# Mobility and Multiaccess in Emerging Internet Architectures

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## Abstract

*This tutorial thoroughly reviews recent developments in mobility and multiaccess technologies. After motivating the need for novel mechanisms to meet the challenges from the emerging network environment, we introduce the long-awaited Media Independent Handover Services standard (IEEE 802.21) and present a blueprint for its implementation in GNU/Linux. Finally, we introduce recent developments in the so-called clean-slate Internet architecture design space, presenting the new paradigms, and elaborating on their impact on mobility and multiaccess*

## 1. Introduction

Popular mobile devices now ship with several integrated wired and wireless network interfaces. PDAs and smartphones, for example, are increasingly supporting communications via both cellular technologies and wireless LANs; laptops typically come with built-in Ethernet, Wi-Fi and Bluetooth. As multiaccess devices proliferate, we move closer to a network environment that is often referred to as "beyond 3G", or B3G in telecommunications speak. Key success factors for cellular 3G communications include better cell capacities, increased data rates, seamless mobility within large geographical areas, and global reachability. For B3G, the next frontier lies beyond seamless mobile connections within the same access technology. Instead, users will soon expect to be globally reachable round the clock and "best-connected" as well. In order to select the best possible connectivity option (anytime, anywhere), mobile devices and access networks will have to work together, thus enabling users to make the most of all available options.

Given the mere diversity of networked applications running on mobile devices there is a call for knowledgeable network resource planning and operation. In other words, there is a need for a framework that allows users and their applications to state their network access preferences. This framework should also allow operators to steer terminal access patterns aiming at maximizing resource utilization and increasing user satisfaction. For instance, podcasts can be downloaded only when connected to an uncongested WLAN, but web, map/navigation, and email clients can use the cellular network or WLAN access on demand. Currently, this can only be done manually: users need to be on the lookout for available access networks and choose which one to attach to based on very rudimentary information such as signal quality. If mobile nodes could collect timely and consistent information about the state of all available networks in range, and were given the means to control their network connectivity, then a whole range of possibilities opens up.

In order to optimize the use of available network resources, mobile nodes need to be able to collect information on a number of heterogeneous networks in a generic and standardized way, irrespective of the underlying network access technology. The collected information, both dynamic and static, can then be utilized by handover decision making processes, such as, say, mobility managers. Mobility managers can be enhanced versions of Mobile IP, proprietary solutions, or other proposals stemming from research projects, such as [1]. Researchers in the area have proposed several cross-layer frameworks for enhancing the efficiency of handover decision makers, reviewed in the second part of this tutorial titled "Mobility and Multiaccess Foundations", but none of them has been formally standardized or is widely-accepted so far. What is needed is a standard framework, which can attract ample support from major vendors and operators, and can be deployed in an incremental manner. This framework, introduced in the third part of the tutorial, is IEEE 802.21.

## 2. Mobility and Multiaccess Foundations

Forthcoming wireless communications will be characterized by the ubiquity of multiaccess. Despite the inherently increased complexity, end-users should be able to take advantage of the most suitable access network. Thus, access selection in an environment with different overlapping radio technologies is of central interest and an architecture is needed that performs equally well on single- and multi-operator scenarios, considers several parameters, and respects the principle of layering. We introduce the Ambient Networks heterogeneous access selection architecture (ANHASA) [1] explaining how it meets such requirements. We present the essential architectural components and explain their interactions. We illustrate how the proposed architecture works in practice and discuss recent results form a prototype-based validation.

ANHASA, the result of a layer-respecting functional decomposition, comprises three modules, which address resource abstraction, resource management, and information sharing, respectively. First, the generic link layer (GLL) exposes a unified, abstract interface to all available radio accesses. Then, multiradio resource management (MRRM) uses GLL measurements and control facilities to direct access selection. Finally, trigger management (TRG) [2] collects and distributes multiaccess and mobility information relevant to the entire protocol stack, and registers it with ANISI, the Ambient Networks information service infrastructure [3].

Furthermore, the tutorial will also review proposals to cope with mobility and multiaccess challenges from the EU-funded projects AROMA, DAIDALOS, ENABLE, and HURRICANE.

## 3. IEEE 802.21: Specification

The IEEE 802.21 working group is finalizing a document that will define the first standard for dealing with handovers in heterogeneous networks, or Media Independent Handovers (MIH) [4, 5]. If implemented, IEEE 802.21 promises to enable mobile users (and operators) to take advantage of overlapping and diverse access networks by providing a framework for efficiently discovering networks in range and executing intelligent heterogeneous handovers, based on their respective capabilities and current link conditions. This tutorial aims to serve as a primer for the upcoming IEEE 802.21 standard. After introducing the IEEE 802.21 reference model, we present the MIH services and provide an illustrative use case that highlights the benefits from adopting the Media Independent Handovers standard in heterogeneous network.

