Global Mobility Management for Next Generation Networks

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'One believes things because one has been conditioned to believe them.'
—Aldous Huxley, Brave New World

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ACRONYMS

3GPP 3rd Generation Partnership Project.
AAA Authentication, Authorization, Accounting.
ADDIP Dynamic Address Reconfiguration.
ALG Application Layer Gateway.
AN Access Node.
ANET Access Network.
AP Access Point.
AR Access Router.
ASP Application Service Provider.
BRAS Broadband Remote Access Server.
BS Base Stations.
BU Binding Update.
CBR Constant Bit Rate.
CCNx Content-centric Networking.
CMM Community-based Mobility Model.
CN Correspondent Node.
CoA Care-of-Address.
CP Customer Premises.
CRAWDAD Community Resource for Archiving Wireless Data at Dartmouth.
CS Content Store.
DAR Distributed Access Router.
DCF Dynamic Community Finding.
DHAAD Dynamic Home Agent Address Discovery.
DHCPv6 Dynamic Host Control Protocol version 6.
DMA Dynamic Mobility Anchoring.
DMM Distributed Mobility Management.
DTN Delay Tolerant Network.
EMA Exponential Moving Average.
EN Edge Node.

ER Edge Router.
FAMA Flat Access and Mobile Architecture.
FBSS Fast Base Station Switching.
FIB Forwarding Information Base.
FMIPv6 Fast Handover for IPv6.
FN Foreign Network.
GPRS General Packet Radio Service.
GSM Global System for Mobile Communications.
GTP GPRS Tunnelling Protocol.
HA Home Agent.
HA-C Home Agent Control.
HA-D Home Agent Data Plane.
HAGGLE An Innovative Paradigm for Autonomic Opportunistic Communication.
HARP Home Agent Redundancy Protocol.
HI Host Identification.
HIP Host Initiation Protocol.
HIT Host Identity Tag.
HLR Home Location Registering.
HMIPv6 Hierarchical Mobile IPv6.
HN Home Network.
HPLMN Home PLMN.
ICMP Internet Control Messaging Protocol.
ICN Information-centric Network.
IETF Internet Engineering Task Force.
IoT Internet of Things.
IPv4 Internet Protocol version 4.
IPv6 Internet Protocol version 6.
ISP Internet Service Provider.
LAI Location Area Identity.
LATP Least Action Trip Planning.
LMA Local Mobility Anchor.
MAG Mobile Access Gateway.
MAN Metropolitan Area Network.
MAP Mobility Anchor point.

MCF Mobile Coordination Function.
MIH Media Independent Handovers.
MIPv6 Mobile IPv6.
MN Mobile Node.
MP Micro-Provider.
Mps Meters per second.
NAP Network Access Provider.
NAT Network Address Translation.
NDN Named Data Networking.
NDP Neighbour Discovery Protocol.
NSP Network Service Provider.
OSN Online Social Network.
P-MIPv6-DMA Proxy Mobile IP with Distributed Mobility Anchors.
PDP Packet Data Protocol.
PIT Pending Interest Table.
PLMN Public Land Mobile Network.
PMIPv6 Proxy MIPv6.
QoE Quality of Experience.
QoS Quality of Service.
RCD Relation-based Community Detection.
RG Residential Gateway.
RNC Radio Network Controller.
RNP Regional Network Providers.
RTP Real-time Transport Protocol.
RV Rendez-Vous.
SA Social Attractiveness.
SCTP Stream Control Transmission Protocol.
SD-PMIPv6 Signal-driven Distributed PMIPv6.
SDN Software Defined Network.
SDR Software Defined Radio.
SHO Soft Handover.
SIMPS Interaction-based Mobility Model.
SIP Session Initiation Protocol.
SLAAC Stateless Address Autoconfiguration.
SLAW Self-similar Least Action Walk.

SP Service Provider.
TCP Transport Control Protocol.
TEA Tunnel Establishment Acknowledgement.
TER Tunnel Establishment Request.
TTH Time-to-Handover.
UCN User-centric Networks.
UDP User Datagram Protocol.
UE User Equipment.
UMTS Universal Mobile Telecommunications System.
UPN User-provided Networks.
URI Uniform Resource Identifier.
UWB Ultra-Wide Band.
VLAN Virtual Local Area Network.
VO Virtual Operator.
VoIP Voice over IP.
VPLMN Visited PLMN.
VPN Virtual Private Network.
Wi-Fi Wireless Fidelity.
WiMAX Worldwide Interoperability for Microwave Access.
WISP Wireless Internet Service Provider.

LIST OF DEFINITIONS

Anycast: A method used to communicate data between a source and multiple points in a network, all of which identified by the same identifier (e.g., IPv6 address). Via dynamic routing, only the nearest element identified by the anycast address is reachable.

