# 10403 Abstracts Collection
# Impact of Human Mobility on Communications : Measurement, Analysis, Modeling, and Simulation
## — Dagstuhl Seminar —

Kevin Almeroth[1], Gunnar Karlsson[2], Cecilia Mascolo[3] and Jörg Ott[4]

[1] Univ. California - Santa Barbara, US
[2] KTH - Stockholm, SE
gk@ee.kth.se
[3] University of Cambridge, GB
cecilia.mascolo@cl.cam.ac.uk
[4] Helsinki University of Technology, FI
jo@acm.org

**Abstract.** From 06.10.2010 to 09.10.2010, the Dagstuhl Seminar 10403 "Impact of Human Mobility on Communications : Measurement, Analysis, Modeling, and Simulation" was held in Schloss Dagstuhl – Leibniz Center for Informatics. During the seminar, several participants presented their current research, and ongoing work and open problems were discussed. Abstracts of the presentations given during the seminar as well as abstracts of seminar results and ideas are put together in this paper. The first section describes the seminar topics and goals in general. Links to extended abstracts or full papers are provided, if available.

**Keywords.** Human Mobility, Vehicular Mobility, Social Interactions, Mobile Networking

## 10403 Summary – Impact of Human Mobility on Communications : Measurement, Analysis, Modeling, and Simulation

Human mobility can be classified using three levels: strategic, tactical and operational mobility. At the strategic level humans decide their daily movement patterns and activities, such as go to work or to walk in the park. The tactical level considers the implementation of a strategic decision, such as choosing a way of travel. At the operational level, human movement is considered, including speed, physical size of nodes and interaction with others due to queuing or for avoiding collisions.

Capturing mobility in all its facets is crucial to the evaluation of mobile communication systems since it affects the quality and availability of a radio

channel. There are two trends that motivate a closer look at mobility. First, the spatial dimensions of cellular wireless communication systems are shrinking with their evolution to enable spatial reuse of spectral bands and higher data rates per node. The second trend is the interest in self-organizing ad hoc networks, as connected multi-hop networks or sparse intermittently connected delay-tolerant networks. When cell sizes shrink and multi-hop ad hoc communication becomes more prevalent, it is apparent that mobility is not only affecting the radio channel but is also causing churn in mobile networks and intermittency.

The performance of wireless communication systems is likely to be affected in a different way by each level of mobility. Decisions at the strategic and tactical levels determine the regularity and routines in movement which in turn affect how and when nodes interact with each other or with infrastructure. Some routing protocols for delay-tolerant networks try to take advantage of such non-randomness to route messages to a destination node. Mobility at the operational level presumably affects node connectivity and individual contact durations. This determines the amount of data that can be transferred per contact. Predictability and repeatability are thus two important aspects of movement patterns.

The mobility used in performance evaluation is synthetic and has several shortcomings including: 1) Migration of people in and out of a modeled area is missing; 2) There are few models that consider obstacles; 3) Periodicity and predictable patterns are not captured; and 4) User behavior, social relationships, and community structure is absent. Recently, there has been interest in measuring mobility, albeit in small and controlled groups (e.g., participants at a conference, or a sample of students on a campus). The measurement results allow for realism but are difficult to generalize from the often small scale and infrequent measurements.

This seminar highlighted human mobility and its connection to communication processes. We considered a wide variety of mobility types and will discussed means to capture mobility on the strategic, tactical and operational levels. In addition to radio communication, we discussed the traffic patterns from mobile nodes and potential correlation between mobility and communication patterns with respect to the three levels. The seminar brought together researchers who take different approaches to mobility and pursue different methodologies: from measurements and analyses in social sciences to mobility modeling and simulations for understanding the impact of mobility on communication protocols and systems.

## Mobile Data Offloading: How Much Can WiFi Deliver?

*Song Chong (KAIST - Daejeon, KR)*

This talk presents a quantitative study on the performance of 3G mobile data offloading through WiFi networks. We recruited about 100 iPhone users from metropolitan areas and collected statistics on their WiFi connectivity during about a two and half week period in February 2010. Our trace-driven simulation

using the acquired traces indicates that WiFi already offloads about 65% of the total mobile data traffic and saves 55% of battery power without using any delayed transmission. If data transfers can be delayed with some deadline until users enter a WiFi zone, substantial gains can be achieved only when the deadline is fairly larger than tens of minutes. With 100 second delays, the achievable gain is less than only 2-3%. But with 1 hour or longer deadline, traffic and energy saving gains increase beyond 29% and 20%, respectively. These results are in stark contrast to the substantial gain (20 to 33%) reported by the existing work even for 100 second delayed transmission using traces taken from transit buses or war-driving. The major performance difference comes from traces: while bus and war-driving traces contain much shorter connection and inter-connection times, our traces reflects the daily mobility patterns of average users more accurately.

*Keywords:*   3G, WiFi, DTN, Human Mobility, Mobile Data Offloading

*Joint work of:*   Chong, Song; Lee, Kyunghan; Rhee, Injong; Lee, Joohyun; Yi, Yung

*Full Paper:*
http://portal.acm.org/citation.cfm?id=1851182.1851244&coll=portal

## Realistic Simulations Models for Inter-Vehicular Communication Protocols

*Falko Dressler (Universität Erlangen-Nürnberg, DE)*

We discuss the need for more sophisticated simulation techniques for evaluating Vehicular Ad Hoc Networks (VANETs) in a simulation framework. In the last decade, much progress can be observed in the domain of protocol engineering for Inter-Vehicle Communication (IVC). Usually, simulation models are used to evaluate the developed protocols. This approach has two major prerequisites: First, detailed network simulation of all layers of communication protocols is necessary as provided by a wide variety of tools by the networking community. Secondly, realistic simulation of vehicles' mobility, i.e. an exact modeling of road traffic, is needed to estimate positions and movements of involved components. In this talk, we briefly discuss the evolution of mobility modeling in VANET simulations. Furthermore, based on a case study using the simulation framework Veins, we investigate how recent advances in bidirectional coupling of road traffic microsimulation and network simulation lead to more realistic results at comparably low computational cost.

