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Architecture and Design for the Future Internet

4WARD Project

Foreword by Joao Schwarz da Silva

Springer

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Foreword

The development of computing and resource sharing as we have known them until recently is about to radically change course as its center of gravity is shifting with technologies, service architectures allowing for applications to migrate to the cloud. This shift from Web 2.0 to Web 3.0 will give rise to an Internet of services of unprecedented scope and scale. We are now entering a new phase of ICT driven innovation and growth based on the Internet of Services which more and more will be accessible through what could be called the Mobile and Wireless Web. Already today applications of wireless technology are a major driver of economic value in the EU economy. These are estimated at 250 bn€ or 2–3% of GDP and rising. In the coming five years it is expected that close to 7 billion users or the entire planet's population will have use of a mobile handset of which a great majority will be devices classified as smart-phones.

This is an unprecedented development exceeding the diffusion rates of technologies such as television or even pen and paper not only in terms of penetration and use but in its speed of take-up. We should expect an explosion of new applications with the potential to radically change the way in which we live and work. Examples are easy to cite: industrial and commercial applications in the supply chain, nomadic services for mobile workers, remote environmental monitoring or disaster and security systems that save lives by putting essential information into the hands of first responders, health and education services.

In such a remodelled world, new alliances will be created, new stakeholders will emerge, new modes of interaction will filter through into business practices, and new business models will proliferate. The Internet itself will no longer be a network of networks simply connecting computers and servers to become an Internet that connects "things" together: communicating devices by the billions, cars, machines of all sorts, household appliances, energy meters, windows, lights, etc. Around this new Internet will be borne a new economy of web based services and applications.

There are two key implications of this new Internet. First, this new world wide web of "things that think" will create a sensory network that will allow a leap forward in the human knowledge about the world we live in. It will lend itself to all sorts of new applications such as energy efficiency, health and welfare services, efficient transport and so on. If we do this well, there will be a massive improvement in our quality of life and sustainability, not just because of the services, not just because of the competitive advantage of being an earlier mover, but because European values of openness and democracy will define the form that the Internet takes.

Second we must liberate the economic potential of the single European market that is still locked up in fragmented national markets. In particular we must now strengthen the real economy by stimulating solid and sustainable business growth in high value goods and services that respond to real market needs. From the current period of uncertainty and as inevitable structural changes emerge it is essential to look for the growth opportunities in tomorrow's world. The industrial and research community gathered around the Future Internet Assembly, has certainly the talent and the capability to shape the future. All it takes is the ambition to overcome fragmented markets and the will to build on our strengths by creating open single markets for innovative goods and services and by going for innovation and change.

In creating the conditions that will allow Europe to benefit from the emerging economic opportunities, we must make sure that the Future Internet remains open. The key economic characteristic of the current Internet has been that it has created an unprecedentedly open platform for innovation and development of new services. We must keep this characteristic of openness by ensuring that open standards and eventually open-source software are the core of our actions. While the financial health of many companies worldwide is still based on proprietary models and gatekeeper business models, the world ahead of us will call for models whose economic basis offers a greater degree of liberty to the consumer or the enterprise.

As the Future Internet unfolds before us, the need will arise to move toward smarter and greener infrastructures. This is a big challenge, but also a great opportunity, because it will amplify the reach of the Internet to novel usages and industrial sectors. Indeed time has now come to go one step beyond what has been achieved so far. We must closely couple our Future Internet technology research and development with applications of high societal value such as health, urban mobility, energy grids or smart cities. In doing so, we will be able to provide an early "Internet response" to the many societal challenges with which we are confronted today.

Multiple regional initiatives are currently emerging in view of defining the future Internet. Japan and Korea have made public their ambitious u-Japan and u-Korea initiatives, China is supporting the domain through an ambitious and integrated industrial policy, in the US the GENI programme and facility is a key contributor to the debate on the future of the Internet. These initiatives are not all tackling the issue of the Internet evolution as part of their core objectives, but are certainly related to technological and socio-economic scenarios (ubiquity, connected devices) that will clearly need to be taken into account when addressing the Internet of Tomorrow.

