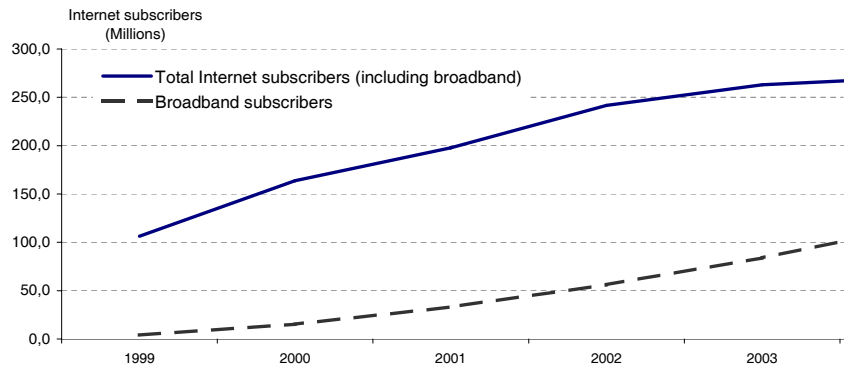
Chapter 1

Introduction

In the last 10 years, the Internet has developed to be the most used source of information in developed countries. Through the use of services like email, world wide web, multimedia streaming, or peer-to-peer filesharing, the amount of data communication exceeds voice communication in terms of data volume by several factors. The evolution of the private Internet access lines is at least partly responsible for this development. While there were only 1.6 broadband Internet access subscriptions with data rates exceeding 1Mbit/s per 100 inhabitants within the EU in 2001 and the majority of users connected via a dial-up connection with data rates below 56kbit/s, the number of broadband subscriptions has increased to 14.2 per 100 inhabitants in 2005 [OEC06]. Fig. 1.1 shows the development of worldwide Internet access in terms of subscriptions and broadband-subscriptions.

At the same time, mobile voice communication has spread throughout the world. In some countries, the number of mobile phone contracts is higher than the total population, and the total number of mobile phones has reached 2 billion



Source: OECD Key ICT Indicators [www.oecd.org/sti/ICTindicators]

Figure 1.1: Development of the total number of Internet subscribers worldwide from 1999-2004 [OEC05].

worldwide [BIT06]. This trend towards wireless communication is also visible in data communication. The predominant cellular wireless network, GSM, only offers small data rates which are not satisfying customers who are used to high bandwidth Internet access. The currently being rolled out UMTS already offers data rates comparable to those provided by digital subscriber lines (DSL), although at high costs and not at every location.

Even higher data rates are offered by technology based on the wireless LAN standard IEEE 802.11. The first widely available version, IEEE 802.11b, already provided data rates as high as 11 Mbit/s which is two orders of magnitude faster than available GPRS data rates and still about 10 times faster than typical UMTS data rates. The most recent version IEEE 802.11n now delivers data with a maximum transmission rate of 300 Mbit/s. However, devices using this standard provide connectivity only in a small area around them and do not offer ubiquitous coverage as cellular networks do. In consequence, these access points have been used mostly indoors, in offices, at home, or in public hotspots. Recently, wireless LAN has been suggested as the communication technology for all kinds of networks. It is even being distributed on a city-wide scale to offer Internet access, e.g., everywhere in Philadelphia [WPh07].

With the increasing use of wireless LAN access points which are connected to the Internet by faster and faster DSLs, it becomes interesting to use the locally available high bandwidth for intermittent Internet access. As current research shows, this is even possible for fast moving vehicles [OK04a, OK04b]. In contrast to the use of cellular high bandwidth networks, the use of these hotspot networks is very cheap. The cost of installation consists of the price for necessary hardware and a sufficiently fast connection to the Internet. No additional licensing cost for frequency spectrum or maintenance of a dedicated network is necessary as wireless LAN uses a common, freely available frequency spectrum, and the Internet connection is usually maintained by a separate entity.

An alternative to accessing a wireless access point directly is to use other wireless equipped terminals as relays in order to access the Internet via multiple hops. This multi-hop ad hoc networking has been the focus of a large research community for several years. Proposals have been made addressing a large diversity of networking issues such as routing, scheduling, security, or energy conservation. One advantage of this approach is the increased area of coverage achieved with the same amount of infrastructure.

In order to analyze these ad hoc access networks and determine their performance, it is necessary to model the wireless network as well as the user behavior and especially the user movement. The reasons why simulation of ad hoc access networks is preferable to measurement are quite obvious. For most proposed applications, there are simply no networks with which measurements

could be undertaken. For those which are available, the cost associated with measuring the large variety of inter-dependence of users and network are prohibitive. Before such measurements can even be planned, simulations have to be carried out to identify the critical situations which then might be measured in a later stage of the design process. Modeling and simulation of networks is also used in the analysis of fixed networks. The main discriminating facts between these two are the constant change of network topology and network load distribution as a result of user movement. Therefore, the modeling of user mobility evidently plays an important role in the evaluation of wireless ad hoc access networks.

The mobility modeling and its influence on the performance of wireless ad hoc Internet access is the scope of this dissertation. Although the investigation is focused on these special networks, the mobility models that are presented in this thesis are not limited to the simulation of ad hoc networks but can be used for all purposes requiring the simulation of user movement.

Chapter 2 specifies the ad hoc access networks which are investigated in this thesis and further emphasizes the importance of mobility modeling in the evaluation of these. Basic requirements for mobility models in wireless network simulations are described, and a survey of available mobility models as well as an attempt of a categorization are presented.

One of the most important properties of network simulations is stationarity. Only in a steady state, meaningful performance metrics can be obtained. Chapter 3 contains the description of a simple mobility model and its parameterization to achieve a desired user distribution, which is identified as a major influence on the performance of the investigated networks.

The following Chapter 4 is concerned with a more realistic modeling of user mobility. First, two basic, frequently used mobility models are defined. Afterwards, street maps are used to restrict the movement of vehicles in urban scenarios. Two different methods of generating movement traces, derived from the two basic models, are studied in a network simulation of isolated wireless LAN hotspots. The user distributions of these models are evaluated and methods to influence them are presented.

In Chapter 5, the metrics of mobility models which influence the performance of ad hoc Internet access are identified and evaluated for the models introduced in Chapter 4. The use of street-based mobility models for the modeling of vehicular movement is justified by a comparison with basic models. An application of the methods to influence the user distribution proves the importance of this property of mobility models in wireless network simulations.

The necessary degree of detail used in modeling of mobility to achieve realistic results is the focus of Chapter 6. The previously introduced street-based mobil-

ity models are refined with additional detail. Afterwards, the effect this has on simulations of different ad hoc access networks is analyzed. The thesis is ended in Chapter 7 where final conclusions are drawn.

Large parts of the material presented in this thesis are based on previous publications. Especially, Chapter 3 is based on [KK04], Chapter 4 on [KK05, KK06, KK07a], and Chapter 5 on [KK07c]. The article [KK07b], the basis for Chapter 6, is currently under review. At the same time, unpublished and unsubmitted material is presented throughout this thesis.