Day 1: An introduction to the Internet of Things (IoT). M2M Markets and Services

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About the Instructor

- **Yevgeni Koucheryavy** is a **Full Professor** in the Department of Elecronics and Communications Engineering at the Tampere University of Technology (TUT), Finland. Received the M.Sc. degree (1997) from the State University of Telecommunications, St. Petersburg, Russia, and the PhD degree (2004) from the Tampere University of Technology (TUT), Tampere, Finland
- **Co-director of Nano Communications Research Center**
- **Has been leading several European and Finnish projects**
- He has been **leading a number of industrial projects** with different companies including Intel, Nokia, Nokia Siemens Networks, Alcatel, Ericsson, Cisco, etc.
- **Leads ITU Activities** on IoT Testing during study period 2013 – 2016
- **Within last years** (2011 – 2013) from the sources external to TUT Yevgeni **attracted over 2 mln Euros as R&D funding**
- Has authored or co-authored over 100 papers
- Expert in Skolkovo IT Claster
- Senior IEEE member

The goals of this course

- To provide a big picture on the Internet of Things
- To analyze future communications trends, enablers and challenges
- To present IoT technology enablers and trends
  - By 3GPP – 3G, USPA, LTE, LTE-A
  - By IEEE – 802.11, 802.15
  - By IETF – 6LoWPAN
  - Others
- To analyze economic dimensions of IoT
  - Mainly from operator's perspective
    - E.g. market potentials, ROI, etc.

Disclaimer

- IoT includes many aspects
  - Microelectronics
  - Software
  - Semantics
  - Sensors
  - Etc.

In this course we will concentrate over the wireless technologies, protocols and communication principles for IoT

IoT Historical Perspective: Devices and Protocols

The Internet of Things revolution

- Started in the 1990s with industrial automation systems
- Early proprietary networks **in industrial automation** were quickly replaced by different forms of industrial Ethernet, and Internet protocols became widely used between embedded automation devices and back-end systems

Machine-to-machine (M2M) telemetry

- Made a breakthrough in the early 2000s, with the **use of cellular modems and IP to monitor and control** a wide range of equipment from vending machines to water pumps
- Building automation systems used wired IP communications
  - *Building Automation and Control Network* (BACnet) and *Open Building Information Exchange* (oBIX) standards

Automatic metering

- **Infrastructures and smart grids are being deployed at a rapid rate**
  - Largely depending on the scalability and universal availability of IP technology

Finally, mobile phones have become almost universally IP-enabled embedded devices currently making up the largest body of devices belonging to the Internet of Things

IoT Historical Perspective: Services

- <u>Equally important</u> **development has been happening** <u>in the services</u>
  - That are used to monitor and control embedded devices
  - The services are almost universally built on Internet technology, and more commonly are implemented using web-based services
  - *Web Service* technologies have completely changed the way business and enterprise applications are designed and deployed
    - It is this combination of Internet-connected embedded devices and Web-based services which makes the Internet of Things a powerful paradigm
- **Hundreds of millions of embedded devices are already IP-enabled**
  - But the <u>Internet of Things is still in its infancy</u> – Why?
  - Devices are complex
    - Though capabilities of processor, power and communications technology have continuously increased, so has the complexity of communications standards, protocols and services
  - <u>Thus, so far, it has been possible to use Internet capabilities in only the most powerful embedded devices</u>
  - Additionally, lowpower wireless communications limits the practical bandwidth
    - Throughout the 1990s and early 2000s we have seen a large array of proprietary low-power embedded wireless radio and networking technologies. This has fragmented the market and slowed down the deployment of such technology.

Today's Internet trends

Current Internet is a collection of rather uniform devices

- Nowadays over 3 billion devices are connected

Mobile device become a key player in service race

Mobile service is a keyword

- Social networking or Web 2.0 – Facebook, Twitter, LinkedIn etc
- Location determination – location-enabled services – Gowalla, Google Latitude, Foursquare etc.
- Video content retrieval – YouTube
- Mobile payments – no killer app so far
- Combined apps
  - E.g. social networking + location
- App, app, thousands of apps – App store etc
  - Most apps are narrow, focused and stand-alone
  - Cloud service
  - etc

IoT as a Concept

We are about to face a new technological revolution

Boost in interdisciplinary research is needed

- Robotics
- Biology
- Physics
- Chemistry
- Materials
- Etc

Generally speaking IoT will encompass Nanotechnology, Biotechnology, Information Technology and Cognitive Sciences

- Over the next 10 to 15 years IoT is likely to develop fast and shape a newer "information society" and "knowledge economy", but the direction and pace with which developments will occur are difficult to forecast

Implementation wise, IoT is a networking paradigm

- Network connecting all possible devices of almost any scale

Today’s Internet trends

Shift in traffic generation paradigm

Human to machine (H2M) vs. Machine to Machine (M2M)

- One of the major trend leading to change of Internet paradigm
- For example, P2P
- IoT is the next step

Future Internet challenges

Health industry

- Ageing, assisted living
- Real-time health tracking
- [Autonomic] robotic surgery

Government and city

- Operation optimization including energy consumption
- Emissions, wastes and other green issues

Automotive industry

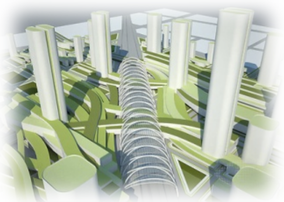
- Car manufacturers etc.

Smart living

- Web 3.0, less footprint








Climate Debt by WWF

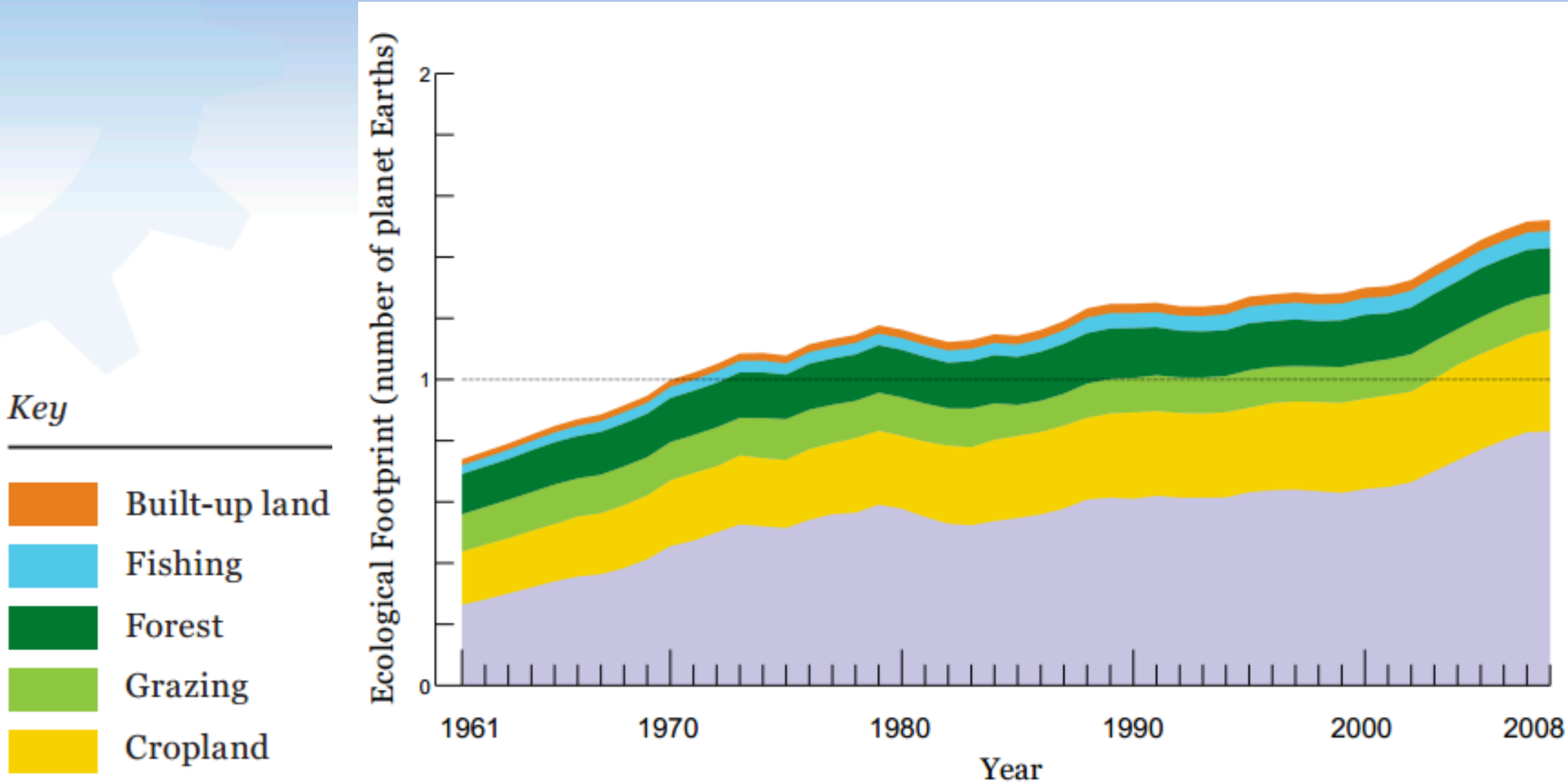


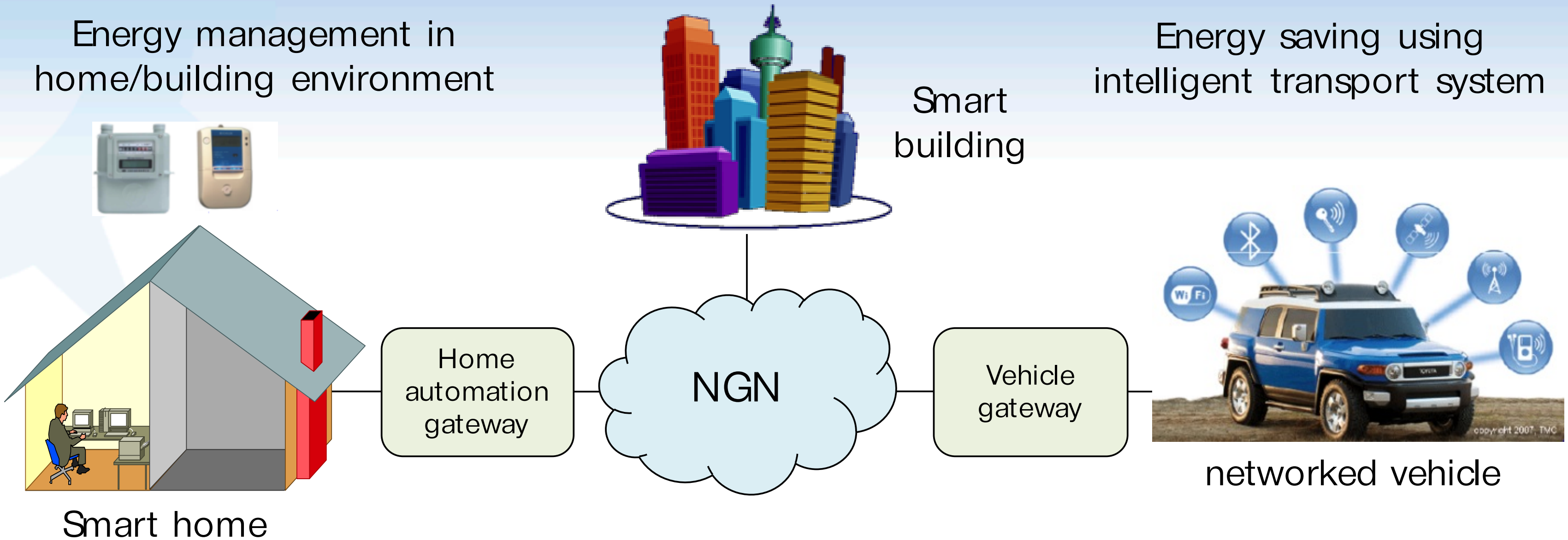
Figure 3: Global Ecological Footprint by component, 1961-2008 *The largest component of the Ecological Footprint is the carbon footprint (55%) (Global Footprint Network, 2011).*


BETTER CHOICES
FROM A ONE PLANET PERSPECTIVE
Preserve Natural Capital
• Restore damaged ecosystems and ecosystem services
• Halt loss of priority habitats
• Significantly expand the global protected areas network
Produce Better
• Significantly reduce inputs and waste in production systems
• Manage resources sustainably
• Scale-up renewable energy production
Consume More Wisely
• Achieve low-footprint lifestyles
• Change energy consumption patterns
• Promote healthy consumption patterns
Redirect Financial Flows
Value nature
Account for environmental and social costs
Support and reward conservation, sustainable resource management and innovation
Equitable Resource Governance
Share available resources
Make fair and ecologically informed choices
Measure success beyond GDP
ECOSYSTEM INTEGRITY
BIODIVERSITY CONSERVATION
FOOD, WATER AND ENERGY SECURITY

Future Internet devices

- The Wireless World Research Forum (WWRF) predicted recently that there will be **7 trillion wireless devices** serving 7 billion people, i.e. around a thousand devices per person, **by 2020**
- What **types** of devices are expected to be among this vast number?
  - **Personal** devices, like wireless sensors – wearable, in-home and in-car devices, electronic home appliances
  - Devices of **autonomic** flavor like robots with communication abilities
  - **Medium-specific** devices like underwater wireless (acoustic) sensors, health in-body sensors and nano-machines
  - **Flying** devices like manned/unmanned terrestrial and [micro, bio] aerial vehicles
  - All other devices of **mixed type** forming an environment possibly with unique highly dynamic and agile requirements
- **Every object will be integrated** onto the network and regarded as a networking device generating, relaying and/or absorbing data

