# Magnets - A Next Generation Access Network


Roger P. Karrer, Petros Zerfos, Nischal M. Piratla
Deutsche Telekom Laboratories
Berlin, Germany
{*roger.karrer, petros.zerfos, nischal.piratla*}*@telekom.de*



***Abstract*— Magnets is a next-generation wireless infrastructure consisting of a wireless mesh with 50 nodes, and a high-speed wireless backbone with a raw end-to-end throughput of 108 Mb/sec. In addition, Magnets is seamlessly integrated with cellular networks based on GPRS and UMTS and next-generation wireless technology based on WiMAX to create a true 4G network. Magnets combines a research environment where new protocols and future architecture ideas can be deployed and experimentally evaluated. It encompasses a production environment where students at the TU Berlin are offered free access to the network. Here, we present the design and deployment of Magnets, which offers an unique environment to generate knowledge beyond theory and simulations, and experiment with the complexity of next-generation access networks.**


## I. Introduction

Wireless broadband technology is revolutionizing society in the 21st century as computing and the Internet did in the 20th. Besides residential networking, wireless broadband connectivity has recently extended its availability into the realm of access networks. It promises to combine the reliability, robustness, and wide coverage of cellular networks with the high bandwidth of 802.11 and WiMax, realizing the vision of a true ubiquitous high-speed Internet access at a fraction of the cost of deploying fiber. However, while most major cities are promising and/or deploying a wireless infrastructure, the understanding of capacity constraints, scalable deployment and efficient management is still in its infancy. It is therefore imperative that we deploy wireless access networks in a real setting and assess not only their fundamental behavior, but also the integration of different wireless access technologies into the Internet infrastructure.

The main theme in the design of the Magnet mesh network and its key distinguishing characteristic from other similar efforts is *heterogeneity* along several dimensions: it features multiple wireless interfaces with diverse link characteristics, nodes with varying degrees of processing and storage capabilities, and interconnection of multiple mesh networks with disparate routing protocols.

To further exploit this uniqueness, Magnets is designed with a three-fold goal: first, it attempts to provide a combination of semi-production environment and research testbed, where traffic created by students of TU Berlin will help assess the suitability of the wireless infrastructure under realistic traffic assumptions. Second, it will serve as a platform for investigating interoperability issues that stem from the diverse ways in which mesh networks are deployed (ranging from a carefully planned, high-speed backbone network to an untethered, low-

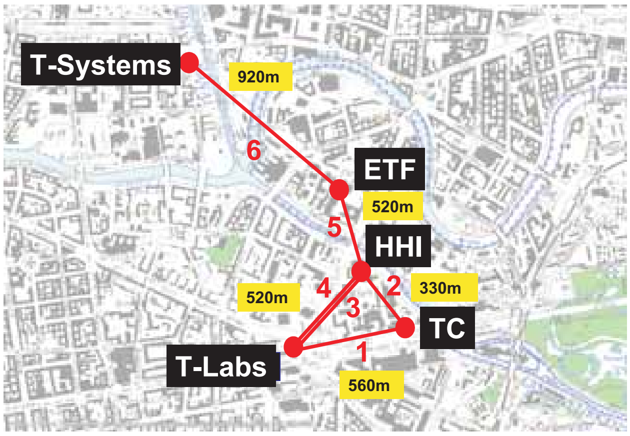


Fig. 1. Magnets WiFi backbone in the heart of Berlin

capacity, and extended-diameter urban mesh). Third, it will leverage and help evaluate the multi-tier design approach in the context of mesh environments, a design trend that is also being followed in other fields such as peer-to-peer networks and sensor networks [2].

## II. Architecture

The Magnets [1] architecture consists of 3 basic parts: a high-speed wireless 802.11 backbone, an 802.11-based wireless mesh network and integration points to alternative technologies (GPRS, UMTS and WiMax).

### A. Backbone

The Magnets backbone features wireless high-speed connection between 5 buildings in the heart of Berlin, as depicted in Figure 1. The total distance between T-Labs and T-Systems is 2.3km. All nodes reside on top of high-rise buildings and have unobstructed line of sight, and all transmissions are in the unlicensed spectrum (2.4 and 5 GHz).

Each node along the backbone consists of a workstation with fast processor (3GHz) and 1 GB of RAM that acts as a router. We opted for a workstation-based solution to install computationally intensive network management and application-specific services on these nodes. Attached to the routers are 12 WiFi access points (APs) suitable for outdoor usage, mounted along the antennas to shorten the cable length between the antenna and the AP. The APs support the 802.11a/g modes at 54Mb/sec, and also a proprietary protocol called *Turbo Mode*, capable of providing raw bandwidth up

[1] http://www.deutsche-telekom-laboratories.de/∼networks/magnets.html

to 108Mb/sec. The access points are connected to directional antennas, 8 of which operate at 2.4 GHz and the rest at 5 GHz.