From an EU perspective, it would be beneficial to build on these various initiatives and create the conditions that would bring about a closer complementarity and cooperation between all actors associated to the definition, testing and validation work. One of the main objectives of multilateral partnerships should be the emergence of global standards. Standards are indeed a key element to achieve interoperability and openness, two of the essential Internet characteristics that have contributed to its success. Indeed the ever growing multiplicity of players as well as the convergence of different sectors has lead to increased complexities in the standards making processes as illustrated by debates on IPR portfolios, as well as on the degree of openness, transparency and access.

Early co-operation and international partnerships on novel technologies are hence key to facilitate broader consensus, early agreements on standards by the key players while holding the promise to alleviate subsequent IPR disputes.

An important point to note is that the new economy created by the Internet is producing beyond a business revolution a unique opportunity to generate enormous environmental benefits, particularly if the right technological choices are made at the level of the infrastructure. In addition by reducing the amount of energy and materials consumed by business and by increasing overall productivity, the new Internet holds the promise to revolutionize the relation between economic growth and the environment.

It is in the above context that I have the pleasure to share with you my satisfaction as to the achievements of the EU R&D Project 4WARD. The book you are about to read, details the many unique contributions of the project to the development of a solid scientific basis for the Future Internet. Key amongst its many contributions are those relating to a new architecture framework where mobility, multi-homing and security become an intrinsic part of the network architecture rather than add-on solutions, hence allowing networks to bloom as a family of interoperable networks each complementing each other and each addressing individual requirements such as mobility, QoS, security, resilience, wireless transport and energy-awareness. 4WARD also addressed particularly well the question as to how virtualization can provide an opportunity to roll out new architectures, protocols, and services with network service providers sharing a common physical infrastructure. Tightly coupled to virtualization is network management, where 4WARD has broken new territory by advocating an approach where management functions come as embedded capabilities of devices. 4WARD has gone further than others by recognizing the paradigm shift brought about by the move from a node-centric age to an information-centric age.

The partners and scientific staff of 4WARD are to be congratulated for the work performed and for providing a perfect illustration of how Europe's commitment and creativity will enable the future.

Dr. Joao Schwarz da Silva
Former Director of DG-INFSO, European Commission

Preface

The current Internet is a tremendous commercial success and has become widely spread after having started as an academic research network to become a network for the everyday life for ordinary people. The Internet of today has its origins from the 70-ties, and was essentially simple but open for new applications and designed for the fixed network. It is however been increasingly challenged by the new transmission technologies based on radio and fiber, as well as by the new applications and media types that increasingly rely on overlays to make up for shortages in the core Internet architecture. In particularly, the even greater success of mobile networks has questioned the current Internet, which has reached a state of high complexity with regard to support of mobility, interoperability, configuration and management and vulnerability in an untrustworthy world.

The project 4WARD, started January 2008 and completed by June 2010, had the task to research on Architecture and Design for a Future Internet. The project took a clean slate research approach, which means that in its research it was not constrained by the current Internet. It does not mean however that the project favored a clean slate deployment, but rather saw a migration approach in how to apply its research results into the current Internet.

The project was partly EU funded under the EU Framework Programme 7 and consists of the 33 partners (see Appendix). There have been over 120 persons in the project, and for this reason it is not possible to list all that have contributed to the project and results. We would however like to acknowledge all for their valuable contributions. Further to that, we would like to acknowledge the help and support the project has experienced by the project officer Dr. Paulo de Sousa and the good collaboration we have had. The work of Daniel Sebastiao (IST, Lisbon) in the editing work is also acknowledged.

This book describes the salient results out of this project and covers not only technical results but deals also with socio-economic issues.

