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Establishing P2P-Overlays for Ad Hoc Networks Using Provider Subscription

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Abstract. Multi-hop ad hoc networks are envisioned to be an integral part of future mobile networks. Today, however, ad hoc networks lack the necessary resilience and reliability. This work proposes to use P2P routing overlays to enhance the dependability and performance of multi-hop ad hoc networks for devices that are subscribed to a provider.

1 Introduction

Overlay networks based on the P2P paradigm have been successfully employed to facilitate reliable data transport [1]. They are used to improve the dependability of traffic flows between end-hosts without changing the underlying infrastructure. By observing connections between neighbors, the overlay can predict the statistical behavior of the network and can thus select proper routes. In particular, if network capabilities are limited and failure recovery times are high, P2P routing overlays achieve significant performance improvements and better resource usage [2].

In contrast, multi-hop ad hoc networks are still in an early phase of development and have not been widely deployed yet, despite the fact that they are investigated in depth by the scientific community [3]. Networks based on the ad hoc networking paradigm bear an outstanding potential and are envisioned to be an integral part of 4G networks for dependable, ubiquitous communication. Moreover, multi-hop ad hoc networks offer an alternative to well-established infrastructure-based networks such as telecommunication networks and may partially or fully substitute such networks in the long run.

However, serious technical challenges arise in ad hoc networks, which have not been successfully addressed so far. One of the key issues that must be addressed is improving dependability in ad hoc communication [4]. Being designed to operate under a wide variety of circumstances, most ad hoc solutions tacitly assume that all nodes in the network are well-behaving and cooperative, which is an unrealistic assumption. Consequently, predicting the behavior of an actual ad hoc network is difficult and the possibility of non-cooperating nodes arises. As a result, network frailty is likely in multi-hop operation. This problem is tightly intertwined with the inherent characteristics of ad hoc communication and is the major reason why predicting the behavior of ad hoc networks is difficult.

Our approach is to address these issues in ad hoc networking by applying P2P overlay technologies, since both, based on self-organization, naturally supplement each

other. In combination with provider-based cellular networking this can result in a synergetic gain in functionality and performance, and will solve many issues in future mobile networks.

2 Related Work

P2P overlay networks have been studied extensively for different application scenarios such as file-sharing, distributed computing, collaboration, and video streaming. Most of this work is focused on network control and search, while data transport follows an end-to-end paradigm [5]. Recently some work addressed data transport and routing aspects using P2P overlays, e.g., [1], [2], and [6]. These routing overlays can be used to enhance current best-effort routing services without any assumption about the underlying infrastructure. But there is some doubt about fairness and effectiveness of overlay routing, because it conflicts with conventional traffic engineering, as is scrutinized, e.g., in [7].

In mobile communications, various proposals for architectures combining aspects from ad hoc and cellular networks exist. Combinations of multi-hop strategies and variable topology concepts were investigated extensively, e.g., in [8] and [9]. However, this work neither addresses routing issues adequately, nor considers P2P overlays for service enhancement. Work focusing on routing aspects in the interoperation between cellular and ad hoc networks, e.g., [10] do not study aspects of provider control or investigate system architectures to facilitate this control.

3 Establishing P2P-Overlays for Ad Hoc Networks

Ad hoc networks consist of highly dynamically behaving devices equipped with a wireless interface for local communication. The devices use a common routing protocol to enable a (best-effort) multi-hop routing service in the ad hoc network. As the capabilities of most devices are limited, routing services will be very simple as is the case for Internet routing. This opens up the possibility for improved routing services on certain devices having additional capabilities. We devise an architecture based on P2P routing overlays, which utilizes network observations and measurements as in OverQoS [6], to enable dependable routing between overlay devices in proximity. Intermediate ad hoc devices form a multi-hop route between neighboring overlay devices. In addition, overlay devices may offer these routing services to local neighbors.

P2P routing overlays in ad hoc networks differ in some characteristics from conventional P2P overlays. (1) The P2P overlay is built on a highly dynamic network platform. Not only nodes but connections are changing continuously. (2) The visibility and range of the P2P overlay is restricted to a close proximity of a participating device. (3) Neighbors are defined on geographical terms that may change over time and require special discovery and mobility monitoring mechanisms. (4) Finally, due to the geographic restriction in ad hoc networks P2P routing overlays will likely not conflict with ad hoc routing mechanisms, whereas this sometimes appears to be the case for P2P overlays in the Internet.

In the future, we envision a hybrid architecture comprising ad hoc and cellular networks. Here, some of the mobile devices are equipped with multiple interfaces and interact concurrently with both networks. In this scenario coupling of data transport abilities of ad hoc networks with the deterministic control mechanisms of cellular networks is possible. We refer to this as "provider-mediated communication". We use the term mediation because the provider neither wants to completely control its subscribed devices nor intermediate nodes forming the multi-hop route. The mediation takes place between the demands of the end-points of the communication and the intermediate nodes forming the multi-hop route with the provider acting as the mediator.

To enable the provider mediation we devise the architecture outlined above based on P2P overlays with add-ons to standard routing techniques. These P2P overlays act on top of existing ad hoc network technology to negotiate and mediate multi-hop communication between subscribed mobile devices that want to exchange data. The provider initiates the P2P overlay network establishment and supports the formation and control only when necessary or advantageous. The P2P overlay autonomously monitors and collects information that is enriched by provider observation.

The provider initiated P2P overlay must allow for continuous operation even under highly dynamic conditions. Moreover, the scheme must increase robustness and dependability of the hybrid network scheme compared to the pure ad hoc network system. This necessitates P2P overlay routing mechanisms, which can efficiently use collected data and additional information supplied by the provider, as well as avoid disruptions in case of high node mobility.

4 Application Scenario

A possible scenario for provider-mediated communication using P2P overlays in ad hoc networks is as follows. Let us assume a cellular network with devices capable of performing multi-hop operation. Two users, which are in proximity, want to set up a connection to exchange a large amount of best-effort data. They can choose among the following communication paradigms. (1) They may exclusively use an ad hoc connection to exchange the data, if a feasible multi-hop route can be acquired (using the P2P overlay). (2) They may exclusively use the cellular infrastructure for the data delivery, if both stations are in range of a base station. (3) A hybrid scheme may be used to enable the delivery of the data. In this case, the infrastructure aids in partially or entirely establishing the control path between the end-systems. The data path follows the so-established multi-hop connection using the P2P overlay.

In the high-bandwidth best-effort data transport scenario this translates to optimizing the throughput of a best effort data connection such as peer-to-peer file sharing between two devices by providing high bandwidth routes in the ad hoc network domain. The creation of the necessary P2P overlay network is controlled by the provider-mediation. As a result, the load in the cellular network can be reduced.

5 Conclusion

In this paper, we proposed the establishment of P2P overlays in ad hoc networks to enhance the performance and dependability of multi-hop ad hoc communication, and identified basic application characteristics. We also introduced the concept of provider mediation to establish the overlay and enable a new service paradigm for future hybrid network architectures. The evaluation of the P2P overlay as integral part of the hybrid architecture is ongoing work. Currently, we have defined a basic set of the necessary protocols and services. In the future we plan to address different characteristics of this architecture to evaluate performance and dependability issues.

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