## Active Tracking in a Cellular Network Using a Modular Signaling Platform

*Michal Ficek (Czech Technical University, CZ)*

We introduce SS7Box modular signaling platform, a tool for rapid application prototyping in a cellular mobile network, and examine some of its use-cases, e.g., application of active network-based tracking, called SS7Tracker. This application is a highly configurable, non-intrusive and cost-effective solution for large-scale data collection on user mobility in the network, uniquely enabling tracking of both active and passive mobile clients. It is deployed in an existing cellular network. We conclude by observing promising applicability for future cellular networks.

*Joint work of:*    Ficek, Michal; Pop, Tomas; Vlacil, Petr; Dufkova, Katerina; Kencl, Lukas; Tomek, Martin

*Full Paper:*
http://portal.acm.org/citation.cfm?id=1814458

*See also:*   Ficek, M., Pop, T., Vlacil, P., Dufkova, K., Kencl, L., and Tomek, M. 2010. Performance study of active tracking in a cellular network using a modular signaling platform. In Proceedings of the 8th international Conference on Mobile Systems, Applications, and Services (San Francisco, California, USA, June 15 - 18, 2010). MobiSys '10. ACM, New York, NY, 239-254. DOI= http://doi.acm.org/10.1145/1814433.1814458


## Does Mobility Matter?

*Olafur Helgason (KTH - Stockholm, SE)*

In modern society, wireless devices are commonly carried by humans. The wireless communication is therefore affected by pedestrian mobility in urban outdoor and indoor spaces which is the scenario we consider in this work. Many of the mobility models currently used for evaluating wireless communication systems have poor resemblance to reality. Although advances have recently been made, there is still a lack of understanding on which elements of mobility affect system performance. In the civil-engineering field of transport and urban planning there exist advanced pedestrian mobility models, used for designing and dimensioning public spaces for pedestrian crowds and emergency evacuation. These models capture micro-mobility of pedestrians better than most mobility models used in mobile networking since the application domain requires that they realistically capture node interactions with its physical environment as well as other nodes. In this work we use Legion Studio, a commercial simulator, to explore which

elements of pedestrian mobility are important with respect to system performance and how sensitive the connectivity metrics of nodes are to input mobility parameters. These studies give insight into whether relatively simple mobility models suffice for evaluating wireless systems. Furthermore, they contribute to our understanding of which parameters are important for modelling mobility and the accuracy in which these parameters need to be estimated to give dependable results.

*Keywords:*    Mobility, Simulations

*Joint work of:*    Helgason, Olafur; Kouyoumdjieva, Sylvia; Karlsson, Gunnar

*Full Paper:*
 http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=5437138

## Mobility, Mobility, Mobility

*Franck Legendre (ETH Zürich, CH)*

In this talk we revisit important mobility parameters for wireless network performance analysis. The aim is to foster discussion among participants.

*Keywords:*    Mobility, performance analysis

## Mobility Modelling Research: The Past and the Future

*Mirco Musolesi (University of St Andrews, GB)*

The design of realistic mobility models is an essential aspect of the performance evaluation of mobile systems. Moreover, the ability of modelling and understanding human mobility has significant applications to many disciplines including social sciences, transportation and urban planning to name a few.

In this talk I will provide a general introduction to the past and current research efforts in the area of mobility modelling. I will discuss the classification of mobility models in two broad classes, synthetic and trace-based models. Then, I will discuss our contributions in the areas of social network founded mobility models and connectivity models. Finally, I will outline the challenges for the research community from both theoretical and practical point of views.

*Keywords:*    Mobility models, connectivity models, social network theory

## The Calendar as a Sensor: Analysis and Improvement Using Data Fusion with Social Networks and Location

*Eamonn O'Neill (University of Bath, GB)*

The shared online calendar is the de facto standard for event organisation and management in the modern office environment. It is also a potentially valuable source of context, provided the calendar event data represent an accurate account of 'real-world' events.

However, as we show through a field study, the calendar does not represent reality well as genuine events are hidden by a multitude of reminders and 'place-holders', i.e. events that appear in the calendar but do not occur. We show that the calendar's representation of real events can be significantly improved through data fusion with other sources of context, namely social network and location data. Finally, we discuss some of the issues raised during our field study, their significance and how performance could be farther improved.

*Keywords:*  Calendar, data fusion, meeting, event, context, context awareness, social network, contacts, location

*Joint work of:*  Lovett, Tom; ONeill, Eamonn; Irwin, J.; Pollington, D.

*Full Paper:*
 http://portal.acm.org/citation.cfm?id=1864349.1864352

*See also:*  Lovett, T., O'Neill, E., Irwin, J. and Pollington, D. (2010) The calendar as a sensor: analysis and improvement using data fusion with social networks and location, Proc Ubicomp 2010, 12th ACM international conference on Ubiquitous computing, pp.3-12, doi 10.1145/1864349.1864352.

## Human Mobility: Correlation among statistical features

*Injong Rhee (North Carolina State University, US)*

In this talk, I discuss the correlation among the statistical features of human mobility patterns. In particular, I focus on temporal and spatial characteristics of human mobility patterns.

*Keywords:*  Human mobility patterns, spatial and temporal patterns, levy walks, power-law flights, power-law inter contact times, self-similar waypoints, temporal lifetime of hotspots