Betweenness centrality: a measure of centrality in a graph. For every pair of vertices in a connected graph, there is at least one shortest path between the vertices, such that either the number of edges that the path passes through (for unweighted graphs) or the sum of the weights of the edges (for weighted graphs) is minimized. The betweenness centrality for each vertex corresponds to the number of shortest paths that cross the vertex.

Cluster: A group of nodes which may or may not exhibit interaction patterns.

Community: Groups of nodes which have an interaction level. From a real-world perspective, examples of communities are an affiliation; family.

Consumer: A system or entity that consumes a service.

Degree centrality: Often associated with the number of links (associations with other nodes) that a node has. The purest form of centrality.

End-to-end delay: Time in seconds that a data packet takes from a source until it reaches a destination.

End-user: A legal entity or individual using or requesting a publicly available electronic communications service for private or business purposes, without necessarily having subscribed to such service; "recipient of the service" [2000/31/EC Art.2.d] any natural or legal person who, for professional ends or otherwise, uses an information

society service, in particular for the purposes of seeking information or making it accessible.

Inter-contact time: The time between the instant when a wireless device enters the radio range of another device and the instant when the device leaves such a range, measured in seconds.

Interaction matrix: Adjacency matrix representing interaction levels between nodes.

Intermittent connectivity: Internet connectivity with gaps in time and space. This means that there may not be end-to-end connectivity between any pair of nodes at any moment in time.

Last-hop: The last network segment to the end-user.

Last-mile: The network segment between an access node and an end-user.

Neighbour: A node that is or has been in the radio reach of another node.

Network access: A region of a multi-access network managed by NAPs.

Network Services: A set of network functionality required to provide services to end-users. Examples of network services are AAA, resource management, mobility management.

Packet loss: The amount of packets lost in a transmission, in comparison to the packets sent, due to computational processing errors, or to network congestion. Packet loss occurs when one or more packets sent, fail to reach the intended destination.

Preferred location: In wireless or cellular environments, a preferred location corresponds to a preferred network, i.e., a wireless network where a device attaches more frequently, than other wireless networks that the device visits.

Prosumer: A system or entity that is, at the same time, a producer and a consumer of services.

Reachability time: Concerns the handover process and corresponds to the time interval that starts at the instant after a mobile node obtains an identifier, e.g., an IP address, and ends when the mobile node is ready, from a network perspective, to handle data packets.

Reconfiguration interval: Time interval specified by users as input to a social mobility model, to allow for repetition. Such an interval is often based on a personal schedule, e.g., 8 hours.

Trajectory duration: The time in seconds that a device takes from starting to move, until it reaches its target location/destination.

Waypoint: A stopping place on a path or route.

LIST OF SYMBOLS

Sign	Description	Unit
L_i	Trajectory duration	Seconds
Δt	Time since the last handover	Seconds
α	Threshold value	-
davg	Average duration	Seconds
dr	Data Rate	Bytes per second
d	Duration	Seconds
n	Node degree	-
q	Signal quality/strength level	dBM
rej	Number of rejected visits to a network	-
si	Social interaction weight. Link cost	-

1. INTRODUCTION

Handling mobility management on the Internet is not trivial, given the heterogeneity of the devices involved; providers involved; and service requirements. The Internet evolution requires re-thinking on mobility management and re-thinking on how best to distribute functionality across the network.

The contributions of this book to research in the field concern the evolutionary design of mobility management architectures and protocols and debate on approaches such as mobility estimation or decoupling mobility management functions. The book starts with today's centralised approaches, going over the evolution towards the de-centralization and distribution of mobility management, and finishes with an explanation on information-centric support. In comparison with state-of-the-art work on mobility management, the book introduces concepts and examples that help to re-think mobility management in a way that is better suited for an Internet of the future.

The book is, therefore, envisioned to assist in developing critical thinking to back up novel functions and networking services. For that purpose, the book debates solutions which are focused on a "better" distribution of mobility management functions, including better approaches to split mobility management functions.

The key findings of this book are four-fold. Firstly, it introduces a debate on mobility management functions, based on different solutions for the TCP/IP stack. Secondly, it introduces a fresh look into decoupling mobility management functions; thirdly, it brings awareness to the need to introduce mobility estimation as an essential function of global mobility management. Fourthly, it addresses mobility management from the perspective of an information and service-centric Internet.

