MobiCom 2009 Poster: Movement Strategies for Intelligent Mobile Routers

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I. Introduction

If we give routers the ability to move, they no longer have to sit idly in a non-optimal position. They can make their own decisions to attempt to improve the efficacy of themselves or the network. In our work, we will focus on how a router can use local information to try and better its contribution to the network. Our main contribution is the development of simple movement strategies that a robot router can employ to try and improve the network. Our long term goal is to understand the role that mobility can play in improving wireless networks.

There are many applications where network connections are not satisfying and a robotic router could improve them. In a simple case, providing temporary self-improving wireless internet to an event, such as a conference, etc., could be more easily accomplished by deploying a mobile robot router. The research area of distributed robots can be aided by allowing intermediate robots to improve the throughput of other robots in the network that are communicating. A robot may need to send high bandwidth data, such as video, to a base station through a set of intermediate ad-hoc routers. If these intermediate nodes could move to account for the robot's movement, they could improve the bandwidth of the network.

Previous work has focused on determining how to provide connectivity to nodes in the field with mobile intermediate wireless router robots [1]. These schemes treat the robotic router problem as a problem of maintaining the visibility of a single moving target. Our work differs because we focus on improving network throughput, while maintaining connectivity.

II. Problem Setting

Our problem can be stated as follows: Given a node, how can it exploit information from its environment to determine the best, if any, direction it should move to improve overall network efficacy? We will show this problem in several network types and show how our movement strategies help improve a node's position. We focus on using local knowledge about the network because this could be more feasibly implemented.

Assumptions

We make the following assumptions. First, Routers can determine incoming signal direction, possibly using a beam-forming array. We hope to remove this constraint in the future. Second, The robot's error introduced through movement is not significant enough to affect gain and the robot can move where told successfully with minimal error. Last, we determine our heuristics assuming that the packet loss model will loosely reflect the theoretical model of radio wave propagation. This is a relatively consistent delivery ratio, with a sharp drop-off as the maximum effective distance is approached. This allows us to assume small movements may aid starving nodes greatly.

III. Movement Strategies

We have chosen to take a heuristic approach to solving the problem. Each node determines the importance of itself to each of its neighbors. We then look at the problem as a local vector field. All of these vectors sum together to create an actual movement in the direction that can better its contribution to the network. We will now devise a set of movement strategies to improve the contribution of a node to the network. We will incrementally introduce our strategies as they apply to increasingly complex scenarios. As a single-path wireless metric, we use Expected Transmission Time (ETT) [2]. For multi-path routing we use a multi-path equivalent to ETT, Expected Any-path Communication Time (ExACT) [3]. ExACT takes the time for all possible routes into account when calculating the path metric.

III.A. Single-Hop Networks

In single-hop networks, such as WiFi, the location of the access point can dramatically affect the bandwidth for its clients. In a home setting, a mobile robot could improve performance for two clients at each end of the house by converging its location to the middle of the home and acting as a forwarder to a wired access

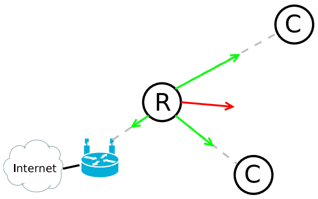

Figure 1: The pull force from forwarding candidates depends differences in the ETT values at next hops.

point. The mobile robot could instead be equipped with cellular internet and act as the access point itself. Due to the simplicity of this example, we only need one movement strategy, the fortunate next-hop rule.

Fortunate Next-Hop

The primary attracting force for a node should be which one of its neighbors needs it to move closer. It is possible that just a small movement could dramatically increase the deliver ratio due to the exponential drop-off of the wireless signal. The main idea of fortunate next-hop is for nodes to exploit next-hops with lower ETT values to send more packets. Our next-hops' ETT values were obtained during the path metric calculation. The magnitude of this force is set to the difference in the next hop's ETT value. Nodes with potential to provide larger gain would have a stronger pull. One issue that arises is how to weight pulls from multiple next-hops. As seen in Figure 1, we first find the average direction, and then determine the average pull of all next-hops.

III.B. Multi-Hop Single-Path Networks

There are many examples of robots forming an ad-hoc network between themselves. Distributed robot communication is often used to solve a complex task with many simple robots. In the event that two robots needed to communicate with each other, the others could move to aid in this communication.

Minimum Distance

Due to node interference, we would like to maintain some minimum level of node separation. It is difficult to impossible for a node to determine its neighbors distance, but in a wireless network distance can be viewed simply as the signal strength. Similar to Figure 2, we can use this measurement to assign a linearly increasing repulsion vector from each neighboring node. The force will grow as the nodes get closer together. For our simulation in Section IV we calculate this force by multiplying the inverse of the distance by a repulsion parameter.

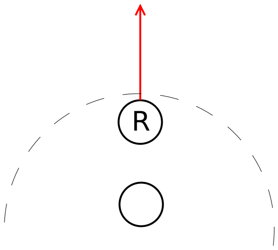

Figure 2: A repulsive force when the robots are within a specified range.

