applying management protocols developed for wireline networks to ad hoc networks is redundant as volatility is the norm and the routing protocols themselves automatically configure and reconfigure the network. In ad hoc networks performance is influenced by other means such as policies for how traffic is handled. The multiple routing tables of NSR provide the means to establish different policies in the transport of traffic. When NSR is combined with the Synchronous Collision Resolution (SCR) protocol [Stine and de Veciana 2004], other policies can be implemented that affect how traffic is prioritized. SCR arbitrates access based on packet priority, i.e. the node(s) with the highest priority packet(s) are assured of gaining access before any of their neighbors. In such a protocol, the higher priority packets see the congestion in the network as though they and the even higher priority traffic are the only traffic in the network. For example, say there are three access priority levels and traffic is evenly split among the three levels. The highest priority sees the load as being one third the total, the second priority traffic sees the load as twice that of the first priority, and the lowest priority traffic experiences a network performance typical of the full load. As a management mechanism, all traffic types can be ranked (more levels than access priorities) and the network manager can set the traffic priority thresholds for each access priority. Traffic may also be engineered. Using SCR's reservation mechanism and NSR's wormhole construct, a manager could create a multihop reservation that in-turn is advertised to the network as a wormhole. The reserved path through a congested region could physically carry traffic around that region.

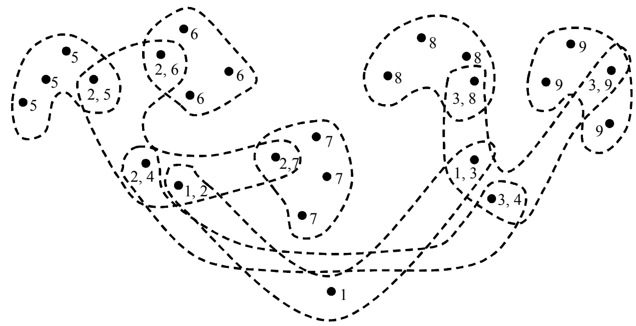


Fig. 2. Example spectrum management scenario

This paradigm supports spectrum management. Fig. 2 illustrates the idea. It illustrates a notional formation. Each circle represents a member of the organization. All have a radio in the common ad hoc network. The numbers adjacent to these circles are the multicast groups (i.e. platoon net, company net, battalion net) that each member subscribes. If a member has one number it has two radios, one is a member of the common ad hoc network and the second is available for the multicast group. If a member has two numbers, it is a member of two multicast groups and has three radios total. The dashed lines circumscribe nodes that belong to the same multicast groups. The number of the multicast group is a logical association; it does not map directly to a radio channel. Rather, it only indicates that all nodes that subscribe to the same group should be on the same channel. The network assigns the channel. Through this approach, multicast groups that are separated from each other, for example 5 and 9, could be assigned the same channel to use.

## 4. FUTURE RESEARCH

The concepts proposed above to exploit NSR are actively being researched in the MITRE Corporation's Advanced Tactical Networking (ATN) research project. The objectives of this project are to create protocols based on these concepts, implement them in high resolution simulations, and explore their suitability for tactical networking.

## REFERENCES

Stine, J.A. and de Veciana, G., 2004: A Paradigm for Quality-of-Service in Wireless Ad Hoc Networks Using Synchronous Signaling and Node States, *IEEE J. Selected Areas of Communications*., Vol. 20, No. 7, 1301-1321.