

M2M

Communications

A Systems Approach

EDITORS | DAVID BOSWARTHICK | OMAR ELLOUMI | OLIVIER HERSENT

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 **ETSI** World Class Standards

M2M COMMUNICATIONS

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Foreword

It was with great pleasure that I accepted the invitation to write the foreword for this first of two books on M2M and Internet of Things, *M2M Communications: A Systems Approach*.

Although the market for Machine to Machine (M2M) devices and applications is still developing, we can already foresee that this technology will have a profound impact on our lives, as new application fields are explored. Numerous projections have been made for the growth of M2M: for example estimates include an increase from the current 6 billion cellular devices to eventually over 50 billion cellular-connected machines. Other estimates indicate the total market volume from M2M and Internet of Things reaching \$11.5bn by 2012. Indeed the M2M market can already be segmented in numerous ways: distinguishing between hardware devices and software, between connection technologies, or according to specific industrial application segment.

Why are M2M markets taking off now, since many of the technologies used have existed for a number of years? A key factor in the growth of M2M today is the widespread availability of ubiquitous, low-cost connectivity. We have become used to cheap, high-speed home and business internet access. Now in many regions 3G and future LTE mobile networks offer similar access speeds at highly competitive prices. Suddenly a host of applications we have dreamt about and which require internet connectivity have become economically viable.

The large-scale deployment of IP-connected sensors, monitors and actuators, in the home and in industry, enables the development of new interconnected, interoperable services which hold the potential to transform our daily lives. M2M technologies offer a vision of mash-up applications founded in reality, utilising multiple new sources of information, in contrast to the virtual world of mash-up web services. This vision is sometimes referred to as 'The Internet of Things', but it's not the connected things which are important. Instead, what is important is the information which they provide us, and how we combine and present and use this information, and how we make decisions based upon it. The Internet of Things offers a technical viewpoint. We must look beyond that to see the societal impact, to understand how we will make use of this technology to change our lives for the better.

A key feature of this vision of the future is the variety and range of technologies, functionalities and requirements which we need to take into account. How can we develop a flexible architecture into which we can place today's and tomorrow's technologies? How can we enable interoperability? How can we preserve confidentiality and privacy

of information while not restricting potentially beneficial new applications? How can we ensure the reliability of these systems we will build, as we grow increasingly dependent on them? The solutions to these challenges lie not with any one organization or individual. This requires cross-industry thinking, it requires collaboration between the different actors concerned and it requires co-ordination at an international level. Consensus-based international standards are essential to ensure the development of M2M technologies and markets, providing solutions to many of these challenges. ETSI's M2M Technical Committee is currently playing a leading role in driving international standards work in this domain.

Beyond the wider societal challenges, we also face many detailed technical issues. A rapid deployment and adoption of M2M technology will result in new demands being placed on our networks. M2M services often require high efficiency, low overhead, low power consumption and greater flexibility in networks. These requirements will compete with the demand for high speed, low latency and large capacity, which our networks are currently equipped to handle. We may need to re-think how we design and how we manage our networks, if M2M services become as widespread as forecast. We will need to consider new access technologies in order to enable new applications which are not well served by the current radio technologies on the market.

The growth of M2M applications will have a profound impact on the standards which define our telecoms and data networks. ETSI has many years of work ahead of it to develop the specifications and standards which will be needed. I am certain that this book and its accompanying volume will provide us with useful guidance in this task, helping us to better understand the issues we need to tackle in order to create an M2M-enabled world.

