Profiles and Multi-Topology Routing in Highly Heterogeneous Ad Hoc Networks

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***Abstract*— This paper points out multi-parameter heterogeneity as one of the main research challenges for future ad hoc network scenarios. Current research is often focusing on dealing with heterogeneity in terms of only one property, such as battery life or link capacity. Instead, we argue for a more holistic approach that can deal with heterogeneity in terms of a number of different parameters simultaneously. Profiled routing and multi-topology routing are proposed as possible solutions.**

I. Introduction

From a network operator perspective, one may perceive ad hoc networks as a threat to current business. In this paper we argue that ad hoc networks can rather be regarded as an opportunity, and sketch several research ideas and challenges.

Ad hoc networks may improve the operator's business case by improving the Internet availability and service portfolio. Customers will still use the network infrastructure wherever possible. If customers in addition make their private infrastructure available for fellow customers, the operator coverage could be extended. Furthermore, devices of fellow customers should be able to form ad hoc networks wherever possible. Such an ad hoc network scenario could typically offer services as Internet browsing, mobile office with email and calendar synchronization, different entertainment services (music, video, TV), location specific information, traffic information and maps (e.g., in a car).

Much research has been done in recent years, but many pieces must still fall into place to realize this vision. The current research scene for routing in mobile ad hoc networks was set by Perkins, Bhagwat [1] and Johnson [2] in the early 90's. They pointed out scalable routing as one of the key challenges, and more than 10 years later a wide range of highly scalable routing schemes exist.

Although many researchers assume homogeneous properties of the components in an ad hoc network when doing evaluations and analysis, they do not agree on those properties. From 61 published scenarios in the proceedings of MobiHoc (2000-2005) only two contributions agreed on number of nodes, area size and transmission range etc. [3].

From this scene of heterogeneity, a one-track focus on scalable mechanisms and protocols can be viewed as designing ad hoc networks with tailored mechanisms for the ”weakest links” only. We therefore seek a routing scheme that is designed to cope with heterogeneity and to take into account both the ”weakest links” and the ”strongest links”. In this way we will be able to exploit the resources on high-capacity devices and save the resources on low-capacity devices.

In fact, there exist already a lot of work focusing on the heterogeneity of properties like energy [4], [5], bandwidth [6] and mobility [7] separately. However, we argue for a more holistic approach that covers heterogeneity in terms of many different aspects simultaneously.

To address this challenge, we propose a twofold solution: profiling the routing (Sec. II) and using multi-topology routing (Sec. III). In Sec. IV, we specify some research challenges and our intended first moves on resolving them.

II. Profiling the Routing in Ad Hoc Networks

An increasingly heterogeneous ad hoc networking system of the future can be more easily managed if the device profile, i.e., attributes denoting device capabilities and user preferences, are described in a standardized fashion. This information can be utilized in the routing process, increasing the service availability and performance.

Attributes of interest include type of device, type of power supply, level of energy, type of wireless inter-

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face, offered data rate, supported and desired routing approach, and mobility pattern. In addition, a user should be able to indicate its willingness to route traffic for others and possibly what kind of traffic. It may not be necessary to represent these properties individually, since one property may implicitly denote other properties. Another approach to minimize the space of properties is to introduce "DiffServ-like" property classes instead of exact values.

The device profile could be configured by the user, by the operator or automatically based on current context. This means that some properties might be updated dynamically. For instance, the mobility pattern can be updated when a person enters a cafe or gets on a bus.

Devices could announce their profiles as a part of the routing information announcement, or use other channels. The profile announcements should be optional in order to assure cooperation with devices without this functionality.

Capability profiling may improve scalability, because it can ensure that the low-capacity components are not used for data forwarding. Traffic requiring a certain quality of service can be routed on devices that have announced sufficient capabilities. High-capacity and stable nodes can form a backbone, running for instance an extensive routing process internally and a less extensive routing process externally. Mobile, low capacity nodes could run the less extensive process only.

Ad hoc routing is normally categorized as either proactive or reactive. In addition, there exist hierarchical and hybrid approaches. Currently, the common proactive protocol OLSR supports exchange of willingness and link quality (Hysteresis) [8]. Also the reactive AODV protocol supports some information about bandwidth and delay [9]. These specifications, and their recently proposed extensions, could be enhanced to support profiling.

A simple example of a routing process could be as follows. All devices supporting profiled routing should participate in a profile information exchange process, resulting in, e.g., a neighbor matrix containing the profiles. Next, the high capacity and stable nodes could join a detailed routing process while low capacity and mobile nodes could participate in a less detailed process. All nodes get opportunity to increase their knowledge of the capabilities in network they participate in. This knowledge could be used for, e.g., enhanced routing or to decide whether an application with specific requirements is worth initiating.