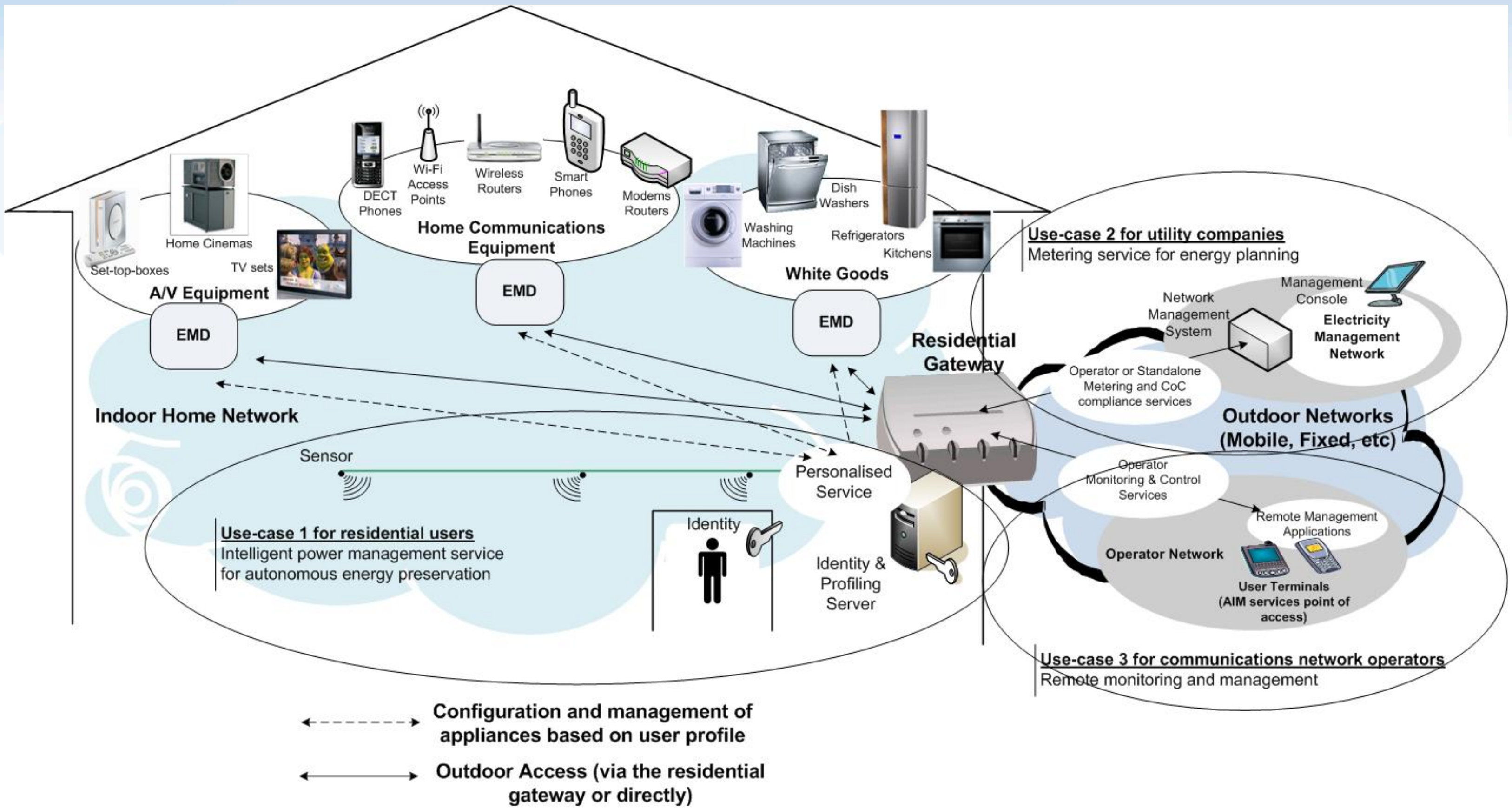
A Future Internet Vision



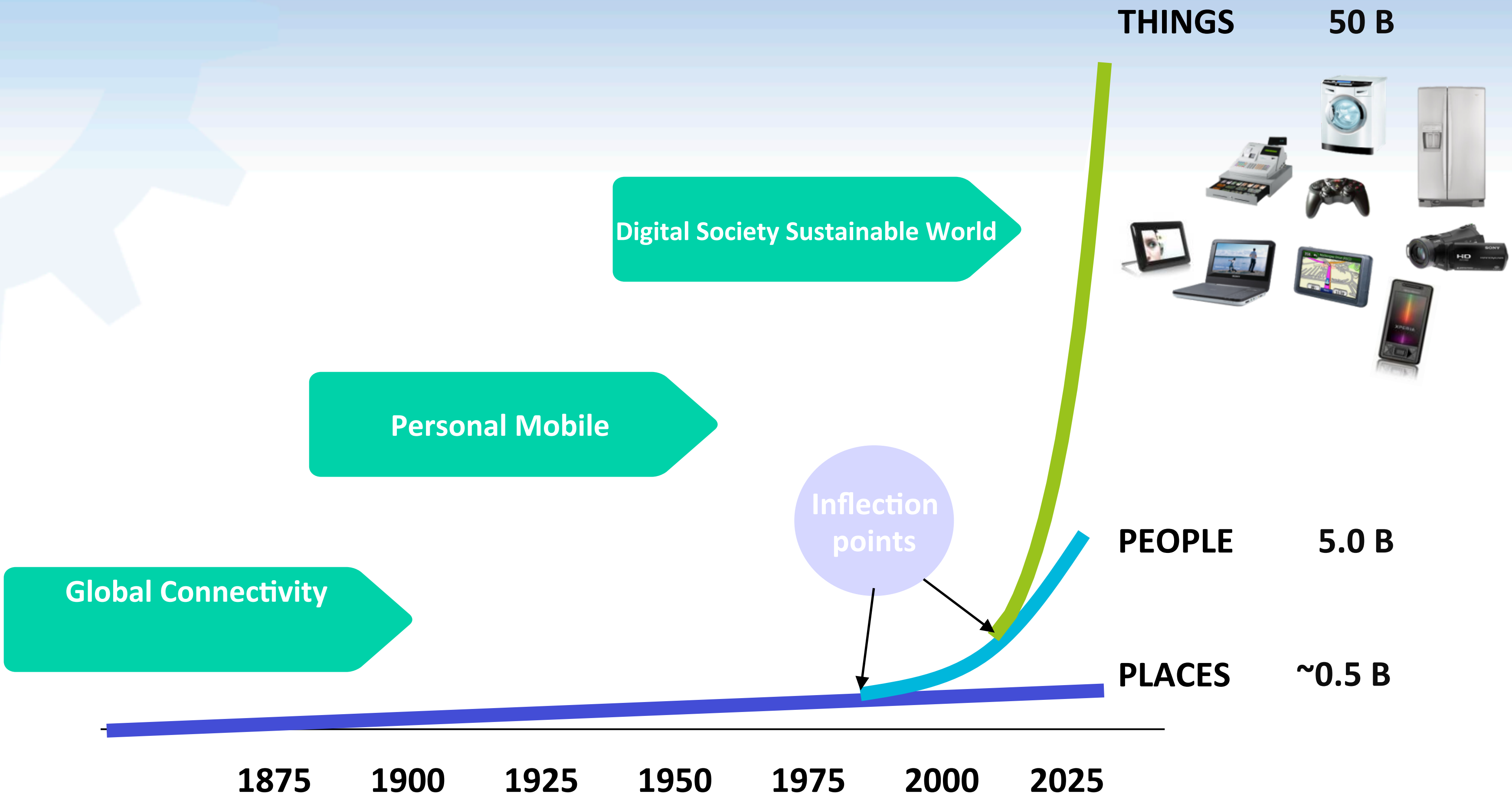
Objects in a home/building (fixed smart environment)
- Energy saving system (ESS)
- Smart Meter /Home automation controller
- Home appliances/ storage/
- Communication equipments
- Surveillance cameras/ Personal devices

Objects in a vehicle (mobile smart environment)
- Passenger devices: mobile phone, PDA, etc
- OEM devices: vehicle dedicated devices for safety, maintenance, power/fleet management, etc
- Vehicle equipped devices: navigation, monitor, etc
- Asset: moving products

A Future Internet Vision



Internet of Things (IoT)



Source: Ericsson

Explosive Traffic

- As diverse mobile devices such as smartphones and tablet computers become ubiquitous, the **explosive increase of data traffic** in 3G cellular networks is a major concern for network operators
- The rapid increase of mobile data traffic is unprecedented — a **tenfold increase in a year is common**
  - AT&T acknowledged a 5,000 percent growth in wireless data traffic in three years (2006–2009), since the iPhone launch
  - **Signaling traffic causes a significant burden** on the 3G core networks as the smartphone applications proliferate
  - Explosive surge in mobile data traffic has caused unprecedented **pressure on the limited spectrum** of the current third-generation (3G) cellular networks, pushing them <u>to capacity limits in many geographical areas</u>
- **Mobile operators need further boost in revenues**
  - The cost of supporting the exponentially increasing mobile data traffic is becoming unsustainable: the rising cost of service delivery is outrunning the increased revenues – **WHO ACTUALLY EARNS MONEY???**

Explosive Traffic

Case study: statistics from South Korea

- Due to the proliferation of smartphones and introduction of flat-rate pricing, we have observed a tenfold data traffic surge in our WCDMA network in 12 months, from around 0.9 to 9.1 Gb/s on average
- In 2010, the average monthly traffic per subscriber in our WCDMA, WiFi, and WiBRO (BWA identical to IEEE 802.16/WiMAX) increased from 100 to 450 Mbytes, from 80 to 160 Mbytes, and from 7 to 11 Gbytes, respectively

Vendors and operators have to response to this trend by

- New architectures for communication networks
- New standards
- New business models

Technological Response

<u>The new traffic need to be handled somehow</u>

- Upcoming traffic shall also be accounted

Technology standardization bodies responses market needs

- Technology
- Architecture
- But **<u>NOT</u>** new business models

If we consider wireless technologies, then most of them have been developed by 2 bodies

- 3GPP responses with 3G and LTE/LTE-A
- IEEE responses with 802.11, 802.15 family, 802.16

Grand challenges of communication tasks in IoT

- **Selection of type of communication** for particular task
  - Electromagnetic
  - Acoustic
  - Optical
  - Biological
- **Channel modeling**
  - For every distinct scenario an **understanding** of communication medium features as well as developing of channel model are of utmost importance
  - What is needed for underground mines and road/subway tunnels?
    - For soil communications the propagation of EM waves, multipath, soil composition, water content, and burial depth are necessary
- **Medium Access Control** protocols
- **Network architectures**
- **Communication protocols**

RFID-based IoT

- **The Internet of Things** is a concept originally **coined and introduced** by MIT, Auto-ID Center and intimately linked to RFID and electronic product code (EPC)
  - Brock DL (2001) MIT Auto-ID Center, MIT-AUTOID-WH-002, "The Electronic Product Code", January 2001.
- In October 2003, the MIT Auto-ID Center split into a research entity – the Auto-ID Labs – and a commercial entity – EPCglobal
- Today, the Auto-ID Labs comprise seven of the world's most renowned **research laboratories located on four different continents**
  - Including MIT (US), Cambridge (UK), St. Gallen (Switzerland), Fudan (China), ICU (Korea), Adelaide (Australia), Keio (Japan)
  - http://www.autoidlabs.org
- IoT is originally was mostly about RFID
  - Tagging the world

IoT Demands

<u>IoT end-user devices are not only RFID</u>, but also many other types of devices

- IoT should enable interactions **<u>between different types of end-user devices</u>** that **<u>enable both global as well as local applications</u>** and services for users

Grand challenges for IoT

- End-user device intelligence
- Global connectivity between physical objects
- Real-time machine-published information for the Web

Grand challenges for IoT 1/3

End-user device intelligence

- IoT end-user device can be
  - Smart or “stupid” / Active or passive
    - Both ways communication is not always needed
      - Shall connectivity be always kept – might be costly
    - Influences wireless technology design
  - Battery-constrained in most cases
  - Computational resources constrained in most cases

Grand challenges for IoT 2/3

Global connectivity between physical objects

- IoT will revolutionize the telecommunications sector **by enabling global connectivity between physical objects**, i.e., global machine to machine (M2M) interactions
- New wireless technologies are needed
  - Will use different technologies to implement the connectivity
    - Different short-range
    - Different long-range
    - Use of particular technology
      - Depends on the application/service
      - Depends on business model

Grand challenges for IoT 3/3

Real-time machine-published information for the Web

- IoT will revolutionize the World Wide Web by bringing real-time machine-published information to the Web
- This enables **new global applications and services for users**
- The Web is accessed by billions and is vital for information sharing, entertainment, education, and commerce – it is an **ECOSYSTEM** used by developers as the main platform for the development of applications and services
- **The information in the present Web is mostly published by people**
- **IoT will change the Web by extending i**t to a vast amount of real-time information coming directly from real-world things, enabling new applications and services
  - **An example, imagine a Web-based mapping system, like Google Maps, that provides a view on things located and events occurring in real time**

Future Internet = IoT

- IoT will consist of **heterogeneous sets devices** and **heterogeneous communication strategies** between the devices
- A heterogeneous system should evolve into a more structured set of solutions
  - It can be excepted that **IoT will provide a set of solutions at different levels and instances** where things (e.g. everyday objects, locations, vehicles, meters, etc.) are extended with sensors, RFIDs, actuators, or processors, made discoverable and enabled to communicate with, and are **closely integrated with Future Internet infrastructure and services**

STANDARDIZATION at all layers is a key challenge for a smooth IoT

IoT Perspectives

- Governmental
- Industrial (see ITU vision)
- Academic
- Standardization

Governmental visions

- A number of countries and districts have realized the importance of IoT in the recovery of economic growth and sustainability
  - Amongst them, European Union, the United States, and China are prominent examples.
- The European Union adopted the concept of IoT in March 2007 in its Commission Communication on RFID (EC 2007)
- In April 2008, the U.S National Intelligence Council (NIC) published a conference report on "**Disruptive Civil Technologies – Six Technologies with Potential Impacts on U.S. Interests out to 2025**", and one of the technologies was IoT
- In November 2009, in a speech of topic "Technology leads China for sustainable development", Chinese Premier Wen Jiabao took IoT **as one of the five emerging national strategic industries**, and emphasized to put force on breakthrough core technology of sensor network and IoT

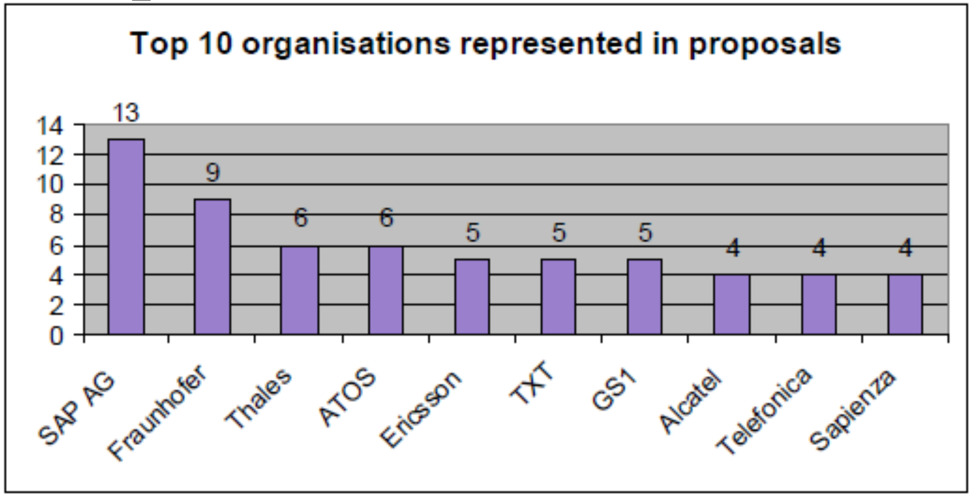
EU Commission's view on RFID

- RFID seen as a predecessor to the IoT
    - RFID becomes a part of IoT
- RFID seen as a potential platform for linking "world of production" with the "world of service"
- RFID seen a means of making items "smart", capable of being networked together and able to communicate with their environment – far reaching and requiring qualification
- RFID seen as a **vehicle for creating opportunities for new business models** that will take advantage of a global network in which any object can be linked to any context

R&D Vision

Europe

- In Europe, the academic research work in IoT was mainly performed in different EU-funded seventh Programme Framework (FP7) projects
- To better utilize the research achievements and to provide a place to share the lessons and experiences from different projects, in 2009, European Research Cluster on the Internet of Things (IERC) was founded and funded under FP7, the goal of which was to "bring together EU-funded projects with the aim of defining a common vision and the IoT technology and development research challenges at the European level in the view of global development"
    - Currently, IERC comprises around 30 EU-funded projects, including AMI-4-SME, ASPIRE, BRIDGE, CASAGRAS, DiYSE, EPoSS, IoT-i, IoT-A, etc.
    - http://www.internet-of-things-research.eu/about_ierc.htm



R&D Vision

Europe

- Furthermore, the European Union realized the importance of sustainable and continuous research work in IoT domain.
- EU Horizon 2020 described some topics related to IoT and Real-world Internet http://ec.europa.eu/research/horizon2020/index_en.cfm
- For IoT technical challenges, the roadmap is still open for new ideas and updates
- **The main topics on the IoT side considered currently are integration of IoT to "generic" Internet architecture, energy-awareness, autonomic and distributed control and management issues**

R&D Vision

China

- The academic research work towards IoT was initiated later than in US
- But it has caught up with the rest of world quickly in recent years, especially with the strong support from Chinese government
- In 2011, three “973” projects (focusing on basic infrastructure research) were funded by the Chinese government, the leading institutes were Beijing University of Posts and Telecommunications (BUPT), Tongji University, and Wuxi SensingNet Industrialisation Research Institute, respectively
- Furthermore, since 2006, several other research institutes have been involved in far-reaching projects, including Shanghai Institute of Microsystem and Information Technology (SIMIT), Chinese Academy of Sciences (CAS), etc, with strong backup from the government