IEEE 802.21 features an extensive set of properties to meet the requirements of effective heterogeneous handovers. It enables seamless service continuity during handovers by specifying mechanisms to gather information from various link types and deliver it to a handover decision maker. The collected information comprises timely and consistent notifications about changes in link conditions and the available access networks.

## 4. IEEE 802.21: Implementation

Unfortunately, there is currently no reference implementation of IEEE 802.21 and its deployment is anticipated to take place at the earliest in 2009-2010. In this tutorial, we present a blueprint for an IEEE 802.21 implementation[2, 6], explaining how link layer information can be collected in GNU/Linux systems, and demonstrating how IEEE 802.21 services can be used by upper layers to decide on handovers and steer traffic and application adaptation. For example, we show how a scalable video receiver can use IEEE 802.21 information to request a streaming rate adaptation and prepare for handovers in advance. The focus of this work is to develop methods for gathering information specified in IEEE 802.21 in a generic manner without driver modification or vendor support. We aim at a GNU/Linux implementation that uses distribution-dependent or native kernel properties as little as possible. To the best of our knowledge this is the first GNU/Linux IEEE 802.21 implementation presented in a tutorial. We expect that researchers and practitioners alike will benefit from the material presented.

## 5. Emerging Internet Architectures

The 4WARD project addresses the challenges of future networks by combining innovative networking concepts that go beyond the evolution of the contemporary Internet. The aim is to revolutionize in particular the current way of communication over wireless for mobile applications. In this part of the tutorial we will discuss how the role of mobility has been changing over time and how it now generates some of the major requirements for the network of the future. The new challenges ahead of us are centered on mobile access to networked information objects, and cannot be met by simply connecting and serving moving devices in a seamless way. The 4WARD vision of for the Future Internet anticipates diverse networking scenarios in the coming decades. Based on recently published work [7, 8] we will introduce the 4WARD research approach for making this vision a reality by meeting the challenges regarding mobility. We will present scenarios where the current host-centric approach to information storage and retrieval is ill-suited for and explain how a new networking paradigm emerges, by adopting the information-centric network architecture approach, which we call Network of Information (NetInf). NetInf capitalizes on a proposed identifier/locator split and allows users to create, distribute, and retrieve information using a common infrastructure without tying data to particular hosts.

Furthermore the tutorial will briefly look into mobility and multiaccess issues in other projects working on Future

Internet paradigms, including TRILOGY, PSIRP, and ICT SHOK.

## 6. Target Audience

Scientists and engineers; telecom researchers and practitioners; network managers, service developers, and R&D staff; postgraduate students. The participants will receive the set of slides as supporting material along with an extensive set of references for further study.

Tutorial Level: Intermediate.

Basic background in networking is highly recommended.

## 7. Presenter's Biography

Kostas Pentikousis, PhD, is a tenured Senior Research Scientist at VTT Technical Research Centre of Finland, in Oulu, Finland. He has been working in research and development positions since 1996 in both industry and academia. Dr. Pentikousis joined VTT in 2005 and has since been involved in several joint and contract research projects. He served as Task Leader for Ambient Networks Phase 2 (Task B.2 Mobile Connectivity) [9, 10], worked on system design, drove dissemination and played the leading role in organizing the First Ambient Networks Workshop on Mobility, Multiaccess, and Network Management (M2NM 2007). More recently. Dr. Pentikousis led VTT's effort in WEIRD [11, 12, 13] on system architecture, mobility and testbed measurements.

Kostas studied computer science at Aristotle University of Thessaloniki (BS 1996; summa cum laude) and Stony Brook University (MS 2000, PhD 2004). He has published more than 70 papers in several areas, including mobile computing, transport protocols, applications, network traffic measurements and analysis, and simulation and modeling. He has given several invited talks on networking topics at USC/ISI, NCSR Demokritos, DoCoMo EuroLabs, and University of Aveiro, to list a few. He presented tutorials at the Asia-Pacific Network Operations and Management Symposium (APNOMS 2005) in Okinawa, Japan and at the IEEE Symposium on Computers and Communications (ISCC 2006) in Aveiro, Portugal. He was an ERCIM Fellow in 2005 and is a member of ACM, IEEE, and TEK. Kostas serves on the TPC of various conferences and reviews papers for journals and conferences on a regular basis.

Dr. Pentikousis is currently involved in two large projects which define Future Internet architectures. In 4WARD [14] his effort is distributed between WP6 (Network of Information), in which he is leading VTT's effort, and WP2 (New Architecture Principles and Concepts). He is in particular interested in information-centric networking, especially as it pertains to multiaccess, energy consumption, and publish/subscribe paradigms. In the national Finnish project ICT SHOK "Future Internet" [15] he is working on dissemination networking.

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