Luis Jorge Romero
ETSI Director General

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List of Acronyms

3GPP	Third-Generation Partnership Project
6LoWPAN	IPv6 Over Low Power and Lossy Networks
AAA	Authentication, Authorization and Accounting
ABRO	Authoritative Border Router Option
ADC	Analog-to-Digital Converter
AKA	Authentication and Key Agreement
ALG	Application Level Gateway
AMPS	American Mobile Phone Service
AODV	Ad hoc On-Demand Distance Vector
API	Application Programming Interface
APN	Access Point Name
ARO	Address Registration Option
ARP	Allocation and Retention Priority
ARPU	Average Revenue Per User
ARRA	American Recovery and Reinvestment Act
ATM	Automated Teller Machine
B2B	Business-to-Business
B2C	Business-to-Consumer
BGA	Ball Grid Array
BOM	Bill of Materials
CA	Certificate Authority
CAPEX	CAPital EXpenditure
CAT	Card Application Toolkit
CBC	Cell Broadcast Center
CCF	CDMA Certification Forum
CDMA	Code Division Multiple Access
CDR	Charging Data Record
CEN	Comité Européen de Normalisation
CENELEC	Comité Européen de Normalisation Électrotechnique
CHAP	CHallenge Authentication Protocol
CID	Connection IDentifier
CIDR	Classless Interdomain Routing

CM	Configuration Management
CoAP	Constrained Application Protocol
CRL	Certificate Revocation List
CSD	Circuit-Switched Data
CSP	Communications Service Provider
DA	Device Application
DAD	Duplicate Address Detection
DAO	DODAG Advertisement Object
DAR	Discovery Address Request
DHCP	Dynamic Host Configuration Protocol
DIO	DODAG Information Object
DIS	DODAG Information Solicitation
DLMS	Device Language Message Specification
DM	Device Management
DNS	Domain Name Server
DODAG	Direction Oriented Directed Acyclic Graph
DoE	Department of Energy
DPWS	Devices Profile for Web Services
DSCL	Device Service Capabilities Layer
DSCP	Differentiated Services Control Point
DTLS	Datagram Transport Layer Security
DTMF	Dual Tone Multi-Frequency
EAB	Extended Access Barring
EAL	Evaluation Assurance Level
EAP	Extensible Authentication Protocol
ECC	Elliptic Curve Cryptography
EEPROM	Electrically Erasable Programmable Read-Only Memory
ESO	European Standard Organisation
ETSI	European Telecommunications Standards Institute
EUSD	European Universal Service Directive
EV	Electric Vehicle
EVDO	Evolution-Data Optimized
FCC	Federal Communication Commission
FDMA	Frequency Division Multiple Access
FOTA	Firmware-Over-The-Air
FP8	8th Framework Program
FQDN	Fully Qualified Domain Name
FTP	File Transfer Protocol
FTTH	Fibre To The Home
GBA	Generic Bootstrapping Architecture
GCF	Global Certification Forum
GGSN	Gateway GPRS Support Node
GMSC	GSM Mobile Services Switching Center
GP	Global Prefix
GPIO	General Purpose Input Output
GPRS	General Packet Radio Service

GPS	Global Positioning System
GPSK	Generalized Pre-Shared Key
GRE	Generic Routing Encapsulation
GSCL	Gateway Service Capabilities Layer
GSM	Global Systems <i>for</i> Mobile <i>Communications</i>
GSMA	GSM Association
GW	GateWay
H2H	Human-to-Human
HCI	Host Controller Interface
HLIM	Hop Limit
HLR	Home Location Register
HSPA	High Speed Packet Access
HSS	Home Subscriber Service
HTTP	HyperText Transfer Protocol
IBAKE	Identity-Based Authenticated Key Exchange
IBE	Identity Based Encryption
IC	Integrated Circuit
ICCID	Integrated Circuit Card Identifier
ICMP	Internet Control Message Protocol
ICS	In-Vehicle System
ICT	Information and Communication Technologies
IDE	Integrated Development Environment
IETF	Internet Engineering Task Force
IID	Interface IDentification
IKE	Internet Key Exchange
IMEI	International Mobile Equipment Identifier
IMEISV	IMEI Software Version
IMS	IP Multimedia Subsystem
IMSI	International Mobile Subscriber Identity
IoT	Internet of Things
IOT	Interoperability Testing
IP	Internet Protocol
IPHC	IP Header Compression
IPSEC	Internet Protocol Security
ISC	IMS Service Control
IS-IS	Intermediate System to Intermediate System
ITU	International Telecommunication Union
J2EE	Java 2 Enterprise Edition
KEG	Key Generation Function
LAN	Local Area Network
LBR	LoWPAN Border Router
LDAP	Lightweight Directory Access Protocol
LGA	Line Grid Array
LLN	Low Power and Lossy Network
LTE	Long Term Evolution
M2M	Machine-to-Machine