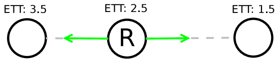

Figure 3: In this scenario, the pull from the previous and next hops are equal, the robot doesn't move.

Suffering Previous-Hop

In order to counter the force from fortunate next-hops, there needs to be an attractive force from previous hops. In this scenario we are now the fortunate node, and we are moving backwards to our previous hop in hope that we will be able to help its large difference in ETT with a small drop in ours. The force vector is calculated similarly to the next-hops' attractive force. Since we may have multiple previous hops, we again must average the force direction and magnitude. Ultimately, there will be a balance point between next and previous hops as shown in Figure 3.

III.C. Multi-Hop Multi-Path Networks (Opportunistic)

All of the previous problems covered can be looked as subsets of the opportunistic routing problem. If a robot needed to send continuous video transmission, opportunistic routing could be preferable to single-path routing. Robots with routing capability on the reverse path could move to improve the throughput of the video communication. Minimum distance has a second purpose in these networks by attempting to make the reception at two neighboring nodes independent of one another.

Insignificant Contributor

The rules mentioned up to this point suffice for single path routing. Opportunistic routing adds an additional twist to our movement decision. We want to determine how much we are actually contributing to our

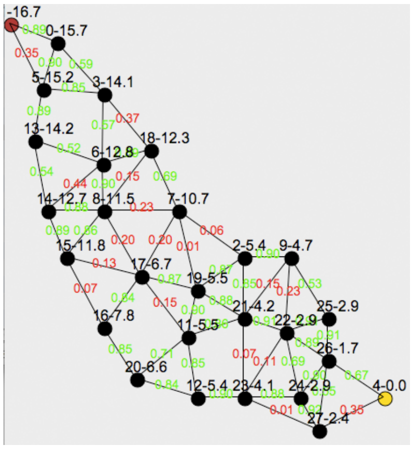

Figure 4: Large opportunistic routing example before running simulation. Each node is labeled with a tuple of its ID and its ExACT value.

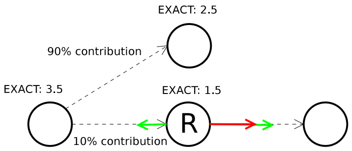

Figure 5: In this example, the force to previous hop is strongly weakened by its small contribution. So the robot will move to the right.

previous hop's ExACT value. For example, it is possible that we only contributes to a maximum of 10% gain to our previous hop, see Figure 5. In these cases, we do not need as strong an attraction vector to our previous hop. We have found through our simulations that squaring the ExACT value difference and multiplying it by its percent contribution performs well.

IV. Simulation

We created a system that builds a network using a theoretical loss model. The model we use is the same as ns-2's free space path loss model. To simulate our loss model, we used the parameters obtained from experiments in [4] for the Orinoco 802.11b wireless card. We then simulated single path routing and opportunistic routing, both with a single flow. Due to lack of space, we only show opportunistic routing. Single path performs exactly as expected and minimizes distance between source and destination (a straight line).

In Figure 4, we present a large network that has many chances for opportunistic routing. Each node is labeled with a tuple of its ID and its ExACT value. The red node in the far top left is the source and the yellow node in the bottom right is the destination. We allowed all nodes to move simultaneously until they reached a stable state. The result, shown in Figure 6, is not a perfectly optimal network, but it is a significant improvement. Because we have minimum distance requirements, spatial diversity is maintained and interference should be reduced. For this scenario, we were able to reduce the ExACT by 21.5%.

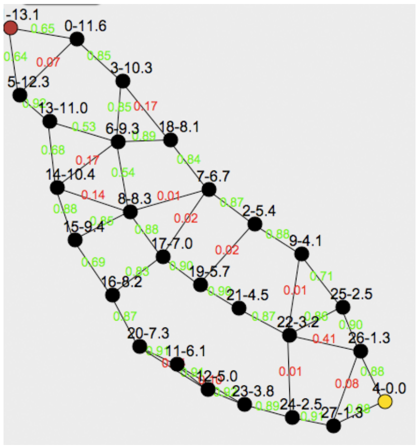

Figure 6: Same opportunistic routing example after running simulation with nodes moving simultaneously using our movement strategies.

V. Conclusion

We have focused on the problem of moving routers to improve throughput with only local information available to the routers. We have presented a set of strategies for moving intelligent routers based on the importance of the moving node to its neighbors. We then simulated our ideas with a network built using theoretical loss models and selected node positions. Areas of future work include removing the need for an additional sensor and using mulit-hop information.

References

[1] V. Tekdas, O. Isler, "Robotic routers," in *IEEE International Conference on Robotics and Automation*, 2008.

[2] R. Draves, J. Padhye, and B. Zill, "Routing in multi-radio, multi-hop wireless mesh networks," in *Proc. ACM Mobicom*, 2004.

[3] C. Gray, N. Santhapuri, and S. Nelakuditi, "On bit-rate selection for opportunistic routing," WiMesh, 2008.

[4] W. Xiuchao, "Simulate 802.11b channel within ns2," Tech Report - National University of Singapore.