Standardization vision

- Standardization bodies also play an essential role in promoting the prosperity of the current IoT domain, especially from the interoperability perspective
- Relevant standardization forums for IoT include IETF, IEEE, 3GPP, ETSI, NFC Forum, W3C, and ZigBee Alliance, etc.
- IETF is responsible for the network related standards, IEEE, NFC Forum, and ZigBee Alliance standardize the lower layer protocols, ETSI is defining the IoT concept and architecture, and W3C is starting to standardize semantic access to IoT data
- Key IETF working groups include 6LowPAN (IPv6 over Low power WPAN), CoRE (Constrained RESTful Environments), Routing Over Low power and Lossy Networks (ROLL)
- ETSI has established the Machine-to-Machine (M2M) Technical Committee that is defining an end-to-end architecture for IoT
- ITU runs Focus Groups on M2M, Smart Grid and Smart Cities

ITU Vision

- ITU Internet Reports 2005: The Internet of Things, Executive Summary, online: http://www.itu.int/pub/S-POL-IR.IT-2005/e
  - The ITU report adopted a comprehensive and holistic approach by suggesting that the **IoT would connect the world's objects in both a sensory and intelligent manner** through combining technological developments in item identification ("tagging things"), sensors and wireless sensor networks ("feeling things"), embedded systems ("thinking things") and nanotechnology ("shrinking things")
  - There are a large number of research proposals, ongoing projects, and standardization efforts around the IoT
  - It is important to emphasize that the **industry and consumers have started deploying IoT networks and products as well**
  - ITU opens new set of questions on IoT during 2013 - 2016

ITU Activities on IoT

IoT Global Standards Initiative (GSI)

- Provides a visible single location for information on and development of global IoT standards
- Harmonizes different approaches to the IoT architecture worldwide, e.g. definitions

Joint Coordination Activity (JCA) on IoT

- Coordinates ITU-T work related to the IoT, network aspects of identification of things and ubiquitous sensor networks (USN), for instance
  - Maintains list and roadmap of ITU-T IoT standardization items

ITU Activities on IoT

The IoT-GSI is working on a new Recommendation 'IoT Overview' which aims to cover

- High level concept (vision)
- Business and social drivers, ecosystem and business models
- Essential terminology
- Scope (applications/services, networks, M2M, devices, security, enabling technologies, etc.)
- Very High Level Requirements
- Key features / key areas / key components
- High level IoT diagrams

M2M Markets and Services

Machine-to-Machine (M2M) Market

- M2M is the key enabler of IoT
- M2M – information exchange between devices **without** any **human** interaction (sensors, smart meters)
- Revenues of US **$300 billion** [Harbor Research 2009]
- Big **industry** players (Ericsson, Samsung, Alcatel-Lucent, NEC, etc.)
- Interest from **governments** world-wide (DOE, NIST, EPRI, etc.)

Evolved Vision*

- Components of IoT
  - Wide variety of devices
  - Highly scalable connectivity
  - Cloud-based device management and services
- M2M usage models
  - Utilities (smart grid)
  - Vehicular telematics
  - Healthcare (M-Health)
  - etc.

* see e.g. G. Wu, S. Talwar, K. Johnsson, N. Himayat, K. Johnson, M2M: From mobile to embedded internet, IEEE Communications Magazine, vol. 49, pp. 36 – 43, 2011

3GPP M2M Applications 1/2

Security	Surveillance systems Backup for landline Control of physical access
Tracking, Tracing	Fleet management Order management Pay as you drive Asset tracking Navigation Traffic Information Road tolling Road traffic optimization/steering
Payment	Point of sales Vending machines Gaming machines
Health	Monitoring vital signs Supporting the aged or handicapped Web access telemedicine points Remote diagnostics

3GPP M2M Applications 1/2

Remote Maintenance/Control	Sensors Lighting Pumps Valves Elevator control Vending machine control Vehicle diagnostics
Metering	Power Gas Water Heating Grid control Industrial metering
Consumer Devices	Digital photo frame Digital camera e-book

M2M Market Adoption: Drivers

Diminishing prices for devices and communication costs

Widespread deployment of wireline and wireless IP networks

Ubiquitous coverage provided by commercial networks

- Advanced technologies that provide good latency and quality of service (QoS) can be used by companies without substantial upfront investment in network costs

Clear regulatory requirements and green technology investments

- Governments around the world are pushing for efficiencies in the distribution and consumption of energy
- It is well understood that information and communication technologies (ICT) can play a significant role in reducing carbon emissions by carefully monitoring and controlling energy consumption.

M2M Market Adoption: Barriers 1/2

Numerous incomplete standards leading to market fragmentation

- ZigBee, IETF 6LowPAN/ROLL all address short-range communication between sensors and a gateway or a router
- Application-level standards exist in some verticals such as healthcare and smart metering, but again there are multiple implementation options

Global regulatory hurdles

- Regulation can also delay global deployments because of different rules in different countries
- Regulation may be at the application level, such as in how healthcare data may be acquired, stored, and disseminated, or even at the communication level
- In addition, certification may have to be acquired in each country or region separately, resulting in higher costs

Security and privacy

- The general backlash against technology owing to privacy concerns may delay or even prevent numerous M2M deployments

M2M Market Adoption: Barriers 2/2

Carrier portability

- Inability to easily change operator
- Several types of device are deployed with a soldered SIM that cannot be removed, therefore preventing any changing of network operator

Network operator and company mismatch

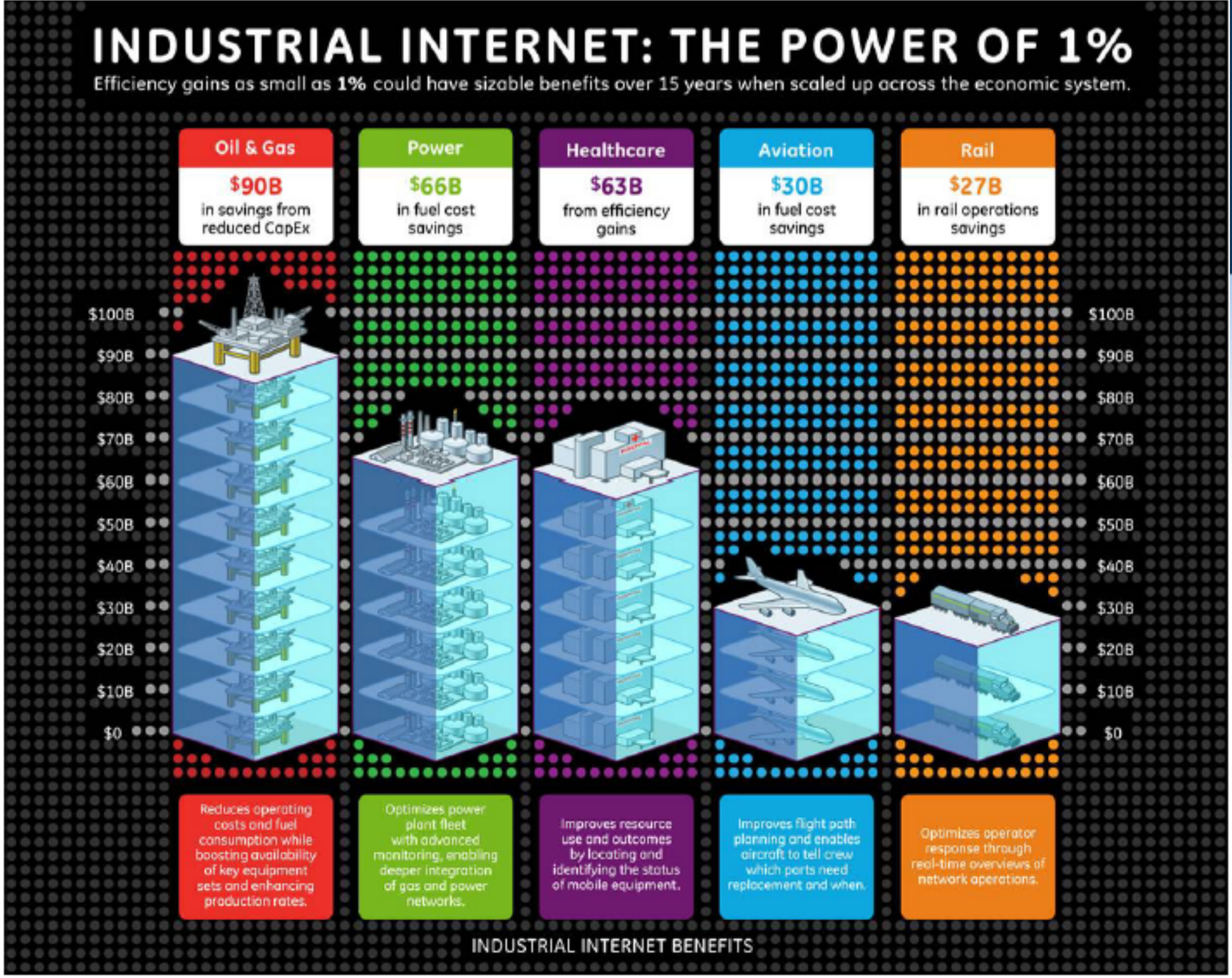
- The life cycle of many M2M services can be up to 15 years
- This means that companies such as utilities want network operators to guarantee availability of a specific technology for a very long period of time
- It is difficult for network operators that need to upgrade the technology frequently in order to make better use of the limited available spectrum

Technology challenges

- Device management
- Network scalability
- Device authentication on the provider's network (initial and repeat request);
- Subscriber network and application policy, charging rules

M2M usage scenarios

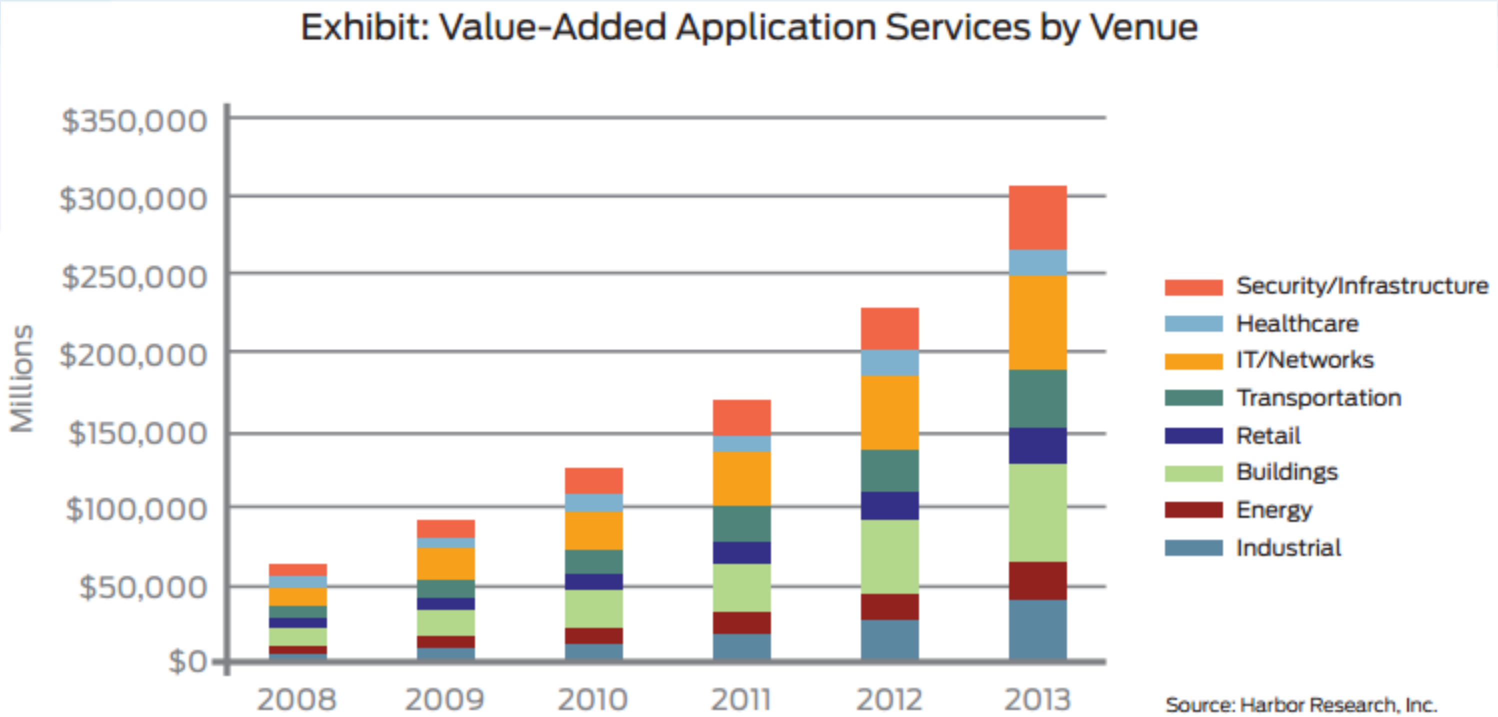
(IoT enabler service)



November 29, 2012: **New Industrial Internet Service Technologies From GE Could Eliminate $150 Billion in Waste**

http://www.gereports.com/new_industrial_internet_service_technologies_from_ge_could_eliminate_150_billion_in_waste/

M2M Revenues



Differences Between H2H and M2M

TOPICS	H2H	M2M
Density	Wireless devices' penetration rate is increasing. There are a lot of us. But maybe not that much compared to M2M potential.	M2M outnumbers human end users by order of magnitude. 3GPP SA1 requires solutions to cater for at least two orders of magnitude. Another possible reason for IPv6. Possible shortage of phone numbers.
Data Volume	Most of the traffic is downloaded and requires significant amounts of bandwidth (file, Web and video streaming).	Traffic is mainly uploaded and most of it requires small amounts of bandwidth (video surveillance might require more).
Battery	We can buy a new one—we can recharge.	It must be capable of auto-generating power or be self-sustaining for long periods.
Delay	We do have a tolerance for it even when it comes to voice.	Some applications are mainly for real-time control; urgent/emergency action would have little tolerance.
Security	Worth comes to worth. Instinct tells us or we just know if it has been stolen.	Not so much here. Robust security, even confidentiality ought to be available. New considerations are being made regarding Machine Communication Identity Module (MCIM) in Universal Integrated Circuit Card (UICC) or Trusted Environment (TRE).
Revenue	Good.	Low ARPD.
Dimensioning	Normal business case.	High level of endpoints connecting from time to time (can be predefined) to transmit small amounts of data. However, control network overload aspects must be considered.
Value Chain	Well defined.	To be created/adapted for new opportunities on top of common infrastructure.
Reachability	Satisfying.	Push/pull behavior. Might require much longer dormant period to minimize signaling on control plane.