This setup allows a wide range of measurements to be performed. The link characteristics along the backbone vary in distance and capacity: the shortest link is 330 meters, and the longest being 920 meters; capacity enhancements are achieved via Turbo Mode or via 2 independent parallel links on orthogonal channels. With the Magnets backbone we will investigate the effective MAC-layer bandwidth for each link individually, and also the end-to-end throughput over several weeks. The differences in distance, frequency and setup (Turbo Mode vs. parallel channels) will provide vital insight into the suitability of 802.11 backbones, especially as the average and variations of the link speeds are subject to uncontrollable conditions. Another area of interest is in measuring performance and assessing the end-to-end throughput of higher layer protocols such as TCP over multiple wireless hops, due to their well-known problems of low-throughput [1].

### *B. WiFi Mesh*

On the campus of the TU Berlin, a WiFi mesh network is being currently deployed. In its final form, the outdoor testbed will consist of  50 mesh nodes, targeting the areas of the campus where connectivity is currently sparse. For the selection of the hardware for the mesh nodes, we primarily opted for a platform that provides maximum extensibility [2]: the ability to attach external storage (e.g. a compact flash card) allows for trace collection and installation of management tools, while multiple Mini PCI slots provide flexibility in connecting several wireless interfaces.

The deployment planning attempts to strike a balance between achieving research goals and allowing practical use of the mesh network. Initially, a cluster of around 15 nodes will be deployed around a populated area of the campus, where several users are expected to connect. Each mesh node is equipped with several WiFi interfaces (between 3 and 6). Deployment is challenging because cards in the mesh nodes must be chosen to balance user access capacity (in the 2.4 GHz band, since users mostly have 802.11b/g cards) and capacity to forward traffic to the fixed network. Once this phase is operational (Section III describes applications that will be evaluated), the “diameter” of the mesh network will be extended in an ad hoc, less-planned fashion, to increase coverage and the number of hops traffic will have to traverse.

Magnets is developed using open source software in an attempt to provide ample opportunities and flexibility to deploy and evaluate protocols at any layer. It will allow experimental evaluation of benefits and drawbacks of cross-layer optimizations that have been proposed in the research literature [4]. The main objective is to shed practical, experimental light on the ongoing discussion.

### *C. Heterogeneous Nodes*

The WiFi backbone and mesh networks will be augmented with alternative wireless technologies to form a 4G heterogeneous network, taking advantage of the 6 Mini PCI slots of the nodes. The availability of wide-area wireless technologies such as GPRS, UMTS, and WiMax (one WiMax base station is currently being deployed at T-Systems with one subscriber station at T-Labs) provides the opportunity to superimpose multiple network configurations on the said set of mesh nodes. Issues such as TCP performance during vertical handovers between multiple access technologies will be explored on the Magnets testbed. Furthermore, investigations will be carried out on operator-driven optimizations for resource management and load balancing, as well as opportunities for separation of control and data planes that exploit diverse characteristics of wireless technologies. Finally, some nodes will also be furnished with low-range Bluetooth and Zigbee communication interfaces for integrating sensor networks.

### *D. Constellation of Mesh Networks*

It is not uncommon nowadays for a large urban area to feature multiple mesh networks that provide wireless connectivity to isolated “islands” in the city. Berlin is such an example, with two other mesh networks -besides Magnets- already in operation: the first is a community effort named Freifunk.net [3], while another one has been deployed by Humboldt University and is called Berlin Roofnet [4]. Interesting research questions arise when “constellations of meshes” are formed, in which mesh networks under different administrative authorities become interconnected. For example, integration of disparate mesh routing protocols with possibly different routing metrics is still an open issue. Specification of policies and their respective effect on inter-mesh routing, as well as mesh gateway functions have not been investigated either. Additionally, management of a large-scale mesh infrastructure is a challenging task and practical experience can prove invaluable. The importance of tackling such challenges has also been recognized by the recent proposal for Global Environment for Network Innovations [3] and its recommendations for an experimental facility that will enable fundamental innovations in networking. It is a goal of Magnets to explore the aforementioned issues by interconnecting with these two other networks (Figure 2).

## III. Applications

A main advantage of Magnets is its deployment at and around the campus of the TU Berlin. Access to Magnets will be free for authenticated students at the TU Berlin. Thus, Magnets will form a semi-production environment where traffic will be generated by real users but no service guarantees are made. One goal for this deployment is to generate a wide range of application traffic with varying requirements.