M2ME	M2M Equipment
MAC	Medium Access Control
MAS	M2M Authentication Server
M-BUS	Meter BUS
MCM	Multichip Module
MEID	Mobile Equipment Identifier
MIMO	Multiple-Input, Multiple-Output
MME	Mobility Management Entity
MMI	Man-Machine Interface
MNC	Mobile Network Code
MNO	Mobile Network Operator
MO	Management Object
MP2P	Multi-Point To Point
MPLS	Multiprotocol Label Switching
MRHOF	Minimum Rank with Hysteresis Objective Function
MSC	Mobile Switching Center
MSF	M2M Service Bootstrap Function
MSIM	M2M Service Identity Module
MSIN	Mobile Subscriber Identification Number
MSISDN	Mobile Station Integrated Services Digital Network
MTC	Machine Type Communications
MTC-GW	Machine Type Communication Gateway
MTU	Maximum Transfer Unit
MVNO	Mobile Virtual Network Operator
NA	Network Application
NAPT	Network Address and Port Translation
NAS	Non Access Stratum
NAT	Network Address Translator
NBMA	Non-Broadcast Multiple-Access
NC	Node Confirmation
NDIS	Network Driver Interface Specification
NDP	Neighbor Discovery Protocol
NFC	Near Field Communications
NGC	Network Generic Communication
NGN	Next Generation Networks
NIST	National Institute of Standards and Technology
NR	Node Registration
NRPCA	Network-Requested PDP Context Activation
NS	Neighbour Solicitation
NSCL	Network Service Capabilities Layer
NSEC	Network Security Capability
NTACS	Narrowband Total Access Communication System
NUD	Neighbor Unreachability Detection

OC	Option Count
OCS	Online Charging Services
OCSF	Online Certificate Status Protocol
OFDMA	Orthogonal Frequency Division Multiple Access
OLSR	Optimized Link State Routing
OMA	Open Mobile Alliance
OPEX	OPERational EXpenditure
OS	Operating System
OSPF	Open Shortest Path First
OTA	Over-The-Air
OTASP	Over-The-Air Service Provisioning
P2MP	Point to Multi-Point
PAK	Password-Authenticated Key Exchange
PAN	Personal Area Network
PAP	Password Authentication Protocol
PCB	Printed Circuit Board
PCM	Pulse Code Modulation
PCRF	Policy and Charging Rules Function
PDA	Personal Digital Assistant
PDN	Packet Data Network
PDP	Packet Data Protocol
PDP-C	Packet Data Protocol Context
PDSN	Packet Data Serving Node
PGW	PDN (Public Data Network) Gateway
PIN	Personal Identification Number
PKI	Public Key Infrastructure
PLC	Power Line Communication
PM	Performance Management
PoS	Point of Sale
PS	Packet Switched
PSAP	Public Safety Answering Point
PTCRB	PCS Terminal Certification Review Board
PWM	Pulse Width Modulation
QoS	Quality of Service
RA	Registration Authority
RA	Router Advertisement
RAN	Radio Access Network
RAT	Radio Access Technologies
REST	REpresentation State Transfer
RF	Radio Frequency
RFC	Request For Comment
RFID	Radio Frequency IDentification
RIP	Routing Information Protocol

