Biological Inspiration Motivates New Network Protocols

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The project provided a new bio-inspired protocol that met the needs of the peculiar scenario…a small military surveillance system installed on-the-fly over the public spaces of an urban environment.

We researched and developed a new protocol for radio network communication for certain military applications. It was prototyped as a standalone program and in OPNET Modeler[1]. A conference paper was submitted [2]. Our protocol, named RatNest, was bio-inspired [3] in that it mimicked certain aspects of the structured society of naked mole rats. Our scenario of interest was nontraditional for *ad hoc* networks: a small military surveillance system installed on the fly over the public spaces of an urban environment. The dynamics of the network were limited: nodes were nonmobile, but locations were unknown, and nodes fail and recover occasionally. Communication was established in an ad-hoc fashion, meaning source and destination were unknowable in advance. But, once established, large amounts of video, audio, or other sensor data were streamed. Nodes were sparsely arranged, say at street corners, and communicated through line of sight, say, along the streets. Nodes had dedicated radio links to each of its (few) neighbors. Link quality varied somewhat.

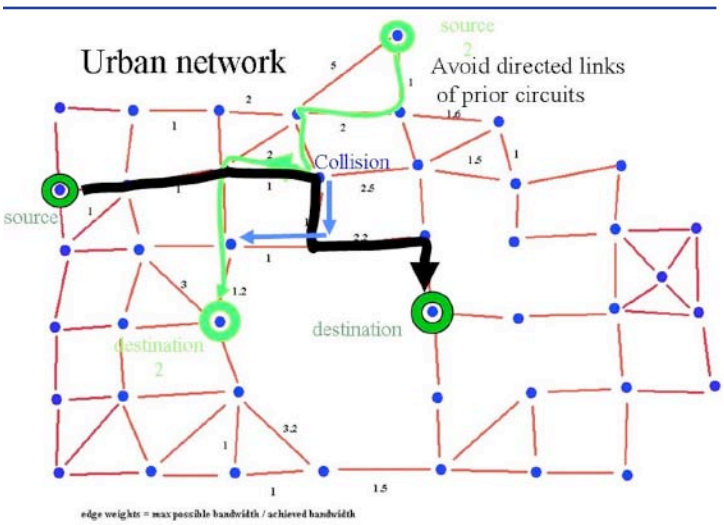

Figure 1. A black circuit from source to destination is established which minimizes the maximum weight of an edge, which maximizes the throughput of the circuit. At a later time, a second circuit from source2 to destination2 is requested. Source2 has outdated information of the network state, in that it doesn't know about the first circuit, and attempts to establish a circuit that uses a directed edge of the first circuit, the blue vertical edge below "Collision." However, when this is detected at node "Collision," the protocol re-routes the second circuit using local information, using an unused backwards-edge of the first circuit, establishing the green circuit.

The protocol we designed found good routes quickly; adapted routes when local information was outdated; was robust (despite the nonrobust nodes) by repairing routes; and had low overhead (a few bits for the protocol and the rest of the bandwidth dedicated to the streamed data) (Figure 1). The protocol can find either a short-latency or a high-bandwidth route for each circuit request.

The scenario of interest was nontraditional. Many of the challenges of this project appeared in the literature and in a variety of other scenarios, but this particular combination of challenges was unique. No other work considered the scenario of *ad hoc* circuit establishment without global positioning system information, with nodes with these capabilities and limitations, and with this hierarchy of protocol goals:

1. Low routing overhead especially when a data message is in hand.
   a. When establishing a circuit, few bits are used for routing. When sending a message, few bits are used for routing overhead and maintenance.
2. Low memory and computational requirements for each node.
   a. The protocol should require very little nonbuffer memory for storing routing tables, network graphs, etc.
   b. A simpler and faster routing engine is preferred.
   c. Messages are not queued. If a circuit cannot be established (or was broken and cannot be repaired), then packets are dropped.
3. High transmission data-rates (good circuits).
   a. For the scenario's network, this translates into low message latency and route redundancy. If packets are only occasionally sent, (e.g., sensor chirps), then low message latency is equivalent to the traditional weighted path length metric. When streaming packets in a bent-pipe mode, (e.g., streaming video where the data are large compared to the bandwidth of a link), then the bottleneck metric is more appropriate.

4. Route repair or "self-healing."
   a. In the event of a node or link failure, the protocol finds alternate routes quickly. Since packets are dropped while the route is repaired (2c), repairing the route quickly and locally is more important than finding the best-metric route.

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The protocol takes a unique technical approach to the structure of data at a node. Since nodes are nonmobile, each node maintains a graph model of the network in its local memory. This includes the graph of all nodes of the network, and the maximum capability of each link of that node. This "persistent" graph is annotated with transient information about which nodes are currently failed, and which links are currently dedicated to circuits. This computer science graph approach contrasts with most other protocols, which store specific route tables. The transient information is gathered proactively and also reactively. The proactive strategy mimics "soldier rats," a fixed pool of agents traversing the network searching for quiet issues; the reactive strategy mimics "tunneling rats," which are created by route events and quickly get information disseminated for rerouting. When requesting a circuit, the graph model at the source node is used to compute a preferred route. This route is then vetted on the actual network; when the route is not feasible, a node close to the problem has the ability to reroute around the problem (Figure 1) or, in extreme cases, to back up and allow a prior node to compute a route. The route is pruned of these dead-ends and loops during route acknowledgement. In a similar way, if a node goes down in an already-established circuit, a neighboring node will detect this and can reroute around the problem, using local information to quickly re-establish the circuit.

We delivered a description of our research to the customer. We built a small C++ program that implements many aspects of the protocol. This protocol was wrapped and demonstrated in OPNET, the standard network simulator protocol.

References

1. OPNET Modeler,
http://www.opnet.com/solutions/network_rd/index.html

2. Mitchell, Scott A. (2009). The RatNest Routing Protocol for Ad-Hoc Circuits Over Fixed Radio Networks, submitted to GlobeCom.

3. Wedde, H. F., Farooq, M. (2006). A Comprehensive Review of Nature Inspired Routing Algorithms for Fixed Telecommunication Networks, *Journal of Systems Architectures*, Vol. **52**(8-9), pp. 461–484.

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