The Editors

Disclaimer

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List of Acronyms

3G	Third Generation
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
AAA	Administration, Authorization, and Authentication
ACK	Acknowledgment
AdHC	Ad-Hoc Communities
AHDR	Ad-Hoc Disaster Recovery
AM	Anchorless Mobility
AN	Access Node
AODV	Ad-Hoc On-Demand Vector
AP	Access Point
API	Application Programming Interface
ARP	Address Resolution Protocol
ARQ	Automatic Repeat Request
AS	Autonomous System
ASN	Autonomous System Number
BE	Best Effort
BER	Bit Error Rate
BEREC	Body of European Regulators
BFD	Bidirectional Forwarding Detection
BGP	Border Gateway Protocol
BIOS	Basic Input/Output System
BLER	Block Error Rate
BO	Bit-level Objects
BU	Binding Update
CA	Channel Assignment
CAIDA	Cooperative Association for Internet Data Analysis
CAPEX	Capital Expenditure
CBA	Component Based Architecture
CBR	Constant Bit Rate
CBSE	Component Based Software Engineering

CCFW	Cooperation and Coding Framework
CCN	Content Centric Networks
CEP	Connected End Points
CF	Cooperation/Coding Facility
CFL	CF Layer
CLQ	Cross-Layer QoS
CMT	Concurrent Multipath Transfer
CN	Correspondent Node
Co-AD	Content Adaptation
CPU	Central Processing Unit
CRC	Cyclic Redundancy Check
CSMA	Carrier Sense Multiple Access
CSMA/CD	Carrier Sense Multiple Access/Collision Detection
CT	Compartment
CTR	Compartment Record
DA	Deviation Advertisement
DBA	Dynamic Bandwidth Allocation
DCF	Dispersion Compensating Fiber
DDOS	Distributed Denial of Service
DF	Digital Fountain
DGE	Dynamic Gain Equalizers
DHCP	Dynamic Host Configuration Protocol
DHT	Distributed Hash Table
DIF	Distributed IP Facility
DL	Downlink
DMA	Dynamic Mobility Anchoring
DMV2	Data-Multimedia-Voice-Video
DNC	Deterministic Network Coding
DNS	Domain Name System
DONA	Data Oriented Network Architecture
DOS	Denial of Service
DSL	Domain Specific Language, or Digital Subscriber Line
DTN	Delay/Disruption Tolerant Network
E2E	End-to-End
EC	European Commission
ECN	Explicit Congestion Notification
EFCP	Error and Flow Control Protocol
EGP	Exterior Gateway Protocol
EMT	Emergency Medical Team
EP	End Point
EPON	Ethernet Passive Optical Network
ERC	Emergency Response Command
ERG	European Regulators Group
ETT	Expected Transmission Time
ETX	Expected Transmission Count

FARA	Forward Directive, Association, and Rendezvous Architecture
FB	Functional Block
FCAPS	Fault, Configuration, Accounting, Performance, and Security
FDP	Forwarding Decision Process
FEC	Forward Error Correction
FER	Frame Error Rate
FI	Future Internet
FIA	Future Internet Architectures
FIB	Forwarding Information Base
FIFO	First-In First-Out discipline
FIM	Flow Interception Module
FIND	The future Internet design
FL	Folding Link
Fl-EP	Flow Endpoint
Fl-RO	Flow Routing
FN	Folding Node
FNE	Forwarding NE
FO	Fixed Operator
ForCES	Forwarding/Control Element Separation
FP7	Framework Programme 7
FPNE	Flow Processing NE
FQ	Fair Queuing
FRR	Fast Reroute
FSA	Flow State Advertisement
FTP	File Transfer Protocol
FTTH	Fiber to the Home
GAP	Generic Aggregation Protocol
GEF	Graphical Editing Framework
GENI	Global Environment for Network Innovation
GF	Galois Field
GGAP	Gossip-Generic Aggregation Protocol
GMOPR	Grid MOPR
GMP	Global Management Point
GMPLS	Generalized Multi-Protocol Label Switching
GMPR	Generic Path Master Record
GP	Generic Path
GPMR	Generic Path Management Record
GPRS	General Packet Radio Service
GPS	Global Positioning System
GRDF	Generic Resource Description Framework
GRX	GPRS Roaming Exchange
GRX	GSM Roaming Exchange
GSM	Global System for Mobile Communications
GSMA	GSM Association
GS-Node	Governance Stratum Node

