Grid: Building a Robust Ad Hoc Network

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1. Why Ad Hoc Networks?

The vision of Project Oxygen is one of pervasive and adaptive computing: a system in which computational devices exist throughout our everyday environment and communicate with each other both autonomously and at users’ requests, forming a self-configuring, robust network.

The networks of today, however, do not lend themselves to operation in this fashion. Most modern networks are largely static in terms of the position of nodes and the availability of network links. As a result, these networks often do not perform well in the face of failing nodes or connections, and, perhaps more importantly, they are not easily modified to provide seamless mobility support.

Wireless ad hoc networking has the potential to overcome these limitations. In an ad hoc network, nodes cooperatively route traffic amongst themselves. Network connections between nodes are not permanent: they are instead based on physical proximity at any given point in time. The network adjusts dynamically to the changing network structure, which results from node mobility or failure.

Skeptics of ad hoc argue that such a network would be of limited use, as cooperative forwarding of traffic limits the bandwidth available to any given node. In [7], however, Li et al demonstrate that ad hoc networks hold promise for networks in which the average distance between source and destination nodes remains relatively constant as the network grows. Indeed, the applications for ad hoc networks that we foresee will maintain this constraint.

In the future, we can be sure that access points to the conventional, wired Internet will become even more commonplace. Due to their high bandwidth, these wired links will become no less important than they are today. Nonetheless, the development of a wide-area, self-configuring wireless network is essential to achieving the goal of robust, versatile, and pervasive computing devices capable of interacting with each other.

Furthermore, our specific implementation of an ad hoc network provides additional benefits towards the Oxygen project. We are designing an ad hoc network, Grid, based on geographic forwarding [4]. All packets are labeled with the destination node’s current geographic location and unique network identifier. Each forwarding node chooses a packet’s next hop so that packets move geographically closer towards the destination.

The geographic forwarding protocol provides two key benefits. First, unlike other ad hoc protocols, the per-node routing overhead is constant, since no routing information is explicitly propagated through the network. Thus, the design is scalable to extremely large networks. Second, and of particular interest to designers of applications within the Oxygen framework, geographic forwarding provides network participants with a rich datatype: location. This would enable context-sensitive computing and location-specific applications, such as service and resource discovery and mapping. We discuss how such applications might be used in Oxygen in Section 2.

2. Applications for Ad Hoc Networks

If it is possible to build efficient networks using only local information, then peer-to-peer applications could be deployed in a very natural way. Interactions and applications such as file and media sharing will be easier, particularly when incorporating the location information which will be available as explained above.

For example, suppose a user using a handheld computer wishes to print a document. The device would quite easily be able to determine which is the printer closest to his current location, or even the one which is closest to the path he is currently moving along. Similarly, consider a handheld computer playing MP3 audio on the speakers closest to the user, or feeding video to the nearest appropriate display.

Streaming multimedia applications such as these, however, may provide the biggest challenge to the Grid network. Packet delay, packet loss and sequence errors may be significantly noticeable. In an ad hoc network environment, such media applications are more likely to encounter these prob-
lems than a wired network, due to unpredictable network disconnection and topology changes. Because any node in an ad hoc network may be moving, the routing path between two nodes may change at any time. We are currently assessing the performance of Voice-over-IP (VoIP) applications on Grid and hope to improve the network’s adaptability to the problems we have addressed.

3. The Design of Grid

As we have already discussed, location information is now required for every destination, so nodes which expect to be contacted must publish their locations using a location service. The Grid network will use the Grid Location Service (GLS) [8], an efficient distributed location service. Intermediate forwarding nodes can still participate in packet forwarding without publishing their locations to the location service.

We assume that location data will be available through the use of indoor location systems, the global positioning system (GPS), or static configuration. Location proxies [3] enable Grid to accommodate nodes that do not know their own position. Location-ignorant nodes learn the position of a nearby location-aware node, and advertise the proxy’s location as its own. The proxy then forwards incoming packets to the ignorant node using an adaptive local routing protocol. Location ignorant nodes participate in the local protocol, and use it to send outgoing packets to the proxy for geographic forwarding.

Although geographic forwarding works well for networks where nodes are uniformly distributed, it may not find a route to a packet’s destination when the packet has to travel around a topology “hole”—that is, when an intermediate forwarding node has no neighbors that are closer than itself to the packet’s destination. Grid uses intermediate node forwarding (INF) [3] to route packets around holes using randomly chosen route midpoints. INF can also be used to avoid congestion in ad hoc networks, by treating congested areas as holes.

4. Current Implementation

The Grid system is currently being implemented and deployed. To ensure network coverage, twelve stationary nodes, manually configured with their locations, are distributed over two floors of our building. A number of handhelds and laptops without location sensors are mobile nodes. The nodes communicate using IEEE 802.11 [5] wireless radios. The routing protocol runs as a user-level process on the nodes using the Click modular router [6]. Currently, a simple flooding protocol provides location information until a distributed service can be implemented.

To allow forwarding from outside Internet hosts to the Grid network, each node is manually assigned an IP address on a dedicated subnet. (This IP doubles as the node’s Grid network ID.) A gateway machine forwards packets between Grid hosts and the Internet. In the future we plan to use multiple gateways: outgoing traffic from the Grid network will use the gateway closest to the originating node, and the gateways will relay traffic amongst themselves to ensure that incoming traffic enters through the gateway closest to the destination.

In order to eliminate manual configuration completely, we will also begin using IPv6 addresses for Grid network IDs. By assigning each node an address based on its embedded MAC address, we would ensure uniqueness across the Grid network [1] and maintain scalability to a large number of hosts.

5. Conclusion

As we have seen, ad hoc networking holds tremendous potential as a large, location-based network which supports mobility from its inception and provides the level of adaptability and robustness necessary for the Oxygen framework. The progress made thus far in the implementation of the Grid network will serve as a basis for future development of protocols for location service and proxying, route determination, and traffic management.

References