M2M Technical Challenges 1/4

Interference

- Intensive interference in ISM frequency band
- The performance of M2M communications may be seriously degraded due to such self-existence/ coexistence interference

Channel dynamics

- Wireless channels in M2M communications are notoriously unreliable due to channel fluctuations and noise, which may become even worse due to the complicated construction in an indoor environment

Resource constraints

- The machines may be extremely resource constrained with respect to computation, storage, bandwidth, and power supply

Devices heterogeneity

- A home network generally comprises a large number of different devices as well as distinct services, which may generate dramatically diverse data sources

M2M Technical Challenges 2/4

Quality of service (QoS) support

- One typical example that requires QoS provision in M2M communications is a biomedical sensor network
- It is extremely important that lifecritical medical data is reliably delivered before being dropped due to the limited memory of most devices

Security

- M2M communications are typically required to be inexpensive and preferably unattended, which may expose them to a number of potential attacks
- These could be physical attacks, compromise of credentials, configuration attacks, and core network attacks

M2M Technical Challenges 3/4

Server-initiated device operation

Decentralized and distributed architecture approach

- High flexibility
- Server and client mixed with a peer-to-peer approach
- Dynamic network groups

Interference control/reduction and preventing electromagnetic pollution

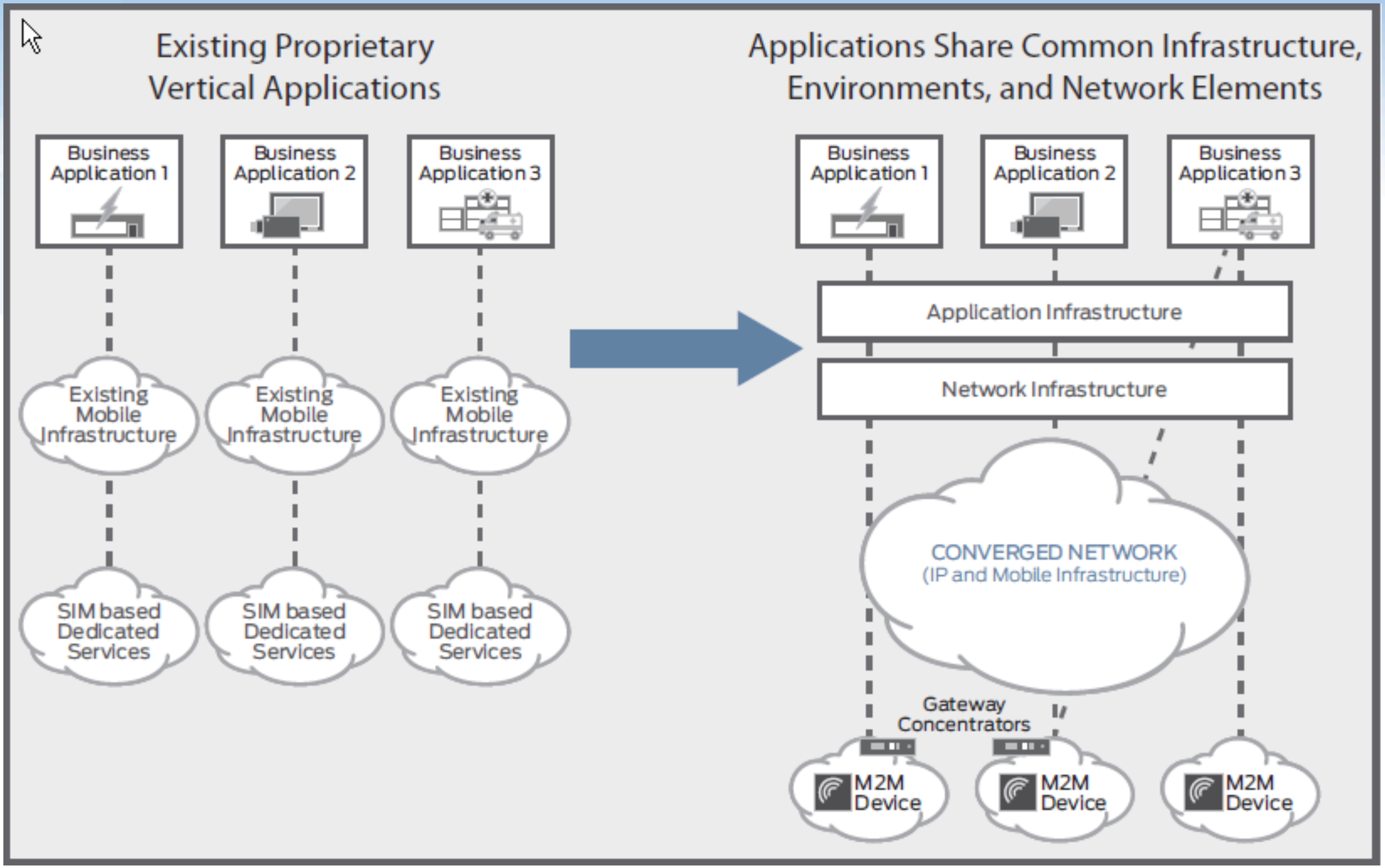
- Connect and transmit when possible instead of stay connected

Low-power consumption per device

Hierarchical QoS criteria

Co-existence with other non-M2M services

Vertical vs Horizontal Service Provision



M2M e2e Network Structure

Access Network – connecting the sensors & actuators:

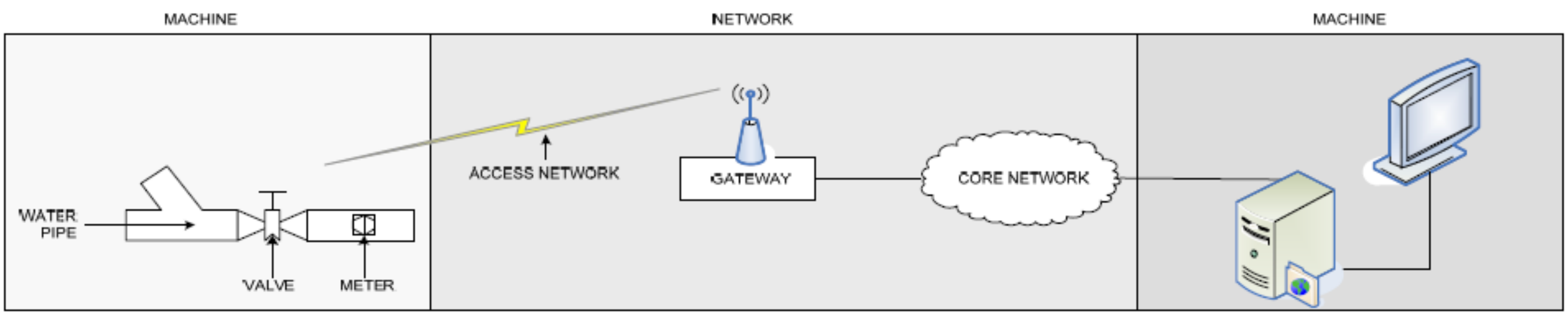
- "wired" (cable, xDSL, optical, etc.)
- wireless "capillary"/short-range (WLAN, ZigBee, IEEE 802.15.4x, etc.)
- wireless cellular (GSM, GPRS, EDGE, 3G, LTE-M, WiMAX, etc.)

Gateway – connecting access and backhaul/core networks:

- network address translation
- packet (de)fragmentation; etc.

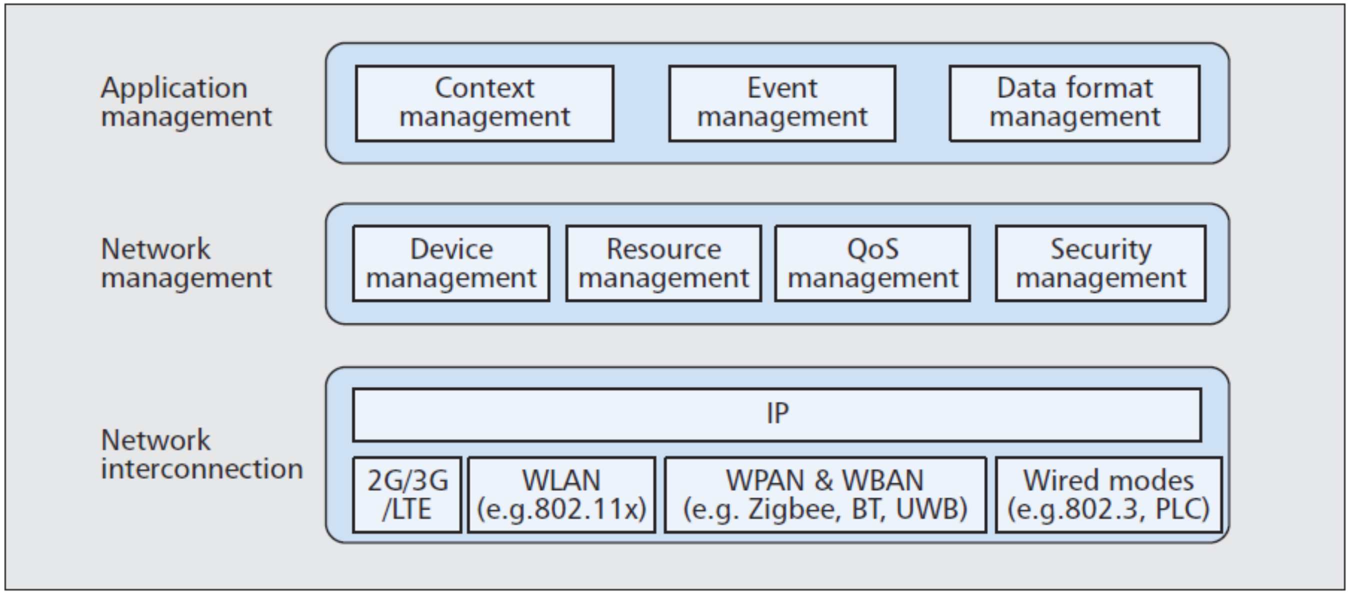
Backhaul/Core/Internet Network – connecting to computer system

- IPv6-enabled Internet



M2M Gateway Architecture (M2MGW)

- M2M network is essentially a heterogeneous network that has a backbone network and multiple subnetworks
- Is a central machine M2MGW, managing the whole network and connecting the network to the outside Internet
- Functions include access control, security management, QoS management, and multimedia conversion



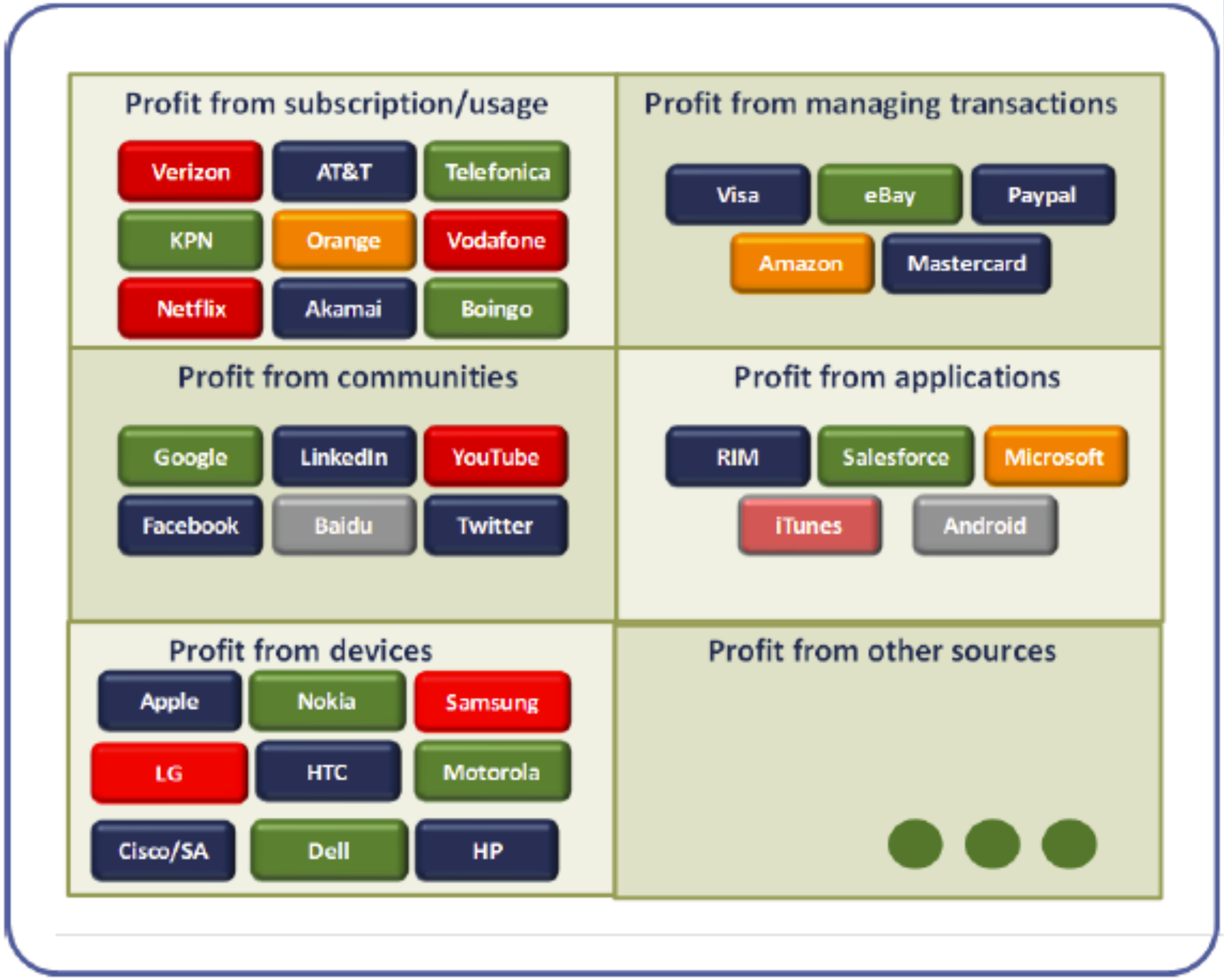
M2M Markets and Economy

Mobile network energy consumption

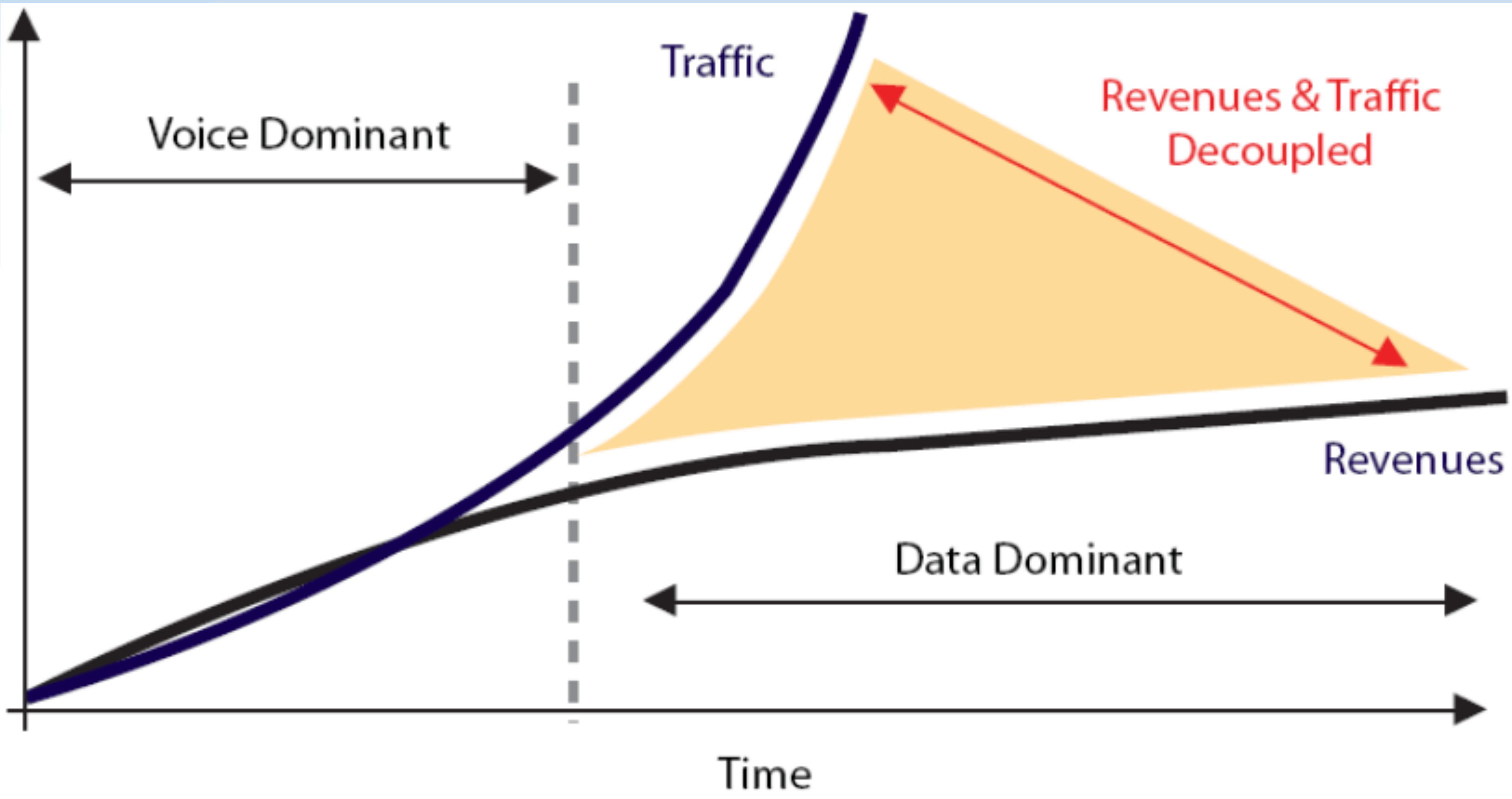
- Green Activities / Energy Efficiency: ICT 2% of global emissions (telecom 0,5%)
- Energy efficient solutions
  - User device battery life / recharging
  - Base stations
    - One NSN Flexi multiradio base station consumes 790W (0.79kWh) of power
    - There are roughly 200,000 3G base stations in China
    - In total that a means power consumption of 1,384 GWh / year
    - A studio apartment consumes roughly 1.25 MWh / year
    - With the power used for those 3G base stations we could cover electricity needs of homes for 1.1 million people
    - Tampere, Finland has 214,000 people

ENERGY HARVESTING IS THE FUTURE

Who is Involved?