RNC	Radio Network Controller
RoI	Return on Investment
RPL	Routing Protocol for LLN (Low Power and Lossy Network)s
RRC	Radio Resource Control
RSSI	Received Signal Strength Indicator
SAC	Source Address Compression
SAM	Source Address Mode
SC	Service Capabilities
SCADA	Supervisory Control and Data Acquisition
SCP	Smart Card Platform
S-CSCF	Serving Call Session Control Function
SDK	Software Development Kit
SDO	Standards Development Organization
SGSN	Serving GPRS Support Node
SGW	Serving Gateway
SID	Subnet IDentifier
SIM	Subscriber Identification Module
SLAAC	StateLess Auto Address Configuration
SLLAO	Source Link-Layer Adress Option
SMS SC	SMS Service Center
SMS	Short Message Service
SMS-C	Short Message Service Center
SMT	Survace Mount Technology
SMTP	Simple Mail Transfer Protocol
SNMP	Simple Network Management Protocol
SNR	Serial NumbeR
SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol
TACS	Total Access Communications System
TCG	Trusted Computing Group
TCO	Total Cost of Ownership
TCP	Transmission Control Protocol
TDMA	Time Division Multiple Access
TD-SCDMA	Time Division Synchronous Code Division Multiple Access
TIS	Total Isotropic Sensitivity
TLS	Transport Layer Security
TLS-PSK	Transport Layer Security Pre-Shared Key
TLV	Type Length Value
TRP	Total Radiated Power
TTM	Time-to-Market
UART	Universal Asynchronous Receiver/Transmitter
UATI	Unicast Access Terminal Identifier
UDC	Universal Decimal Classification

UDDI	Universal Description Discovery and Integration
UDP	User Datagram Protocol
UE	User Equipment
UICC	Universal Integrated Circuit Card
ULA	Unique Local Address
UMB	Ultra-Mobile Broadband
UMTS	Universal Mobile Telecommunications System
USB	Universal Serial Bus
USIM	Universal Subscriber Identity Module
VLR	Visitor Location Register
VPN	Virtual Private Network
WAN	Wide Area Network
WLAN	Wireless Local-Area Networks
WPAN	Wireless Personal Area Network
WSDL	Web Service Description Language
WSN	Wireless Sensor Network
WWAN	Wireless Wide-Area Networks
xDSL	x Digital Subscriber Line

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Introduction to M2M

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M2M (Machine-to-Machine) has come of age. It has been almost a decade since the idea of expanding the scope of entities connected to “the network” (wireless, wireline; private, public) beyond mere humans and their preferred communication gadgets has emerged around the notions of the “Internet of Things” (IoT), the “Internet of Objects” or M2M. The initial vision was that of a myriad of new devices, largely unnoticed by humans, working together to expand the footprint of end-user services. This will create new ways to care for safety or comfort, optimizing a variety of goods-delivery mechanisms, enabling efficient tracking of people or vehicles, and at the same time creating new systems and generating new value.

As with every vision, it has taken time to materialize. Early efforts concentrated on refining the initial vision by testing new business models, developing point solutions to test feasibility, and also forecasting the impact of insufficient interoperability. Over the past few years, the realization that there are new viable sources of demand that can be met and monetized has created the push for a joint effort by industry to turn a patchwork of standalone elements and solutions into a coherent “system of systems”, gradually turning the focus from the “what” to the “how” and developing the appropriate technologies and standards.

This chapter introduces the M2M concept and proposes a definition from the multitude of definitions available today. It outlines the main characteristics of the emerging M2M business and presents a high-level view of the M2M framework that is further analyzed and dissected in subsequent chapters. Moreover, this chapter analyzes some of the main changes that have occurred recently and that have largely enabled the development of M2M, namely the emergence of regulation and standards as market shapers. The role of

standards is one of this book's central themes and a presentation of the main actors and the latest status of related work is provided as a guide through this complex ecosystem.

The reader will finally be introduced to the structure and content of this book, which is actually the first of a set of two. In the hands of the reader in paper format or on an eBook reader after being loaded by an M2M application, the first book *M2M Communications: A Systems Approach* essentially introduces the M2M framework – requirements, high-level architecture – and some of its main systems aspects, such as network optimization for M2M, security, or the role of IP.