Apart from the traditional bulk data traffic from and to servers outside the TUB, we expect a significant fraction of instant messaging and peer-to-peer traffic within the university. We will investigate self-organizing algorithms within the mesh and potentially across the different network technologies to

[2] E.g. RouterBoards, http://www.routerboard.com/rb500.html

[3] http://www.olsrexperiment.de

[4] http://sarwiki.informatik.hu-berlin.de/BerlinRoofNet

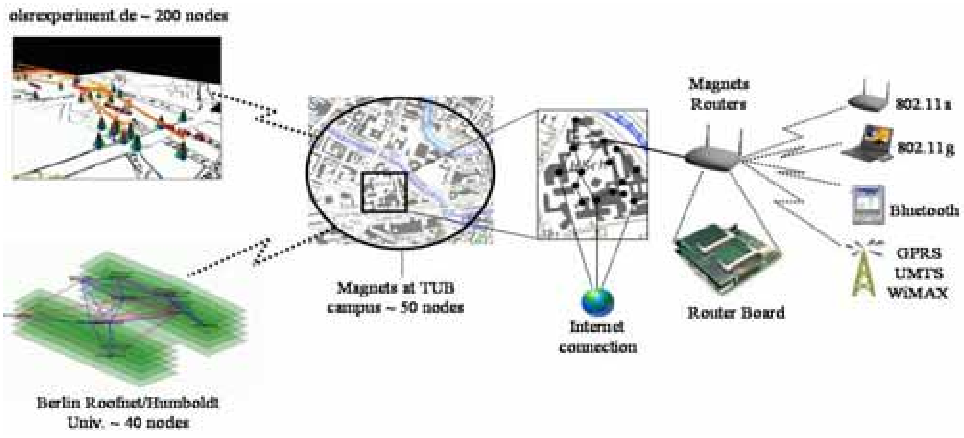


Fig. 2. Constellation of Meshes in Berlin

better utilize the resources. For example, traffic within the mesh does not have to be routed to the backbone.

Another area of investigation will be the suitability of Magnets mesh to support voice calls. We will provide SIP gateways for VoIP communication to the students, and are interested in assessing the ability of the mesh network to support Quality of Service for delay- and jitter-constrained applications. To this end, experimental evaluation of scheduling algorithms that have been proposed in the literature but have only been tested through simulations will also be performed. We are currently planning real-time streaming of video and the Campus radio to laptops. Since the traffic volume is expected to increase considerably, we will be able to measure the scalability and capacity aspects of Magnets.

## IV. Performance

| Link | Freq [GHz] | Chan-nel | Level [dBm] | TCP [Mbps] | UDP [Mbps] | RTT [ms] |
|---|---|---|---|---|---|---|
| 1 | 5 | DFS | -49/-49 | 26.3/24 | | 2/2 |
| 2 | 2.4 | 7 | -55/-55 | 13.6/13.7 | 12.6/7.7 | 3/3 |
| 3 | 2.4 | 1 | -58/-57 | 12.3/12.3 | 15.3 | 21/21 |
| 4 | 2.4 | 13 | -56/-56 | 15.5/16 | 15.7/13.3 | 3/3 |
| 5 | 2.4 | 13 | -80/-77 | 6.4/4 | 2.9/1.6 | 10/10 |
| 6 | 5 | DFS | -81/-81 | 5.2/1.7 | 8.7 | 150-200 |

TABLE I
Preliminary backbone performance results

Table I shows an overview of preliminary performance results from the backbone deployment. The first four columns denote the link (see Figure 1, the frequency and the assigned channel (5 GHz: Dynamic Frequency Selection). The remaining columns denote the measured level (dBm), the TCP throughput (Mbps), the UDP throughput with 1.5 kB packets (Mbps) and the RTT [ms] in each direction. Link 5 suffers severe performance drawbacks because of the distance but also due to frequent radar impulses (probably from the nearby airport) that force it into DFS. Links 2, 4 and 5 are asymmetric. Links 3 and 4 are parallel, but their TCP throughput differs by 3 Mbps. These results show an overall good performance, but also highlight many real-world influences that we will study in the following weeks.

## V. Research challenges and impact

Magnets will have a three-fold impact on research and industry. First, the deployment of the infrastructure is a challenge by itself. The objective to study various parameters of a distributed system in a large scale requires a careful planning. Even though the final deployment will be specific due to the TUB topology, we will leverage our experience to derive conceptual deployment strategies for future research testbeds as well as telecom operators.

Second, on top of the infrastructure, protocols at multiple layers can be deployed, tested and their benefit can be assessed in a semi-production environment. The wide variety of mesh node configuration and deployment will offer ample opportunities to study protocol behavior. Of particular interest will be the opportunity to study the interaction of multiple access technologies - GPRS, UMTS, WiFi and WiMAX - in parallel, contributing to the realization of the 4G vision.

Third, the open router platform provides the flexibility to deploy and experiment with future Internet architectures. In the wake of a clean-slate Internet design (GENI) it is important to deploy novel approaches. Thus Magnets will provide the opportunity to gain experiences beyond theory, simulations and lab experiments. Finally, Magnets, a project of the Deutsche Telekom Laboratories, is not only based on open standards, but explicitly encourages collaboration with other research institutions worldwide.

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