Trends in Operators Revenue



Challenging Service Providers (SP)

Blurring of roles within and between marketing, network and IT

- Traditional product silos are being disrupted with **customer centric approaches** by players like Apple
- Customer experience focus is taxing siloed analytics and business intelligence

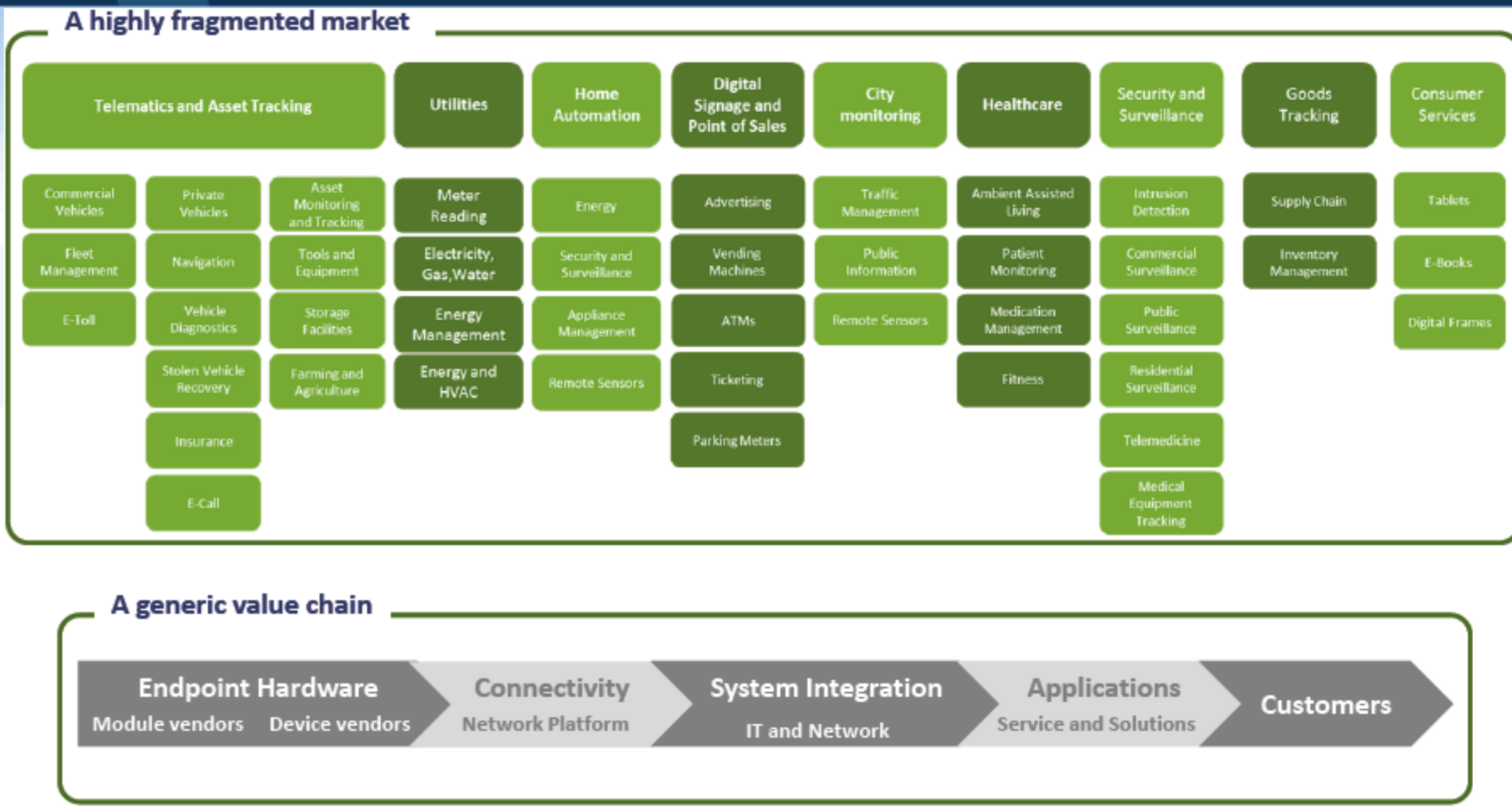
Over "whose dead body"

- As traditional organizational empires are dismantled, power struggles stifle SPs ability to respond

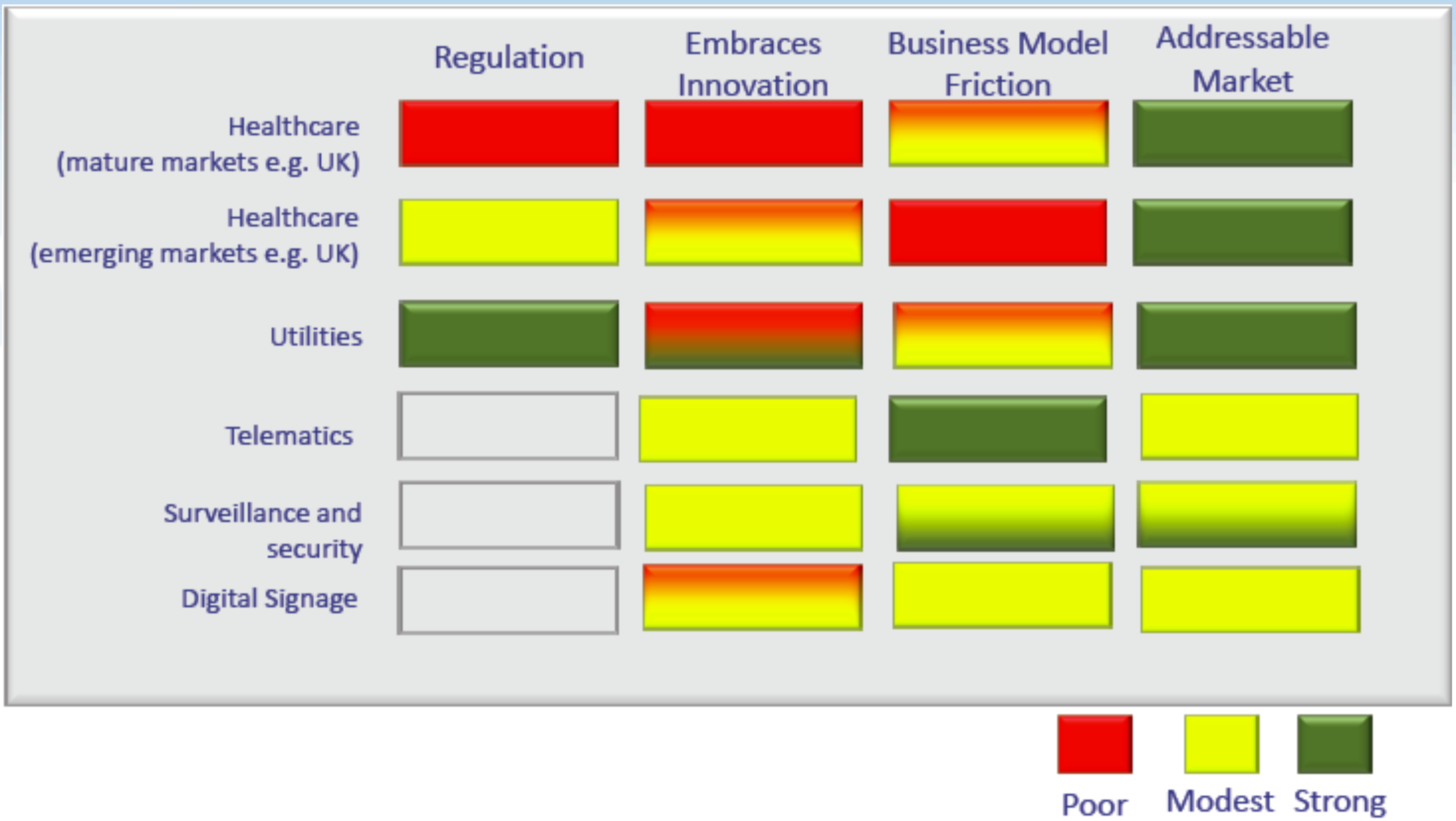
Change can't happen over-night

- SPs are taking phased approaches to transformation, recognizing that they cannot occur without appropriate employee incentives

M2M is Highly Fragmented Market



M2M Market Opportunities for Service Providers



M2M market expansion opportunities are not straightforward!!!

Service Providers to Form a NEW Ecosystem for M2M

Key Considerations for SPs

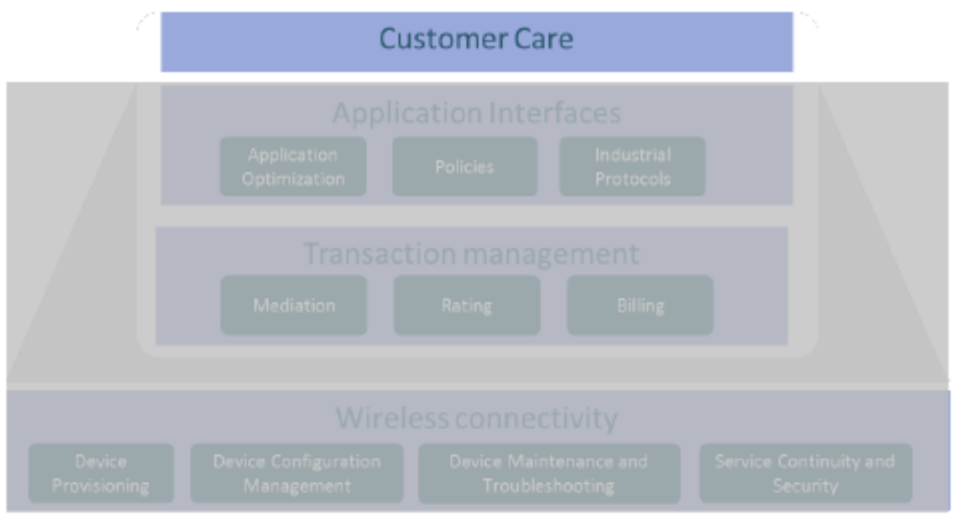
- Architecture standard-based platform
- Impact of business models on solution architectures
- Target industry verticals and partnership structures (if any)
- Ecosystem evolution, which is particularly the case where complex ecosystems are required
- Interoperability, roaming and partnerships
- Regulation – e.g. Healthcare

While solutions vary amongst SPs, consistent technology demands are emerging and forming the basis of SP platform strategies

New Demands for SPs in M2M Business

New Customer Care Requirements

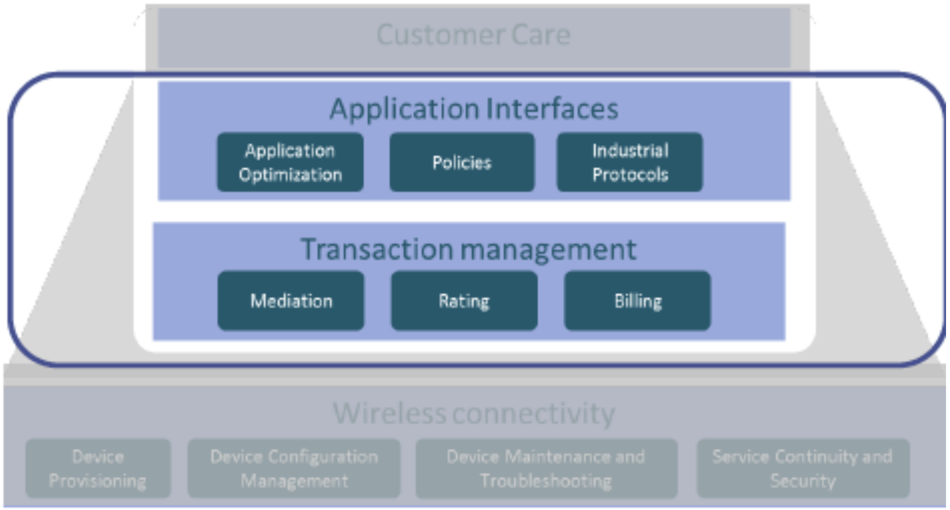
- Automation to enable profitability from low ARPU services
- Ability to integrate competencies amongst partner players
- Anticipate one customer might have thousands of devices (M2M modules) on the network



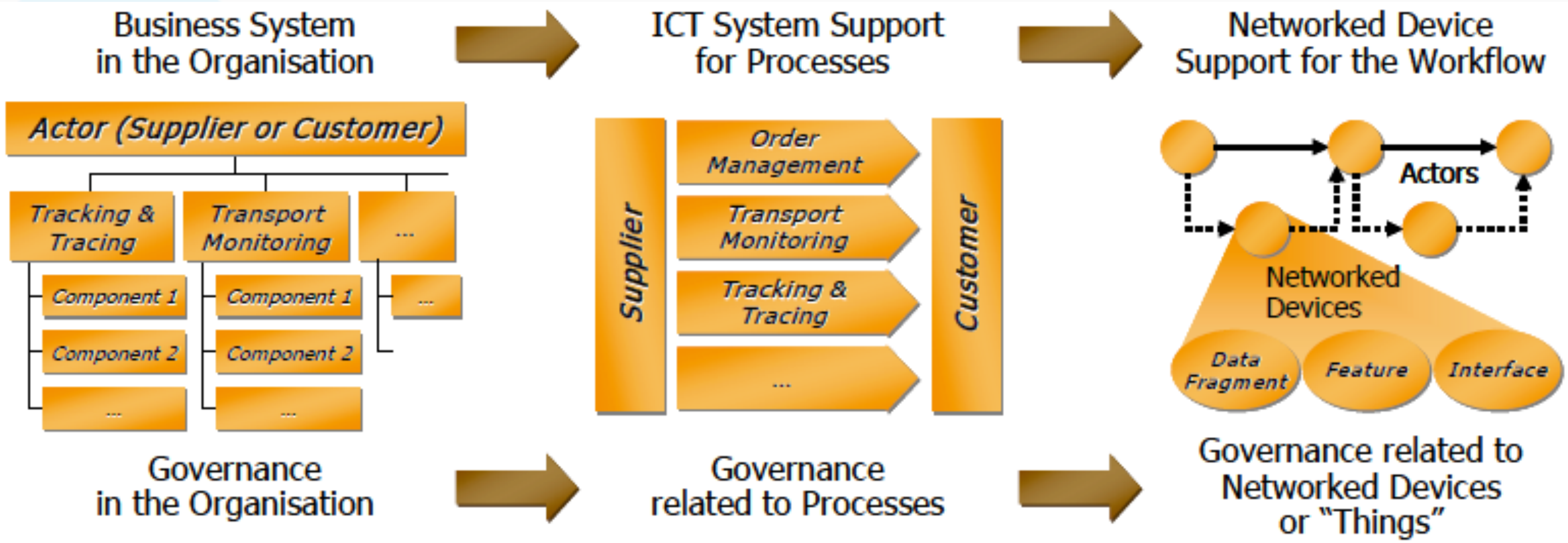
New Demands for SPs in M2M Business

Key Requirements

- Standards based solutions to ease development challenges and application portability – Including industry specific standards
- Security and Fraud Management – particularly with Transaction Management
- Emergence of new Policy Management and Enforcement regimes