The second book *Internet of Things: Key Applications and Protocols* will address more specifically the domain in which the “Internet of Objects” will be acting, namely the M2M area networks, in particular the associated protocols and the interconnection of such networks. It will also analyze, from this perspective, some of the future M2M applications, such as Smart Grids and Home Automation.

1.1 What is M2M?

Many attempts have been made to propose a single definition of the M(s) of the M2M acronym: Machine-to-Machine, Machine-to-Mobile (or vice versa), Machine-to-Man, etc. Throughout this book, M2M is considered to be “Machine-to-Machine”. This being decided, defining the complete “Machine-to-Machine” concept is not a simple task either: the scope of M2M is, by nature, elastic, and the boundaries are not always clearly defined.

Perhaps the most basic way to describe M2M is shown in Figure 1.1 (the “essence” of M2M). The role of M2M is to establish the conditions that allow a device to (bidirectionally) exchange information with a business application via a communication network, so that the device and/or application can act as the basis for this information exchange. In this definition, the communication network has a key role: a collocated application and device can hardly be considered as having an M2M relationship. This is why M2M will often be a shortened synonym for M2M communications, which is itself a shortened acronym for M2(CN2)M: Machine-to-(Communication-Network-to-)Machine).

In itself, this description still does not fully characterize M2M. For instance, a mobile phone interacting with a call center application is not seen as an M2M application because a human is in command. Some of the more complex characteristics of the M2M relationship are discussed below in order to clarify this.

In many cases, M2M involves a group of similar devices interacting with a single application, as depicted in Figure 1.2. Fleet management is an example of such an application, where devices are, for example, trucks, and the communication network is a mobile network. In some cases, as shown in Figure 1.3, the devices in the group may not directly interact with the application owing to having only limited capacities. In this scenario, the relationship is mediated by another device (e.g., a gateway) that enables some form of consolidation of the communication. “Smart metering” is an example of such an application where the devices are smart meters and the communication network can be a mobile network or the public Internet.

To take this into account, the term “M2M area network” has been introduced by the European Telecommunication Standards Institute (ETSI). An M2M area network provides physical and MAC layer connectivity between different M2M devices connected

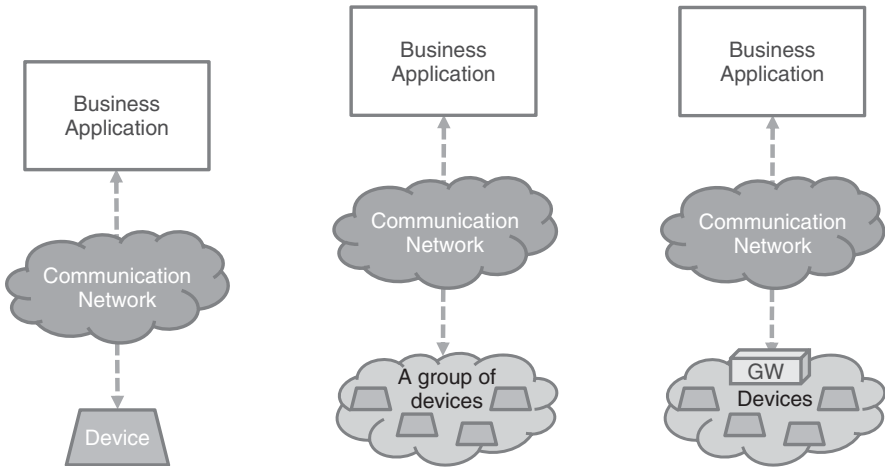


Figure 1.1 The essence of M2M.

Figure 1.2 Group of devices in an M2M relationship.

Figure 1.3 The mediated M2M relationship.

to the same M2M area network, thus allowing M2M devices to gain access to a public network via a router or a gateway.