1.1. Goals

The chapters explore both existing solutions; new ways to investigate mobility management; and directions and challenges for the future, having in mind the evolution of next-generation networks towards content-centric infrastructures. The main goals, from an audience perspective, are:

- To learn about the evolution of mobility management approaches, the reasons for their architectural design, and the challenges to overcome.
- To better understand the functional aspects of mobility management, as well as the supported tasks; how to assist their evolution; and the implications that arise from an operational perspective.
- To understand the role of mobility anticipation functions and how estimation techniques can assist mobility management for different environments, e.g., cellular, wireless environments.
- To acquire knowledge about the functional aspects of mobility management solutions and, therefore, to understand how such functions can be placed and supported via new approaches, such as mobile edge computing.
- Globally, to become acquainted with one of the most relevant networking functions that the Internet requires today and for the future.

1.2. Structure

The book is based on a modular format with six distinct chapters. Chapter 1 introduces the motivation and structure. Chapter 2 covers mobility management notions and principles, including supporting tasks and methods, as well as functional blocks. Chapter 3 presents today's main mobility management architectures. Chapter 4 debates how and why to distribute mobility management functionality end-to-end. Chapter 5 describes the new fields of mobility modelling and mobility estimation/anticipation, be it from a temporal perspective (time to handover) or a location management perspective (target to handover). Chapter 6 focuses on information-centric mobility management aspects. Each chapter ends with an analysis of related work followed by a summary. Chapters can, therefore, be handled as

modules, for which the full content is as follows:

• **Chapter 2, The Quest for Global Mobility Management.** This module covers notions concerning mobility management, namely, what is mobility management; basic notions; roles, functions, and tasks supported. The aim is to provide a theoretical and operational perspective for network management as a network service. It comprises the following sections:

- Basic Notions of Multi-access Networks. These comprise fundaments to assist the reader in understanding the complex structure behind access networks and the limitations that mobility management solutions face.
- Personal, Device, Session, Service Mobility. These provide an understanding of different definitions of mobility.
- Supported Tasks: Multihoming, Location and Handover Management. These concern the different processes handled in mobility management.
- Mobility Management Functional Entities. These debate functional concepts, such as the concept of mobile node, correspondent node, and mobility anchor points.
- Related Work. This provides pointers for related work, so that readers can deepen their knowledge on mobility management.
- Summary.

• **Chapter 3, Mobility Management Approaches**. This chapter covers mobility management approaches that are available today in multi-access, heterogeneous networks. The module provides examples of different TCP/IP stack layers. The motivation is to explain that mobility management is feasible in different layers, and which implications arise from relying on a specific solution. The module is also intended to assist in understanding the limitations that current solutions face if applied in the context of next-generation networks. The content provided is as follows:

- Link Layer Management. This provides an example of how mobility management is handled at the link layer, for cellular networks (2G and 3G) and WiMAX.
- Network Layer Management. This addresses the most popular-based mobility management solutions, namely, Mobile IPv6 and relevant extensions.

- A bump-in-the-stack: HIP. This debates the Host Initiation Protocol support for mobility management.
- Application Layer: SIP. This provides details on the Session Initiation Protocol support for mobility management.
- Transport Layer Management: SCTP and M-SCTP. These debate the solutions that support mobility management on the transport layer.
- Related Work.
- Summary.

• **Chapter 4, From Centralised to Distributed Mobility Management**. This chapter covers different attempts to further evolve mobility management into a Decentralised operation, "closer" to the end-user. The module explains the requirements of emerging network architectures and provides a logical analysis as to how mobility management functions can be decoupled, and the trade-off associated with such design choices. The chapter provides the following content:

- Requirements of emerging network architectures. These explain and exemplifiy new types of network architectures that are emerging due to wireless and cellular advancements, as well as due to user empowerment in the context of Internet access and services.
- User-centric Networking Notions. These explain the notion of user-centricity from a network architectural perspective.
- Defining Mobility Management: A Characterization. This provides a functional debate on mobility management, based on the emerging types of network architectures and their requirements.
- Moving Towards Decentralisation, an Example of Functional Splitting. This explains how mobility management can evolve to support decentralisation of services, based on a specific example of data and control plane splitting.
- Distributing Mobility Anchor Points. This debates the need to handle a better placement and distribution of mobility anchor points, explaining which solutions are available today.
- Automatic Detection of Mobility Anchor Points. This debates solutions to assist the automatic detection of mobility anchor points, a relevant aspect to take into consideration in scenarios with high mobility, as occurring today on the Internet.

- Related Work.
- Summary.

• **Chapter 5, Mobility Modelling and Anticipation**. This module introduces mobility modelling, concerning mobility models that relate to human interaction (social mobility modelling). It also covers mobility anticipation as an essential mobility management function and provides an operational example of how mobility anticipation can be useful, from a user and network perspective. The content of this chapter covers the following aspects:

- Background on mobility modelling and anticipation. This provides fundaments concerning mobility modelling and mobility models; anticipation techniques; applicability environments.
- A Primer on Developing Social Mobility Models. This explains different social mobility models, which are relevant in the context of the Internet and services to nomadic users and provides guidelines to assist the development of more realistic mobility models, and more realistic mobility anticipation engines.
- Mobility Anticipation. This provides notions concerning mobility anticipation techniques and explains how such anticipation can be provided based on both active and passive measurement.
- Related Work.
- Summary.

