The Design of PaMaNet
The Paderborn Mobile Ad-Hoc Network

Extended Abstract

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ABSTRACT

Wireless connectivity is state of the art for local area networks. Currently, most W-LAN networks rely on a centralized design with access points routing all inner and outbound traffic. These access points are intrinsic communication bottlenecks. Mobile Ad Hoc Networks (MANET) overcome this problem, because every participant serves as a simple node as well as a router. Current MANETs are restricted in scalability, because they rely on flooding mechanisms or complete routing tables. Other approaches, providing better scalability use clustering, yet network performance deteriorates in case of high node mobility.

We describe the design of a PaMaNet, the Paderborn Mobile Ad Hoc Network, a MANET overcoming these problems providing scalability and reliability in a mobile scenario. When implemented, PaMaNet works with standard W-LAN IEEE 802.11 radio devices, provides IPv6 communication interfaces and works on personal computers under a standard Linux distribution.

First, we present current routing protocols and classify them with respect to scalability and stability in dynamically evolving MANETs. Then, we discuss related research in the area of distributed hash tables and consistent hashing, used for relieving hot spots in the Web, storage area networks and peer-to-peer networks, which inspires the design of PaMaNet.

PaMaNet consists of three main components: First, the embedding of the routing layer into IEEE 802.11 and IPv6 by using techniques used at the ad hoc support library (aslib) by Gupta et al. Second, the routing layer which combines a landmark routing, hierarchical clustering, consistent hashing for providing location dependent addresses and lookup-service for the location of nodes. Third, a peer-to-peer data storage system based on egoistic distributed caches enabling hop and traffic efficient data access on replicated data partitions.

The routing layer incorporates a variety of new approaches. Link distances reflect the failure probability of links, which is estimated by the reciprocal age of the link. Then, we combine a landmarking system on this metric with the hierarchical layer graph yielding small landmark addresses and small routing tables. To balance the load of the distributed lookup-service for landmark addresses, a hierarchical weighted consistent hashing scheme is used. This ensures that each node receives an equal part of all landmark addresses. Using these mechanisms (regularly and on demand) PaMaNet adjusts IPv6 routing tables such that short stable routes are preferred.

For the distribution of control data like landmark information PaMaNet uses a message box system interface to provide fast one-hop communication. On top of this system, PaMaNet provides a peer-to-peer data storage and lookup system that realizes time, traffic, and load efficient access using egoistic caches and data segmentation strategies.

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1. INTRODUCTION

A Mobile Ad Hoc Network is an autonomous, self-configuring wireless network, where every participant behaves like a node and is also responsible for routing tasks.

Commonly mobile ad hoc network protocols are classified into three categories: *proactive*, *reactive* and *hybrid protocols*. Proactive protocols permanently communicate for maintaining valid routes before they are needed, whereas reactive protocols explore possible routes on demand. Hybrid protocols represent a combination of both.

Examples for proactive protocols are DSDV [13] and OLSR [4]. Dynamic Source Routing (DSR) [9] exemplifies an on demand routing protocol for mobile ad-hoc networks. Further reactive protocols are the Ad-hoc On-Demand Distance-Vector Protocol (AODV)[12] and the Cluster Based Routing Protocol (CBRP)[8]. For all these protocols the network performance degrades for large or highly dynamic networks.

An example for a hybrid routing protocol is the *Zone Routing Protocol* (ZRP) [6]. This protocol reduces communication traffic compared to the other protocols. Nevertheless, full scalability is also not provided. Landmark ad hoc Routing Protocol (LANMAR) [18] is well suited for an ad hoc network that exhibits group mobility. An open question in LANMAR is how to find appropriate groups and the lookup service for the landmark addresses. We will follow this track and use LANMAR as a building block for PaMaNet.

PaMaNet is similar to a hybrid network like ZRP and LANMAR. The main difference is the multi-hierarchical routing approach. Each node in the network acts as a landmark and thus has a unique landmark address.

Recent work in communication networks shows that hierarchical partitioning comprises a huge potential for efficient networking, e.g. see [14] for oblivious routing in networks. If the transmission power of participating nodes is adjustable, then congestion, dilation and energy can be approximated by a similar network topology called Hierarchical Layer Graph (HL-graph) [11]. This network design provides small number of interferences and small number of nodes. Such an HL-graph is constructed starting from the bottom, where layers of networks of comparable edge lengths are constructed by reducing the number of participating nodes. In [16] it is shown that in a worst case mobility scenario such a HL-Graph also provides good properties like scalability, small number of interferences, small congestion and a small degree. PaMaNet is based on a HL-graph using hop-distance as a distance measure.