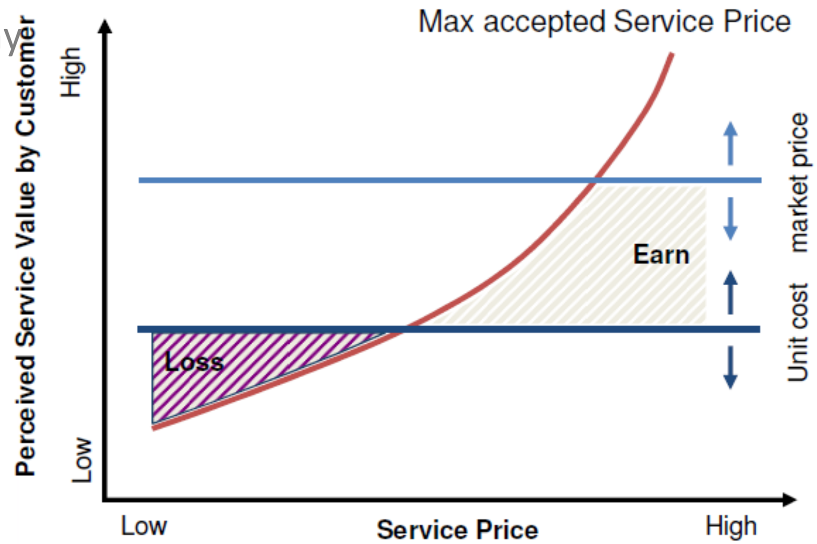
Change in Business Organization



Key Success Factors for M2M

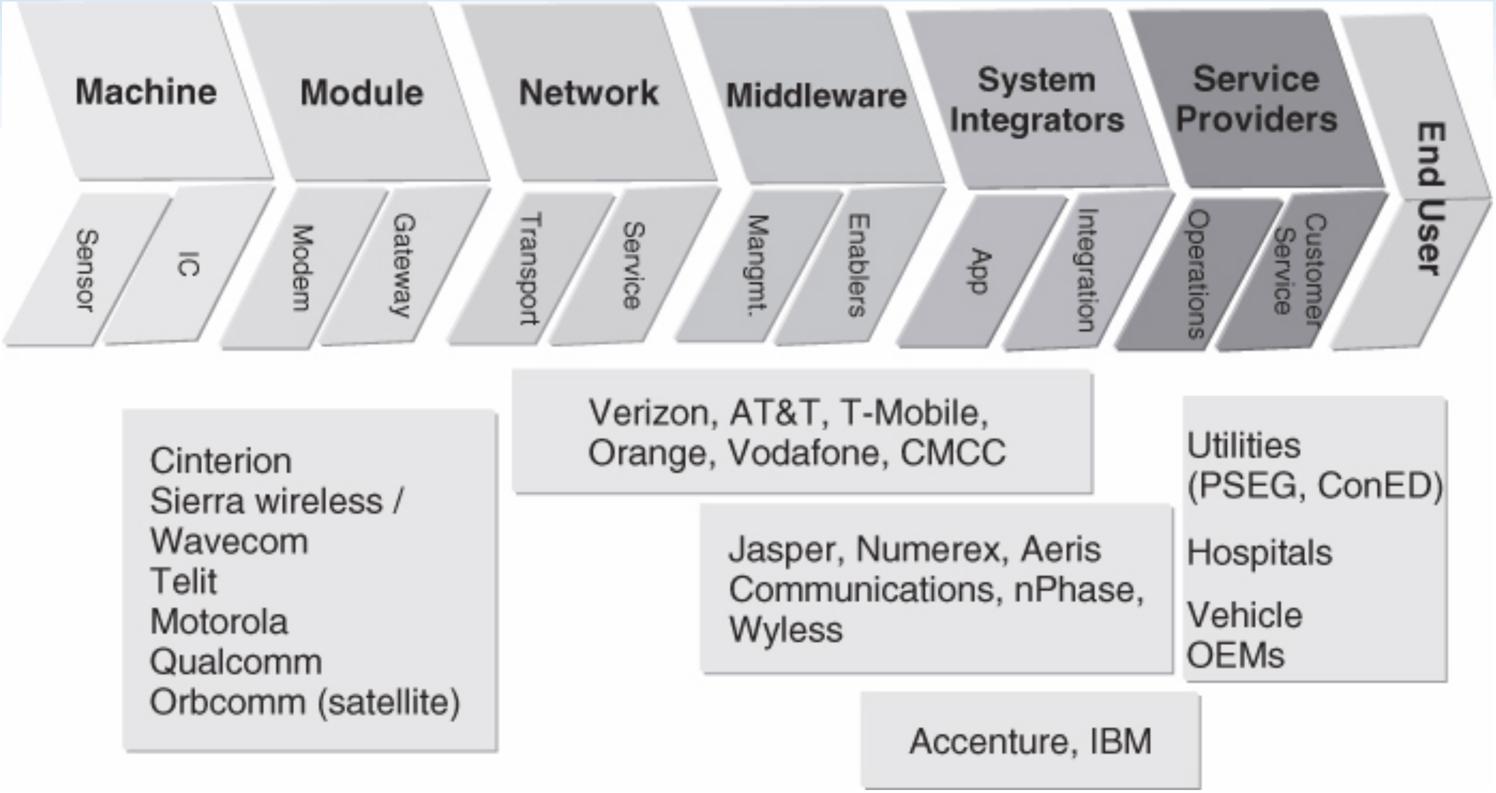
Key Takeaways

- The perceived **value of a product is heavily influenced by the way the customer's individual needs** are addressed and less by its technical nature
- **M2M Business is about partnering** as one company (usually) cannot offer the entire Service alone
- In order to be competitive the costs need to be managed
  - Openness & Standardization
  - Freedom of Choice for Components / Partner
  - Design with Options for Evolution



ETSI: In IoT the value proposition is not primarily about physical products and not even about services, it's mostly about experiences and feelings

M2M Value Chain



Strategic Partnerships

BMW Connected Drive Service

- Vodafone and DT Germany
- China Unicom
- AT&T (BMW Assist)

Hyundai

- Vodafone (European coverage)

Ford

- Vodafone Germany and United Kingdom, LTE pilot in partnership with Ericsson

General Motors OnStar service outside of the United States

- Vodafone

Kia

- Vodafone

Audi

- T-Mobile USA

Renault

- Telenor Connexion

MNO and Partnership Model co-operation for M2M

THE REVENUE OPPORTUNITY FOR MOBILE CONNECTED DEVICES IN SATURATED MARKETS		
TELENOR	New business unit "Telenor Objects" and co-operation withTelit and Volvo for in-car SIM card	TELIT VOLVO
T-MOBILE	Echelon and T-Mobile alliance to reduce the cost of a secure smart grid network for utilities; also co-operation with Celevoke to sell wholesale data services to M2M clients	CELEVOKE ECHELON
VERIZON WIRELESS	Co-operation with OnStar/GM, also Verizon Wireless and Qualcomm announce joint venture to provide advanced M2M solutions (nPhase)	QUALCOMM ONSTAR BY GM
AT&T	Emerging devices business unit launched in October 2008; combined platform with Jasper Wireless	JASPER WIRELESS
ORANGE	"Orange M2M Connect" platform; strategic partnerships with Wavecom, Alcatel, and Cinterion, Orange (France and Spain) are co-operating with Securitas Direct to use wireless GSM network for more advanced surveillance solutions	WAVECOM CINTERION SECURITAS DIRECT
VODAFONE	New M2M platform July 2009, Vodafone Spain also co-operates with Securitas Direct	SECURITAS DIRECT
TELEFONICA	Telefonica's Smart M2M platform in co-operation with Telit	TELIT

Source: Northstream white paper, February 2010

Case Study: BMW Connected Drive

Source: BMW 2012

The global shipments of cars and small trucks was 75 million in 2011.
Telemetry solutions are likely to be profitable and "sticky" but integrated solutions will be niche relative to traditional mobile market scale.

SP roles current and *potential*

Connectivity Services:

- Persistent connectivity
- Device Management
- Message Management
- Data Management

Location Based Services

- Real time location
- Mapping and Traffic Reporting

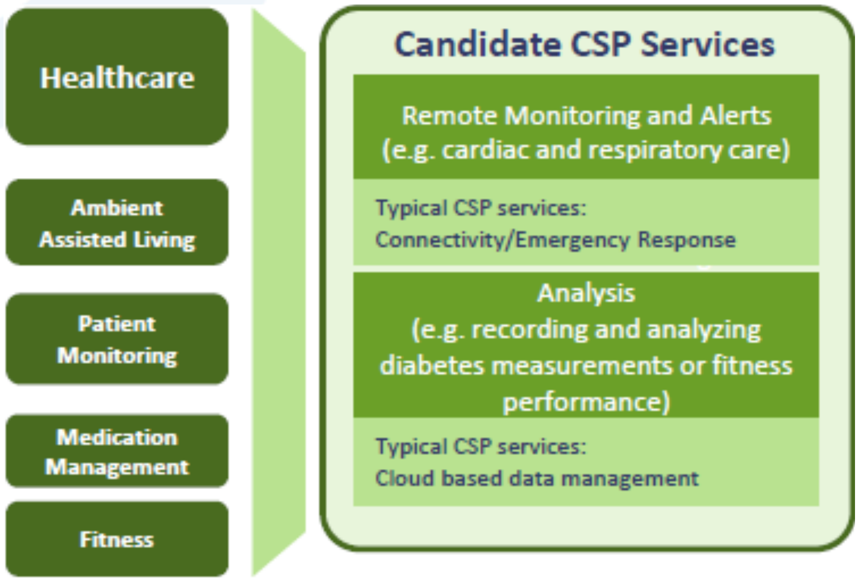
Safety

- e-Call (EU Mandate)

Infotainment

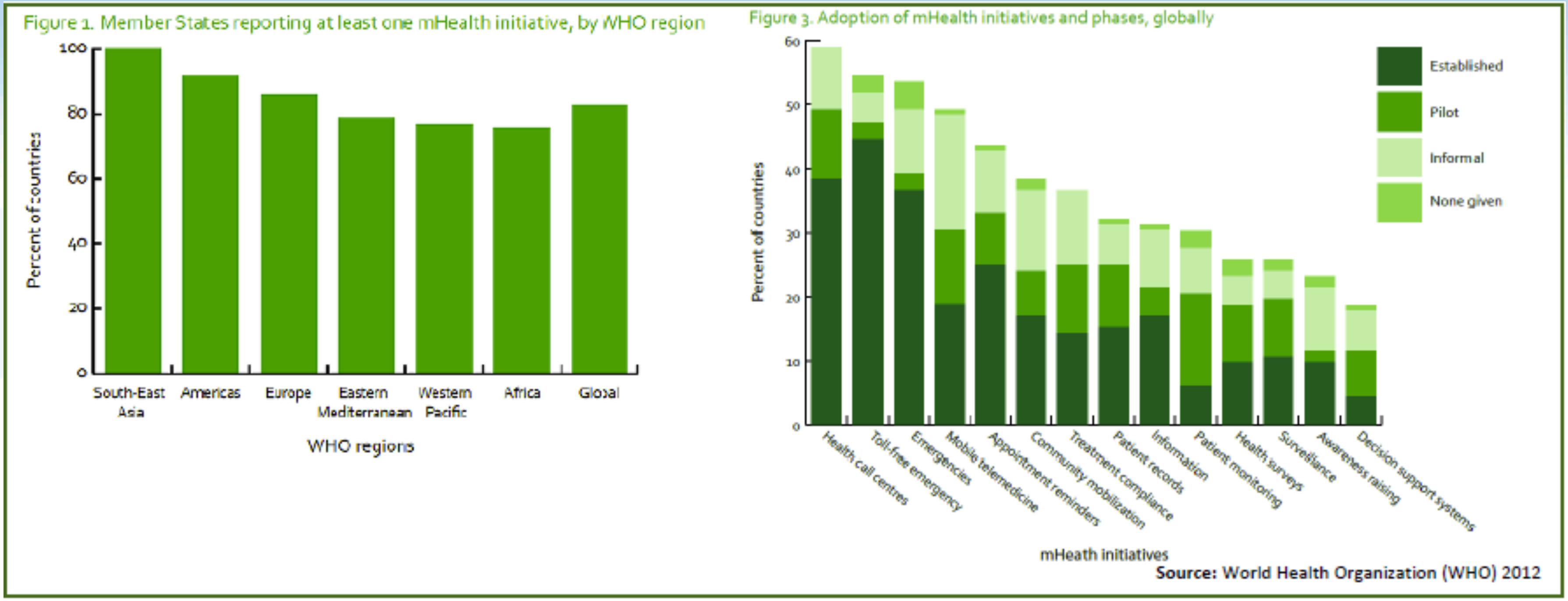
- *Cloud services*
- *Policy driven personalization*

mHealth Case



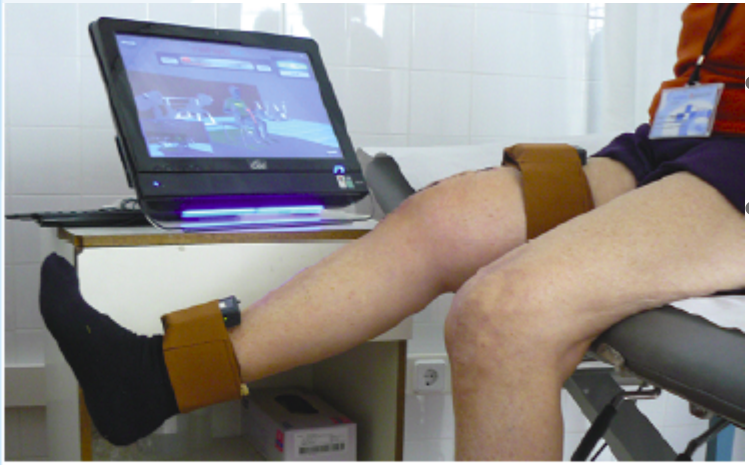
- <u>Fragmented value chains can stifle innovation</u>
- Innovation influenced heavily by safety considerations and driven by consensus
- Typically insurance payments depends on clear evidence of clinical benefit and adequate fraud management
- mHealth solutions associated with Fitness and Health have less difficult market demands with direct to consumer applications being delivered with over-the-top applications
- Activities in emerging markets are very intensive, but **in most cases business models STILL need further refinement**

WHO Reports Strong Interest in mHealth



- 83 percent of WHO (World Health Organization) member countries have one or more have established mHealth initiatives
- Call centers, connectivity, emergency services and mobile telemedicine gaining greatest attention