GUI	Graphical User Interface
HA	Home Agent
HEN	Heterogeneous Experimental Network
HIP	Host Identity Protocol
HTTP	Hypertext Transfer Protocol
iAWARE	Interference Aware routing metric
ICANN	Internet Corporation for Assigned Names and Numbers
ICN	Information-Centric Network
ICVNet	Interconnecting Virtual Network
ID	Identifier
IDR	Inter Domain Routing
IETF	Internet Engineering Task Force
IGP	Interior Gateway Protocol
ILA	Interference-Load Aware routing metric
ILC	Inter Layer Communication
ILR	Inter Layer Routing
ILS	Information Lookup Service
INI	Information Network Interface
INM	In-Network Management
InP	Infrastructure Provider
IO	Information Object
IOLS	Information Object Lookup Service
IP	Internet Protocol
IPC	Inter-Process Communication
IPTV	Internet Protocol Television
IPv6	Internet Protocol version 6
IPX	IP packet eXchange
ISP	Internet Service Provider
IT	Information Technologies
ITU	International Telecommunication Union
IXP	Internet Exchange Point
JSIM	JavaSim
KS-Node	Knowledge Stratum Node
LAN	Local Area Network
LLC	Late Locator Construction
LLID	Logical Link ID
LQO	Link Quality Ordering
LQODV	Link Quality Ordering-based Distance Vector
LSA	Link State Advertisement
LSP	Label Switched Path
LSR	Label Switch Router
LT	Luby Transform
LTE	Long Term Evolution
MAC	Media Access Control
MANET	Mobile Ad Hoc Network

MAP	Mesh Access Point
MBMS	Multimedia Broadcast/Multicast Service
MC	Management Capabilities
MDHT	Multiple Distributed Hash Table
MED	Multi-Exit Discriminator
MEE-GP	Multihomed End-to-End GP
MEEM	Multihomed End-to-End Mobility
MIC	Metric of Interference and Channel-switching
MIH	Media Independent Handover
MILP	Mixed Integer Linear Program
MIP	Mobile IP
MMS	Multimedia Messaging System
MN	Mobile Node
MNE	Mediating NE
Mo-AH	Mobility Anchor
MOPR	Multi-Objective MPR
MP	Mediation Point
MP2MP	Multipoint-To-Multi-Point
MP2P	Multipoint-To-Point
MP-BGP	Multi-Protocol BGP
MPC	Multi-Party Computation
MPLS	Multiprotocol Label Switching
MPR	Multi-Path Routing
MPR-CT	MPR Compartment
MPR-GP	MPR GP
MPR-ME	MPR Master Entity
MR	Master Record
MS-Node	Machine Stratum Node
MTU	Maximum Transfer Unit
NACK	Negative Acknowledgment
NAT	Network Address Translation
NATO!	Not all at once
NC	Network Coding
NDL	Network Description Language
NE	Networking Entity
NED	NEtwork Description language (of OMNeT++)
NetInf	Network of Information
NGN	New Generation Network
NHLFE	Next Hop Label Forwarding Entry
Ni-IO	NetInf Information Object
Ni-MG	NetInfo Manager
NIN	NetInf node
NLRI	Network Layer Reachable Information
Node	CT Node Compartment
NR	Name Resolution

NRS	Name Resolution Service
NSF	National Science Foundation
NSIS	Next Steps in Signalling
NSLP	NSIS Signalling Layer Protocol
NTP	Network Time Protocol
NW	Network
OADM	Optical Add Drop Multiplexers
OCS	Optical Circuit Switching
OD	Origin Destination
OFDM	Orthogonal Frequency Division Multiplex
OLA	Optical Line Amplifiers
OLT	Optical Line Terminal
OM	Observation Module
ONU	Optical Network Unit
OPEX	Operational Expenditure
OS	Operating System
OSGi	Open Services Gateway initiative
OSI-SM	Open Systems Interconnection—System Management
OSPF	Open Shortest Path First
OSPF-TE	Open Shortest Path First—Traffic Engineering Extensions
OSS	Open-Source Software
OTN	Optical Transport Network
OWL	Web Ontology Language
OXC	Optical Cross-Connect
P2MP	Point-to-Multipoint
P2P	Peer to Peer
Pa-EP	Path Endpoint
Pa-RO	Path Routing
PC	Personal Computer
PCE	Path Computation Element
(P)CN	Congestion and Pre-Congestion Notification
PDU	Protocol Data Unit
PER	Packet Error Rate
PHY	Physical Layer
PIM-DM	Protocol Independent Multicast—Dense Mode
PIM-SM	Protocol Independent Multicast—Sparse Mode
PMD	Polarization Mode Dispersion
PMS	Personal Mobile Scenario
PN	Provisioning Network
PnP	Plug-and-Play
PNP	Physical Network Provider
Po-EN	Policy Engine
PON	Passive Optical Network
PPP	Point-to-Point
PSR	Packet Success Rate