• **Chapter 6, Moving Towards Content-centric Mobility Management**. This module deals with the next steps towards global mobility management, namely, analysing mobility management support from an information-centric perspective, instead of from a host reachability perspective. It is organized as follows:

- Background on Information-centric networking. This provides fundaments on information-centric networking paradigms.
- ICN Architectural Advantages for Mobility. These highlight the ICN architectural advantages to support mobility management.
- Mobility Management in ICN Paradigms. This explains how the different mobility management processes are handled via different information-centric networking solutions; how multihoming, consumer and producer mobility is supported.

- Guidelines. These are proposed to develop mobility models that are information-centric, keeping design properties that allow the automatic and seamless support of service decentralisation and user as well as terminal mobility.
- Related Work.
- Summary.

2. THE QUEST FOR GLOBAL MOBILITY MANAGEMENT

Internet services and models have been going through a paradigm shift, a product of three main factors: i) widespread wireless technologies; ii) an increasing variety of user-friendly and multimedia-enabled terminals; and iii) the availability of open-source tools for content generation. Together, these three factors are changing the way that Internet services are delivered and consumed. Currently, the Internet end-user also has a specific role in providing content as well as connectivity, similar to occurrences in energy grids.

Today, the Internet is a complex system where heterogeneous wireless networks complement cellular and fixed environments. Different network architectures and protocols co-exist to provide multiple services to end-users who have a highly nomadic lifestyle.

Moreover, such end-users often hold more than one subscription, e.g., at least one cellular and one fixed access subscription. Moreover, the end-user relies on several interconnected objects. "Smart" environments, with people-to-thing and thing-to-people communication, bring in new requirements. For instance, these new environments require supporting new data processing paradigms, stream processing, filtering, aggregation, and data mining. Often, interconnected devices in these situations are resource constrained. Low power consumption is a firm requirement. Energy is wasted each time data are transmitted, due to the protocol overhead, and non-optimized communication patterns. There is an increasing demand for different *Network Services*, from low data-rate non-real time to high-speed real-time applications, in different environments, over an increasing set of heterogeneous multimedia devices.

Therefore, future Internet architectures need to integrate properties that allow a nomadic end-user experience for any application across multi-access or single-access networks, if one or more operators are involved. Hence, *global mobility management*, which historically started

as a differentiating service, has become one of the most relevant networking functions to be supported on the Internet. Still, handling mobility management on the Internet is not trivial, due to the heterogeneity of devices involved; providers involved; and service requirements, as illustrated in Figure 2-1.

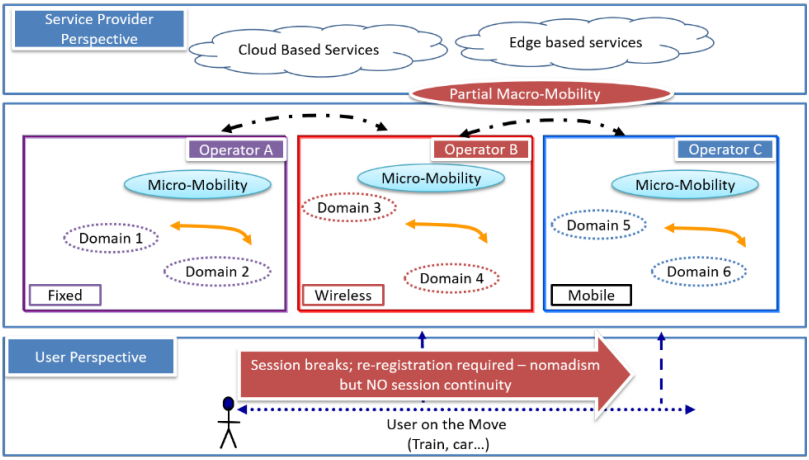

Figure 2-1: The Internet is multi-access and heterogeneous. While on the move, the user experiences service disruption

Currently, the most popular solutions for global mobility management have in common a model where a centralised and static mobility anchor point is in charge of controlling associations between previous and current identities for a mobile node that roams across different networks. While such a model subsisted in supporting communications well, today it is not compatible with the variable nomadic lifestyle of Internet users.

With technological advances such as virtualization, there are the means to better support mobility management, in a way that best suits end-user provided services and network requirements. The ultimate purpose is to support services with the least disruption possible, across multi-access networks, as illustrated in Figure 2-2.

To further evolve mobility management architectures in a way that allows them to become interoperable, and to be service-centric, there is the need to address mobility management logical functions, and to