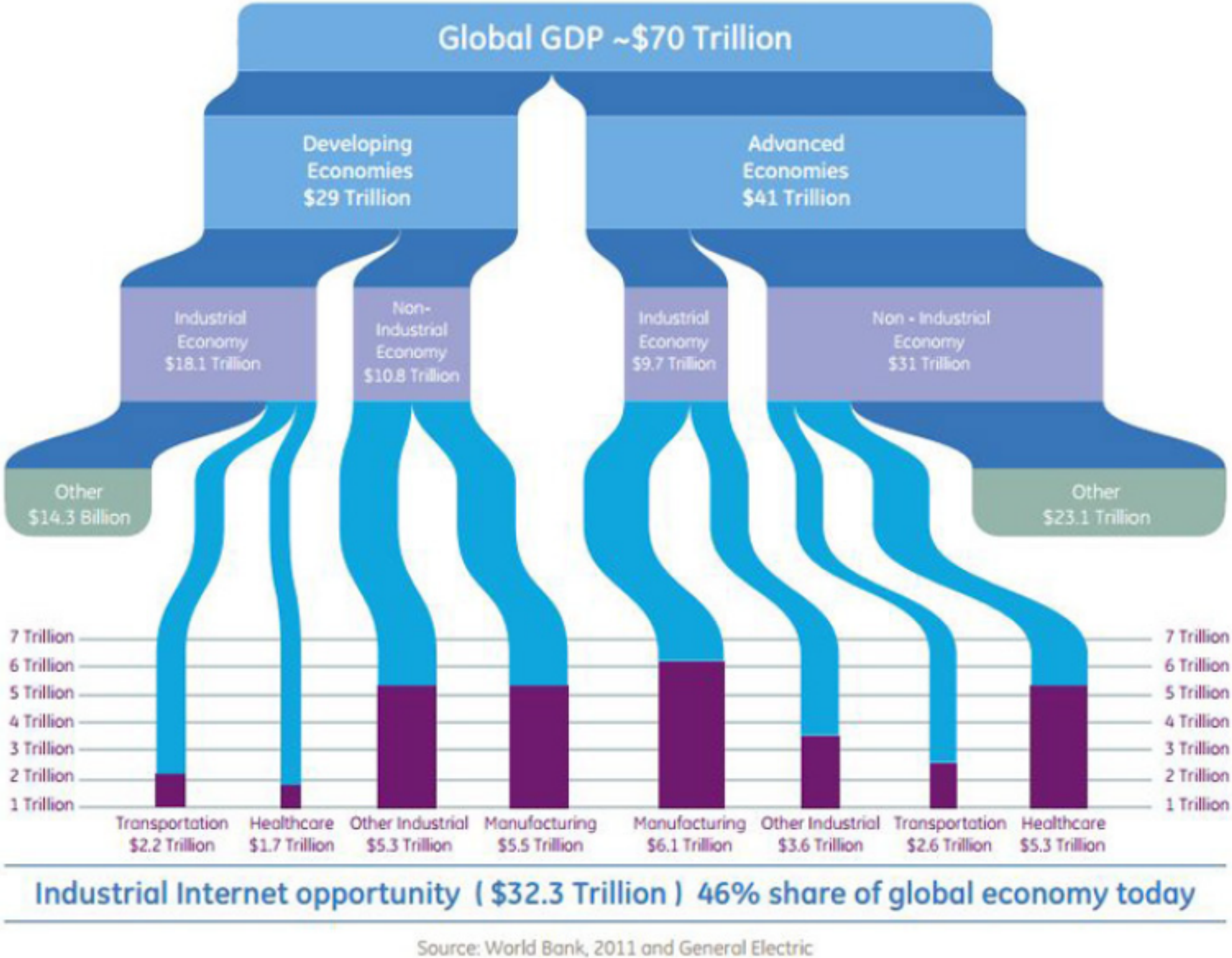
Case Study: Telefónica Tele-Rehabilitation



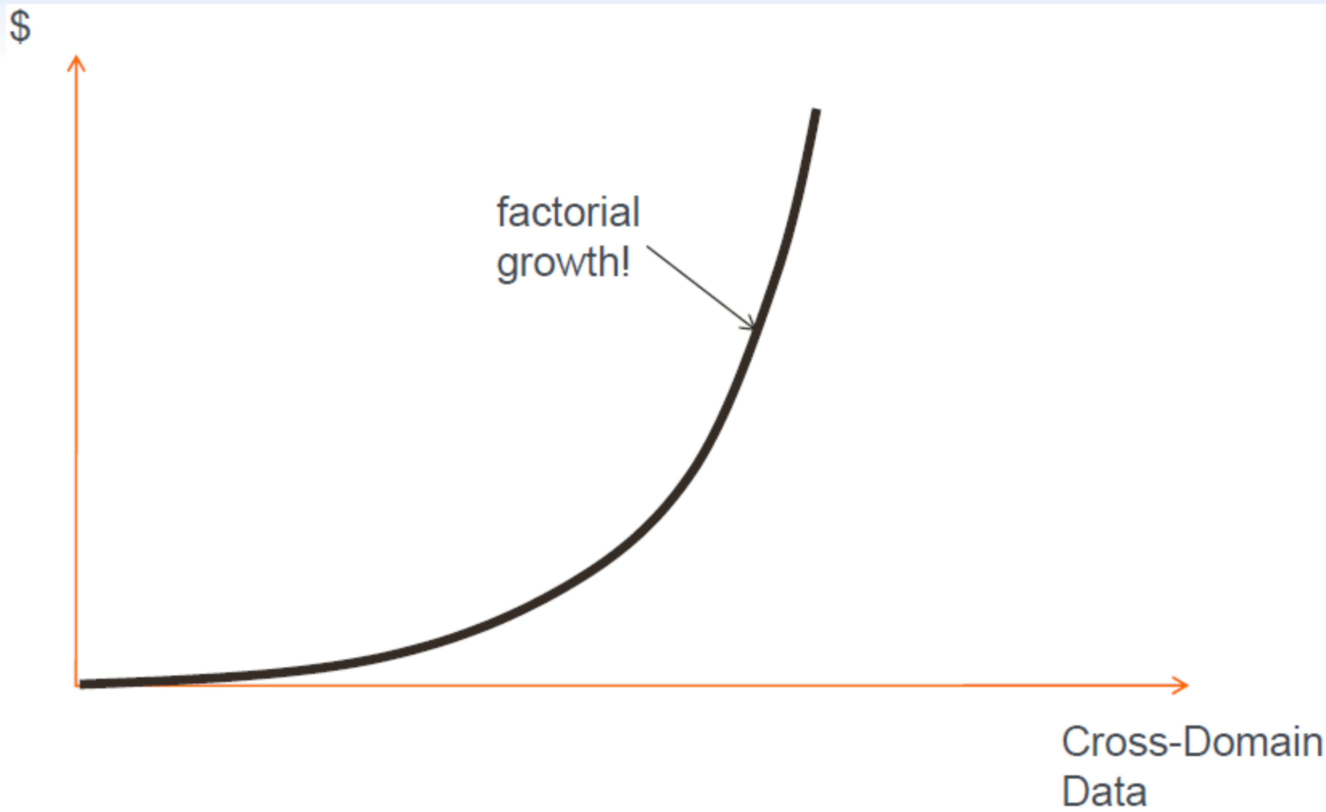
Source: Telefonica 2012

- Solution catering for patients rehabilitating from injury or operation
- Patients are provided with a touchscreen kit in their home and medical monitoring devices connected to the affected region
- Doctors remotely monitor patients, assign exercises and respond to feedback from the patients
- **Currently Telefonica's role is largely focused towards delivering connectivity and systems integration services**
  - The market is still defining itself with the potential for extension into areas such as assisted living, personal fitness, and other functionality such as image processing.
  - As new solutions emerge other considerations such as **information security, policies, personalization**, advertising etc. are likely to emerge

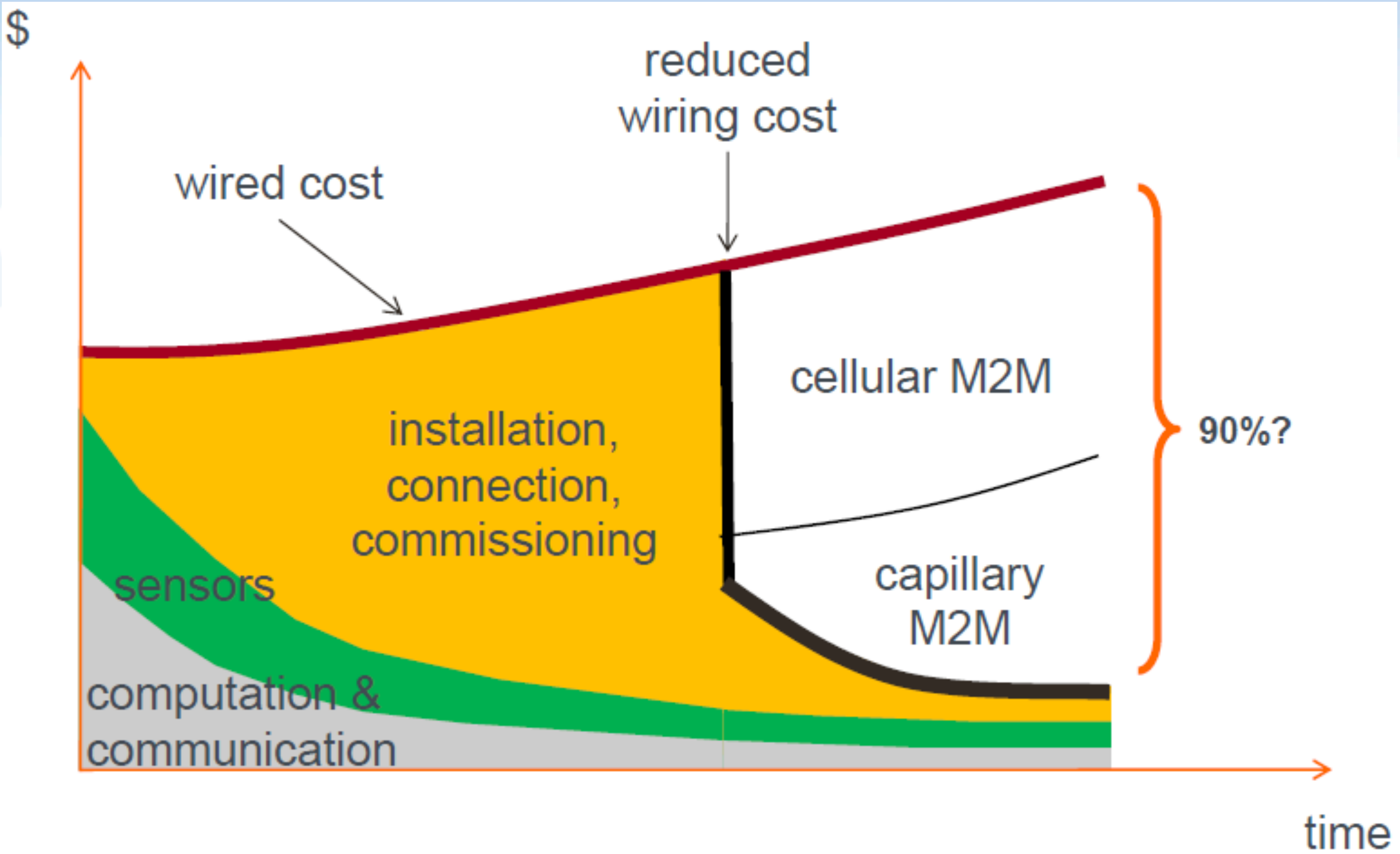
ROI


Global GDP ~$70 Trillion
Developing Economies $29 Trillion
Advanced Economies $41 Trillion
Industrial Economy $18.1 Trillion
Non-Industrial Economy $10.8 Trillion
Industrial Economy $9.7 Trillion
Non - Industrial Economy $31 Trillion
Other $14.3 Billion
Other $23.1 Trillion
7 Trillion
6 Trillion
5 Trillion
4 Trillion
3 Trillion
2 Trillion
1 Trillion
Transportation $2.2 Trillion
Healthcare $1.7 Trillion
Other Industrial $5.3 Trillion
Manufacturing $5.5 Trillion
Manufacturing $6.1 Trillion
Other Industrial $3.6 Trillion
Transportation $2.6 Trillion
Healthcare $5.3 Trillion
Industrial Internet opportunity ($32.3 Trillion) 46% share of global economy today
Source: World Bank, 2011 and General Electric

ROI – Cross Domain Dividends



ROI – Savings by M2M



Opportunities for New Business Models

M2M provides low Average Return Per Device (ARPD)

- But at the same time offers low efficiency (if any), making it possible for operators and executives to design lucrative business models that offer services as the industry shows converging signs that this market segment can emerge as a serious and significant opportunity

The current marketplace is extremely fragmented

- With many small, vertical and specific niche applications

Efforts are underway

- To bring some level of normalization in the direction of moving away from the current siloed landscape to a more horizontal integrated approach
- Occasionally, some in the industry refer to this as "inverting the pipes and going to mass market applications"

M2M in Smart Cities

M2M is needed

From the humanity point of view

- we are now more than 7bn people on the planet
- 1 out of 2 is living in cities today; impact onto people's health is enormous
  - 80% in Europe
- e.g. 2 Million people are estimated to die annually due to pollution

From the political point of view

- politicians have hence become very susceptible to this topic
- politicians are eyeing ICT technologies as a possible remedy