PSTN	Public Switched Telephone Network
QoE	Quality of Experience
QoS	Quality of Service
R&D	Research and Development
RA	Resource Advertisement
RAID	Redundant Array of Inexpensive Disks
RDF	Resource Description Framework
RDL	Resource Description Language
RDP	Routing Decision Process
RESCT	Resolution Compartment
RFC	Request For Comments
RFID	Radiofrequency Identification
RI	Routing Instruction
RIB	Routing Information Base
R-MAC	Radio Medium Access Control
RNC	Random Network Coding
RNE	Routing NE
RNG	Random Number Generator
RO	Routing Object
ROADM	Reconfigurable Optical Add-Drop Multiplexer
RSVP	Resource Reservation Protocol
RSVP-TE	Resource Reservation Protocol—Traffic Engineering
RTT	Round-Trip Time
RUI	Routing Update Interval
SA	Service Agent
SAP	Service Access Point
SATO	Service-Aware Transport Overlay
SCTP	Stream Control Transmission Protocol
SDH	Synchronous Digital Hierarchy
SE	Self-managing Entities
SGP	Service Gateway Point, or Stratum Gateway Point
SHIM6	Site Multihoming by IPv6 Intermediation
SIM	Subscriber Identity Module
SINR	Signal to Interference and Noise Ratio
SIP	Session Initiation Protocol
SLA	Service Level Agreement
Sl-MA	Service Level Agreement Manager
SNMP	Simple Network Management Protocol
SNR	Signal to Noise Ratio
SOA	Service Oriented Architecture
SOCP	Second Order Conic Program
SON	Service Oriented Networks
SONET	Synchronous Optical Network
SP	Service Provider
SQF	Shortest Queue First discipline

SRDF	Semantic Resource Description Framework
SRMF	Semantic Resource Management Framework
sRTT	smoothed Round-Trip Time
SSDP	Simple Service Discovery Protocol
SSP	Service Stratum Point, or Stratum Service Point
SVN	SubVersioN
SW	Software
Tagg-GP	Transport aggregate GP
TCG	Trusted Computing Group
TCP	Transmission Control Protocol
TDM	Time Division Multiplex
TDMA	Time Division Multiple Access
TE	Traffic Engineering
TENE	Traffic Engineering NE
TGP	Transport GP
TIC	Time Interval Counter
TLS	Transport Layer Security
TM	Transformation Module
TMN	Telecommunications Management Network
TO	Time-out
To-DB	Topology Database
Tr-MO	Traffic Monitoring
TTL	Time to Live
TTM	Time To Market
TV	Television
UA	User Agent
UDP	User Datagram Protocol
UIP	Unmanaged Internet Protocol
UL	Uplink
UML	Unified Modelling Language
UMTS	Universal Mobile Telecommunications System
UPnP	Universal Plug and Play
URL	Uniform Resource Locator
VBR	Variable Bit Rate
Vi-Node	Virtual Node
VLAN	Virtual Local Area Network
VLC	VLC media player
VNet	Virtual network
VNM	VNet Management
VNO	VNet Operator
VNP	VNet Provider
VoD	Video on Demand
VoIP	Voice over IP
VPN	Virtual Private Network
WAN	Wide Area Network

WAP	Wireless Access Point
WCETT	Weighted Cumulative ETT
WDM	Wavelength Division Multiplexing
WFQ	Weighted Fair Queuing discipline
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
W-LLC	Wireless Link Layer Control
WMAN	Wireless Metropolitan Area Networks
WMN	Wireless Mesh Network
WMOPR	Wireless MOPR
WMVF	Wireless Medium Virtualization Framework
WP	Work Package
xDSL	Digital Subscriber Line
XML	eXtensible Markup Language

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