M2M's unique characteristic is largely due to the key role of the end-device. Devices are not new in the world of information and communication technologies (ICT), but with M2M that market is seeing a new family of devices with very specific characteristics. These characteristics are further discussed below, particularly their impact on the requirements for applications and networks that have not until now been fully taken into account.

- Multitude** – This is the most advocated change brought about by M2M. It is generally agreed that the number of “devices” connected in M2M relationships will soon largely exceed the sum of all those that directly interact with humans (e.g., mobile phones, PCs, tablets, etc.). An increased order of magnitude in the number of devices results in significantly more pressure on applications architectures, as well as on network load, creating in particular scalability problems on systems that have been designed to accommodate fewer “actors” and far greater levels and types of traffic. One of the early instances of such problems is the impact of M2M devices on mobile networks that have not been designed with this set of devices in mind and are in the process of being adapted to allow large numbers of devices with non-standard usage patterns (this will be discussed later in this chapter).
- Variety** – There are already a particularly large number of documented possible use cases for M2M that apply to a variety of contexts and business domains. The initial implementations of M2M applications have already led to the emergence of a large variety of devices with extremely diverse requirements in terms of data exchange rate, form factor, computing, or communication capabilities. One result of the wide variety is heterogeneity, which is in itself a major challenge to interoperability. This can be a major obstacle to the generalization of M2M. It is also a challenge for the frameworks

on which M2M applications have to be built, in order to define and develop common-enabling capabilities.

- **Invisibility** – This is a strong requirement in many M2M applications: the devices have to routinely deliver their service with very little or no human control. In particular, this is preventing humans from correcting mistakes (and also from creating new ones). As a result, device management more than ever becomes a key part of service and network management and needs to be integrated seamlessly.
- **Criticality** – Some devices are life-savers, such as in the field of eHealth (blood captors, fall detectors, etc.). Some are key elements of life-critical infrastructures, such as voltage or phase detectors, breakers, etc, in the Smart Grid. Their usage places stringent requirements upon latency or reliability, which may challenge or exceed the capabilities of today’s networks.
- **Intrusiveness** – Many new M2M devices are designed with the explicit intention to “better manage” some of the systems that deal with the end-users’ well-being, health, etc. Examples are the eHealth devices already mentioned, smart meters for measuring and/or controlling electrical consumption in the home, etc. This in turn leads to issues of privacy. In essence, this is not a new issue for ICT systems but it is likely that privacy may present a major obstacle in the deployment of M2M systems. This may occur when the large deployment of smart meters demands prior arbitration between the rights of end-users to privacy and the needs of energy distributors to better shape household energy consumption.

In addition to the above-listed characteristics and their impact on the architecture of M2M systems, it is important to consider the other specificities of M2M devices that put additional constraints on the way they communicate through the network. This may require new ways to group the devices together (the “mediated” approach mentioned in Figure 1.3). Among other things, devices can be:

- **limited in functionality** – Most M2M devices have computational capabilities several orders of magnitude below what is currently present in a modern portable computer or a smart phone. In particular, devices may lack remote software update capabilities. One of the main reasons for this design choice is cost, often because the business model requires very competitively priced devices (e.g., smart meters in many cases). Limited functionality also results from rational decisions based on the nature of the exchanged information and performable actions: most sensors are not meant to be talkative and operationally complex.
- **low-powered** – Although many M2M devices are connected to a power network, many of them have to be powered differently (often on batteries) for a variety of reasons. For instance, a large number of them are, or will be, located outdoors and cannot be easily connected to a power supply (e.g., industrial process sensors, water meters, roadside captors). This will reduce the amount of interaction between such devices and the M2M applications (e.g., in the frequency and quantity of information exchanged).
- **embedded** – Many devices are, and will be, deployed in systems with specific (hostile, secure) operating conditions that will make them difficult to change without a significant impact on the system itself. Examples are systems embedded in buildings or in cars that are hard to replace (e.g., when they are soldered to the car engine, as is the case with some M2M devices).