PaMaNet and peer-to-peer-networks share several concepts,e.g. all mobile hosts are equal and the communication load and memory usage is balanced. Both apply consistent hashing, referring to other efficient peer-to-peer-systems like CHORD, CAN, or Tapestry [7, 15, 17]. However, there are some crucial differences. PaMaNet is not an overlay network and it guarrantees routes which are only a constant factor longer than the shortest stable route.

XML-Caching techniques for databases have recently been investigated in different contributions ranging from physical approaches based on XML nodes to logical approaches based on fragments that are described by arbitrary logical XPath expressions. We have followed the approach of [1] by using tree patterns, which can be regarded as a compromise between physical and logical structuring of cache fragments. Like in [2] we aim at efficient data caching.

2. SYSTEM OVERVIEW

PaMaNet is designed as an IPv6 enabled, extremely scalable, mobile ad hoc network, for highly dynamic network demands. The idea is to replace the routing, based on locality information given by an IP address, with a multi-hop routing and a special location service to find nodes using the IP-address as search key.

Therefor we develop a strategy using **Hierarchical Clustering** and **Landmarking** which defines a virtual positioning system within this network. Every node is a landmark for other nodes. Most of them only for their local neighborhood, others for a larger area, and at the top only one of them for the whole network. Due to its position, each node informs its neighborhood within the hierarchy that is defined via the **Neighborhood Management**. This sub-structure builds up the **Position Based Routing** for PaMaNet that is based on this landmark address system.

Due to the fact that we want to provide standard TCP and UDP connections in the transport layer, the routing layer provides a standard IPv6 interface to the upper layer as shown in Figure 2. If the next hop to a given destination is set within the forwarding table, **PaMaNet routing** uses the default **IPv6 stack**. Otherwise we have to identify this next hop. Therefor we use **Weighted Consistent Hashing** for storing information hierarchically within clusters, deduced from the landmark hierarchy.

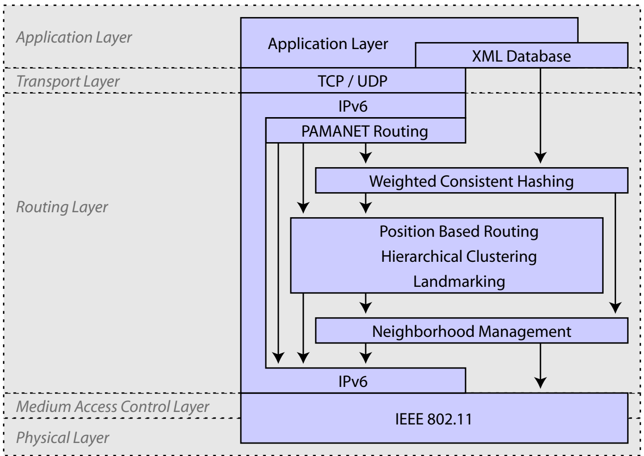

Figure 1: System Overview of the PaMaNet

Each node entering the network publishes its landmark addresses by using a weighted hash function with its unique address as key. This function specifies where a node has to store the relation between its landmark addresses and its IPv6 address.

If a node does not know the next hop to a chosen destination, it can use the same weighted hash function as above, again with the destinations IP address as the key, to achieve the landmark addresses of the destination. Based on the obtained addresses position based routing can be used to reach the destination.

For the interface to the physical layer we provide a standard IPv6 interface. It passes IPv6 packets supplemented with control information of the routing layer to the **IEEE 802.11** standard communication layer. There messages are transmitted in ad hoc mode.

As shown in Figure 2 an **XML database** using distributed caches is provided on top of the transport layer of every peer in our PaMaNet. It uses key based routing as well as the IPv6-stack for communication purposes. Certain peers are lookup-peers which store location information about the XML database. We do not follow the strategy of testing whether cached data can contribute to a new query with the help of intersection testers as shown in [2], as (according to [5]) such tests can be NP-hard and resource consuming. Instead our framework uses a set of pre-calculated cacheable XML fragments, making such tests unnecessary. Similarly as in [19] we have a peer-to-peer like network consisting of caching peers. In contrast to this approach, we still use an information provider in terms of a data origin peer. Our approach follows [3] which focuses on efficient computation on the requesting peers and thereby consumes only minimal resources. Beyond [3] we use caching with the benefits of consistent hashing as introduced in [10].

2.1 State of the art

As of this paper's writing PaMaNet is not fully implemented. Experimental studies will be conducted with the implementation of the prototype in the fall of 2004. To prove the scalability of PaMaNet, the main issue of this project, a large scale communication network at least 100 mobile ad-hoc nodes will be established starting at winter 2004/2005. These experiments will answer the question how large the network need to be such that the asymptotic proved in this paper outperform mobile ad-hoc-networks studied so far.

3. ADDITIONAL AUTHORS

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