III. Using Multiple Routing Topologies

Multi-Topology (MT) routing has recently been introduced as an extension to normal routing in fixed IP networks (e.g., [10]). It utilizes independent logical topologies to compute different paths for different types of traffic, i.e., a router/device maintains different routing tables for different purposes. In [11], the authors use MT-routing to improve the resilience of fixed IP networks. Based on the full topology they proactively build backup topologies that are used when a node detects a failure on the primary interface. The backup topologies are built so that some of the nodes and links are isolated and not used for routing. When a node detects a failure, it routes the packets according to the backup topology where the failed component is isolated.

Our goal is to explore the benefits of using multi-topologies for routing in ad hoc networks, and particularly in a context based on profiled routing. As separate routing processes can be run in each topology, a device can participate in a routing processes suitable for its profile. Low-capacity devices can participate in one cheap process only, while high-capacity devices can participate in several processes.

Different traffic could be routed in different topologies, e.g. video downloads could follow a topology consisting only of high-capacity stable nodes. Traffic could also be balanced between topologies. Ad hoc networks could also benefit from using multiple topologies for resilient routing, and continue traffic forwarding without route repair even if links are broken or devices leave the network.

Figure 1a shows an ad hoc network scenario where devices have different profiles. The squares depict the most capable and the triangles the least capable devices. We also assume that there are two gateways to the Internet (nodes 5 and 11). In this scenario we envision three different routing processes. One extensive proactive process exists between square nodes, forming Multi-topology 1 (MT1). Another less demanding process involves square and circle nodes, forming MT2. The triangle nodes, offering no routing resources, could be imagined to only run a reactive process. This means that square and circle nodes must also be able to reply on a reactive request, and thus participate in more than one routing process.

Figure 1b shows a candidate topology that could be used for routing high-priority and high-demanding traffic. In this topology all traffic uses exit point 11 and circle nodes are not used as transit nodes. Only high-capacity (square) nodes are used for this traffic. Such a routing approach decreases the use of resources in nodes with sparse resources. In this topology, some nodes (e.g., node 10) may not be able to run high-capacity applications at all, due to no high-capacity neighbors. We could also imagine another topology tailored for low-

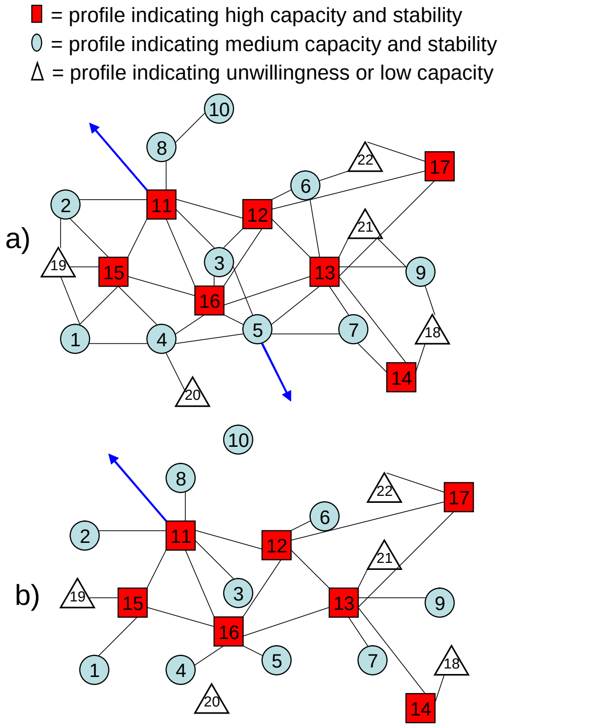

Fig. 1. Sample ad hoc network (a) and high-demand topology (b).

capacity traffic. In such a topology also node 5 could be used as an exit point. In addition, circle nodes might be used as transit nodes.

IV. Research Challenges

This paper describes our future work, and raises interesting upcoming research challenges. Our basic goal is to explore the benefits of using profiles and multi-topology routing in ad hoc networks. To the best of our knowledge, this has not been done before, and even basic questions such as architectural constraints are unanswered.

It is necessary to develop a framework for profile specification and dissemination. Profile granularity and trade-offs with routing complexity have to be addressed. Device heterogeneity must be accounted for in order to avoid overloading low-capacity devices. Scalability is important with respect to the dissemination of profile information, since low-capacity nodes are also expected to participate in this process.

Based on the information received from the process of profile dissemination, devices should in a distributed manner build special-purpose topologies. Algorithms and mechanisms for building and maintaining consistent topologies should be developed. Furthermore, avoiding routing loops is a goal in itself, and may be required in certain resilience scenarios.

Performance evaluation and scalability estimation will be necessary, in order to compare our approach with the state-of-the-art solutions with similar functionality. We intend to evaluate our mechanisms in a discrete event simulator first. A prototype implementation of selected mechanisms may later be used in a field experiment with a multitude of laptop computers.

As a very first step forward, we intend to improve the resilience of ad hoc networks using multi-topology routing in a similar manner as described in [11]. The main idea is to let high-capacity stable nodes join a full topology information mode of OLSR. Based on this information the nodes can build backup topologies that can be used when nodes or links disappear or move. The goal is to identify what scenarios could benefit from this approach. In addition, we will investigate how it performs compared to other mechanisms, such as multi-path routing (e.g., [12]).

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