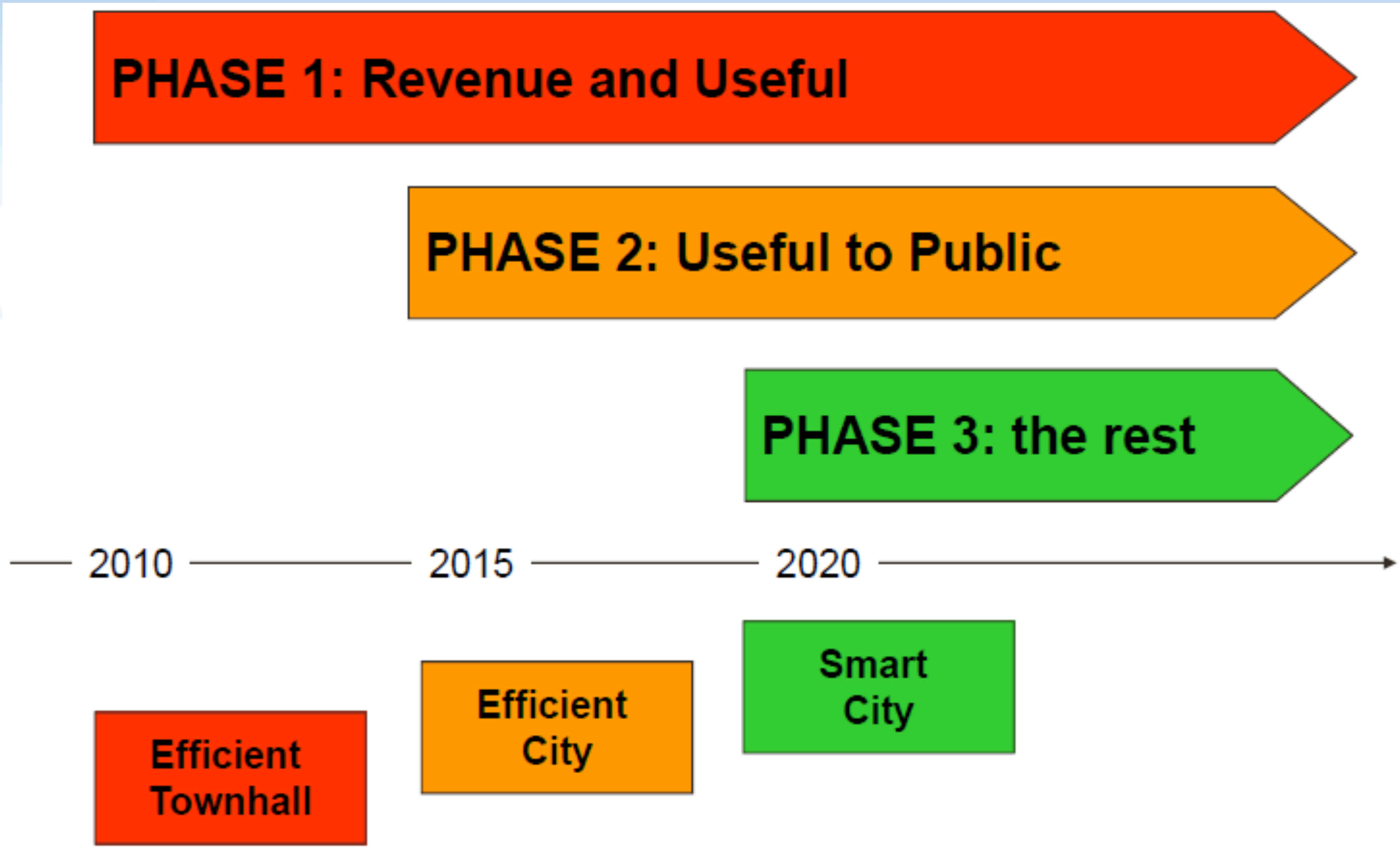
From the market point of view

- >$100bn per year in 2020 with >$20bn annual spending on Smart Cities

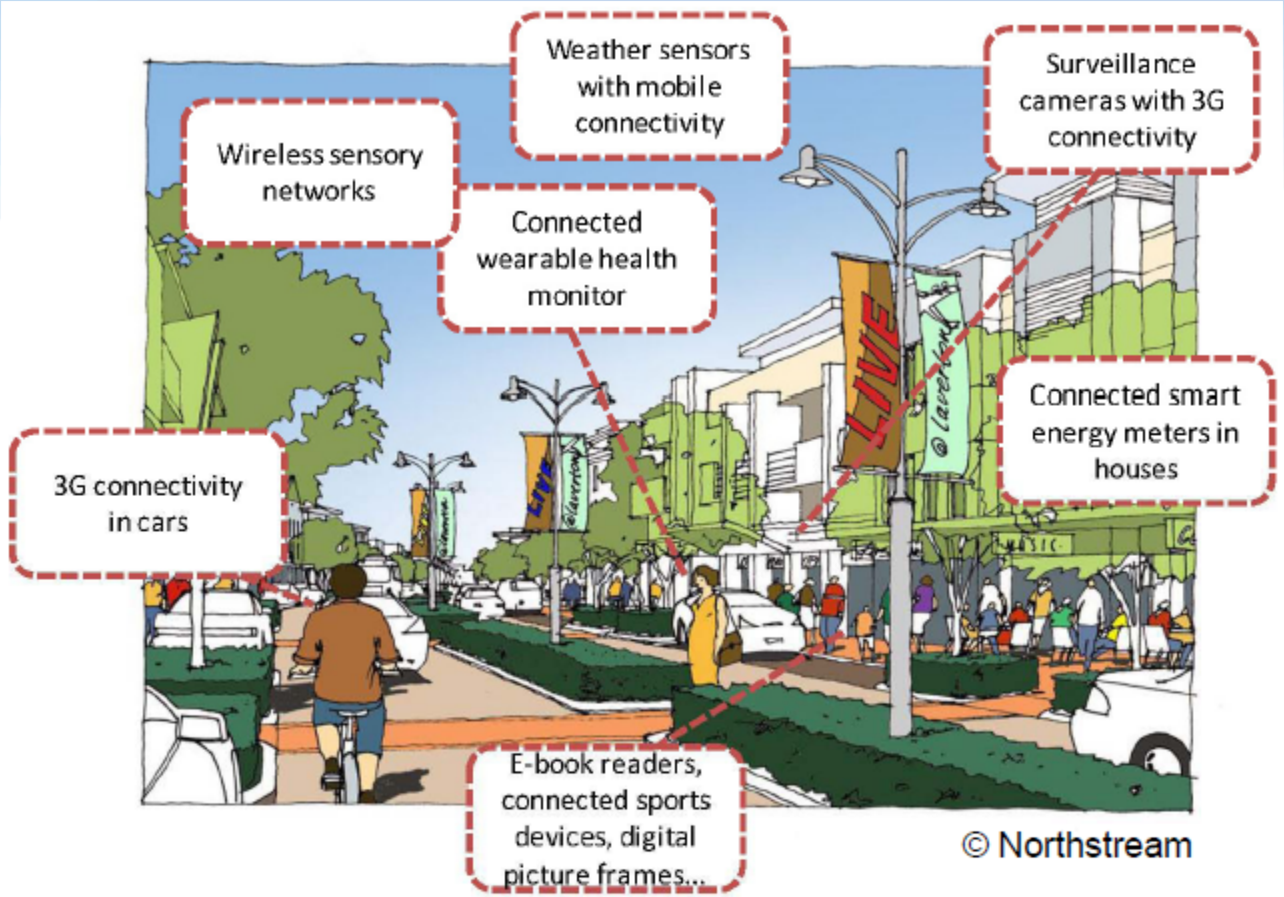
From the technology point of view

- technology players are hence trying to enter this market (IBM, Cisco, HP, Oracle)

Smart Cities (SC) Rollout Phases



Yesterday's SC Vision



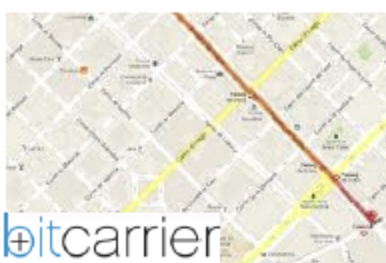
Today SC Reality

Smart Parking

© Worldsensing

Traffic Flow

Travel Time



Smart City Control Platform

Proven Technologies With Solid Deployment Track-Record Today!

Smart Bins

Critical Infrastr.

Historic Sites

M2M in Smart Grids

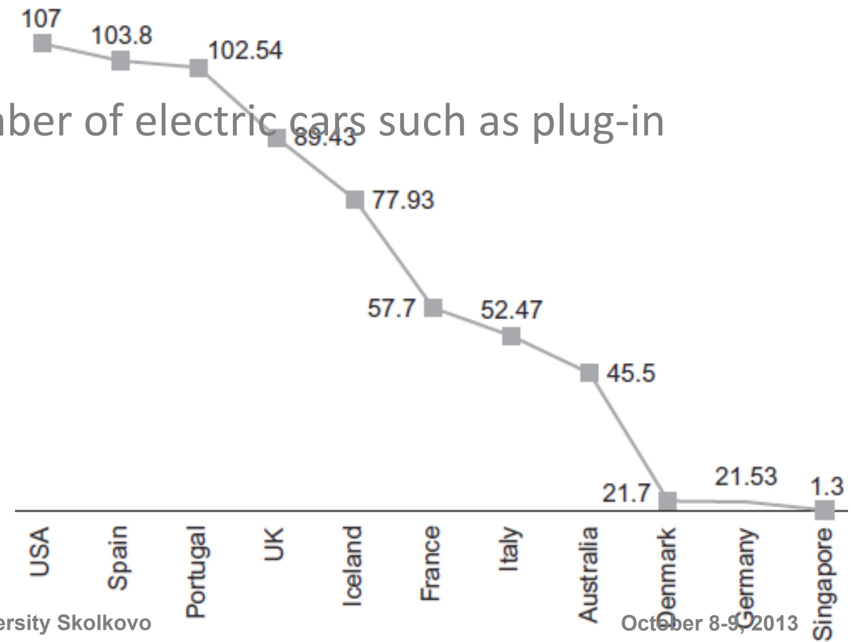
Grid Challenges

Grid Reliability

- Each minute of network outage has economical consequences
- Today's electricity system is 99.97% reliable, yet still allows for power outages and interruptions that cost US population at least $150 billion each year — about $500 for every man, woman and child
- Figure shows the number of minutes of outage in the distribution grid
  - http://www.oe.energy.gov/1165.htm

New challenges ahead

- The introduction of a potentially large number of electric cars such as plug-in hybrid electric vehicles



Smart Grid Driving Forces

The smart grid will be one of the most important applications of the Internet of Things

A major paradigm change is happening in electricity markets, driven by the convergence of several factors

- Accelerated introduction of renewable-energy sources, which brings an increasing degree of randomness to the traditionally deterministic supply side
- Penetration of the Internet in homes and businesses, and the increased confidence in next-generation smart distributed networks for mission-critical applications
- Gradual opening of electricity markets, with **new regulation** opening production facilities and distribution networks to all
- **Increasing volatility of electricity prices**, resulting from the underlying volatility of oil and natural gas, but also increasingly from the propagation of external shocks, such as exceptional climatic events, through energy exchanges

Electricity Operators need SG

The current credo of electricity operators "Demand is unpredictable, and our expertise is to adapt production to demand", is to be reversed into "production is unpredictable, and our expertise is to adapt demand to production"

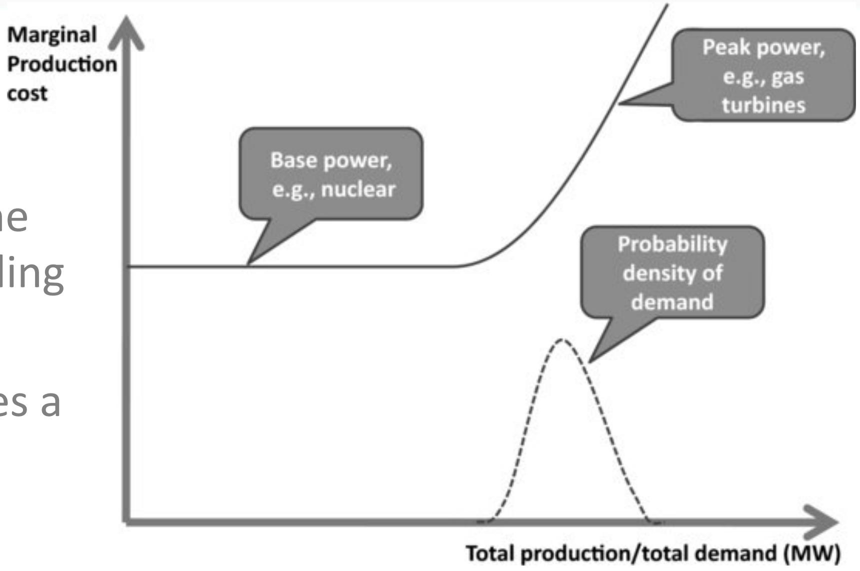
- How to predict and react fast and promptly – **the key issue**
- **The key assets of an energy operator will** no longer **be** the means of production, but **the next-generation communication network** and information system, which they still need to build entirely

Marginal Cost of Electricity: Base and Peak Production

- The cost of electricity generated by a power plant is the sum of the cost of the primary energy supply and the amortization of the plant itself
- Base demand: the component of demand that varies most slowly and can be produced from plants running continuously close to their maximum capacity
  - Has the cheapest marginal production cost
- Variable demand: which can be supplied from plants operating at a lower utilization rate, or purchased on the market
  - Has a higher marginal production cost

Electricity Operators need SG

- For all electricity operators the marginal production cost gets higher and higher as the current production level increases beyond the “base demand”
- At some point
  - The cost of generating each additional MWh gets so high that it may exceed the final, usually fixed or slowly varying, selling price of the MWh to the end consumer
  - At this point, demand response becomes a no-brainer: <u>instead of producing more power and losing money, the operator should create an incentive for its customers to use less energy</u>



Electricity Operators need SG

The current electricity industry has developed extremely sophisticated strategies to adapt production to demand in real time

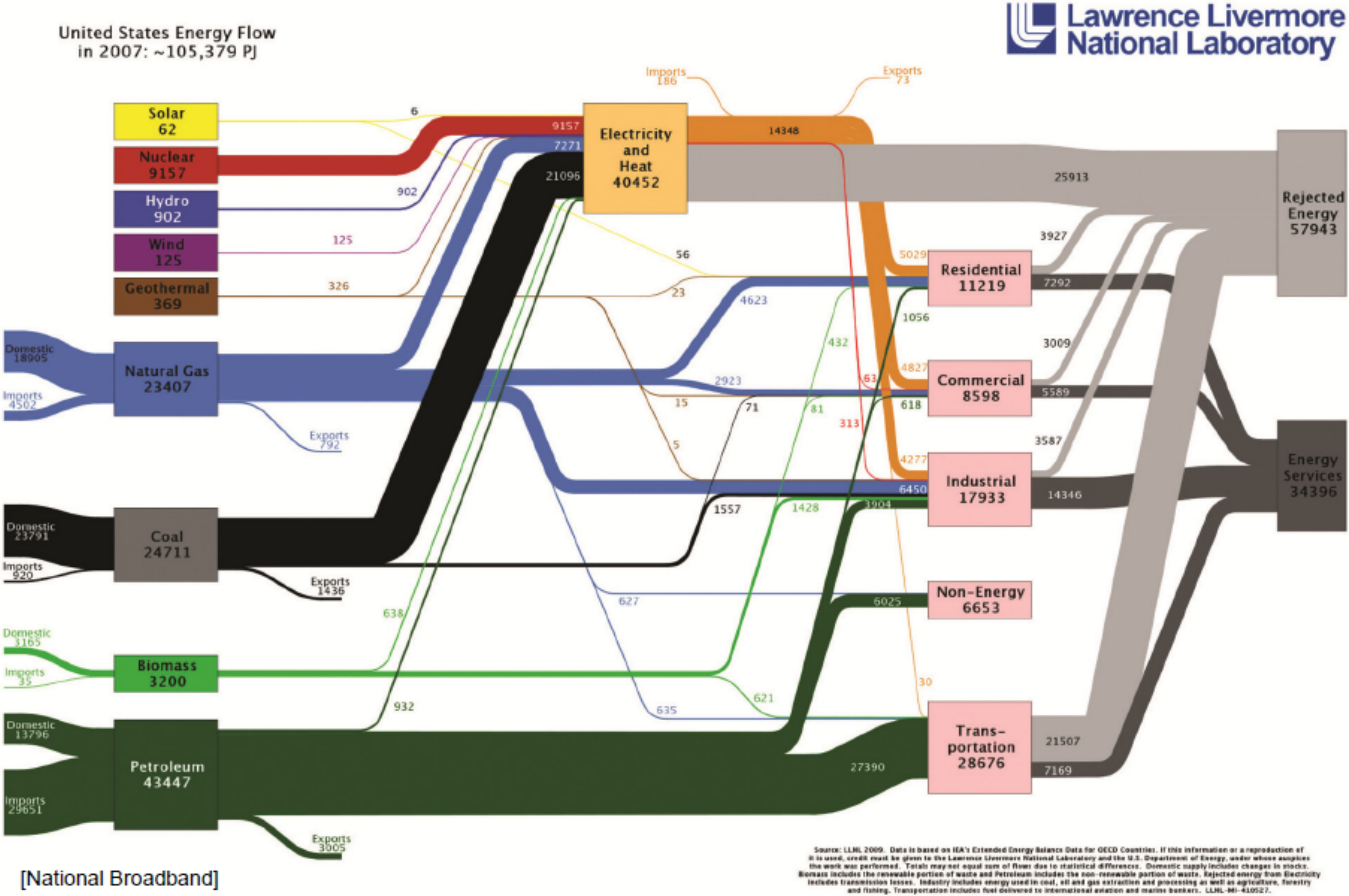
The costs associated to this lack of control on demand are very high

- Dimensioning of public grids for peak transmissions
- Building of “peak power” plants used only a few hours during the year
- Extremely inefficient CO2 emissions during peak hours

M2M is a solution, however

- M2M network and infrastructure do have a cost
- Instead, these smart-grid applications should be considered as applications of the Internet of Things
  - The communication network and the controllers should support general-purpose M2M communications and applications, decreasing the marginal cost (energy, amortization) of the smart-grid use cases
  - In order to enable this infrastructure sharing, standards such as IP and ETSI M2M are critical
    - IP ensures that the communication network is application and physical layer agnostic
    - ETSI M2M forms the middleware layer controlling the information flows: which application can access which sensor/actuator, for which usage

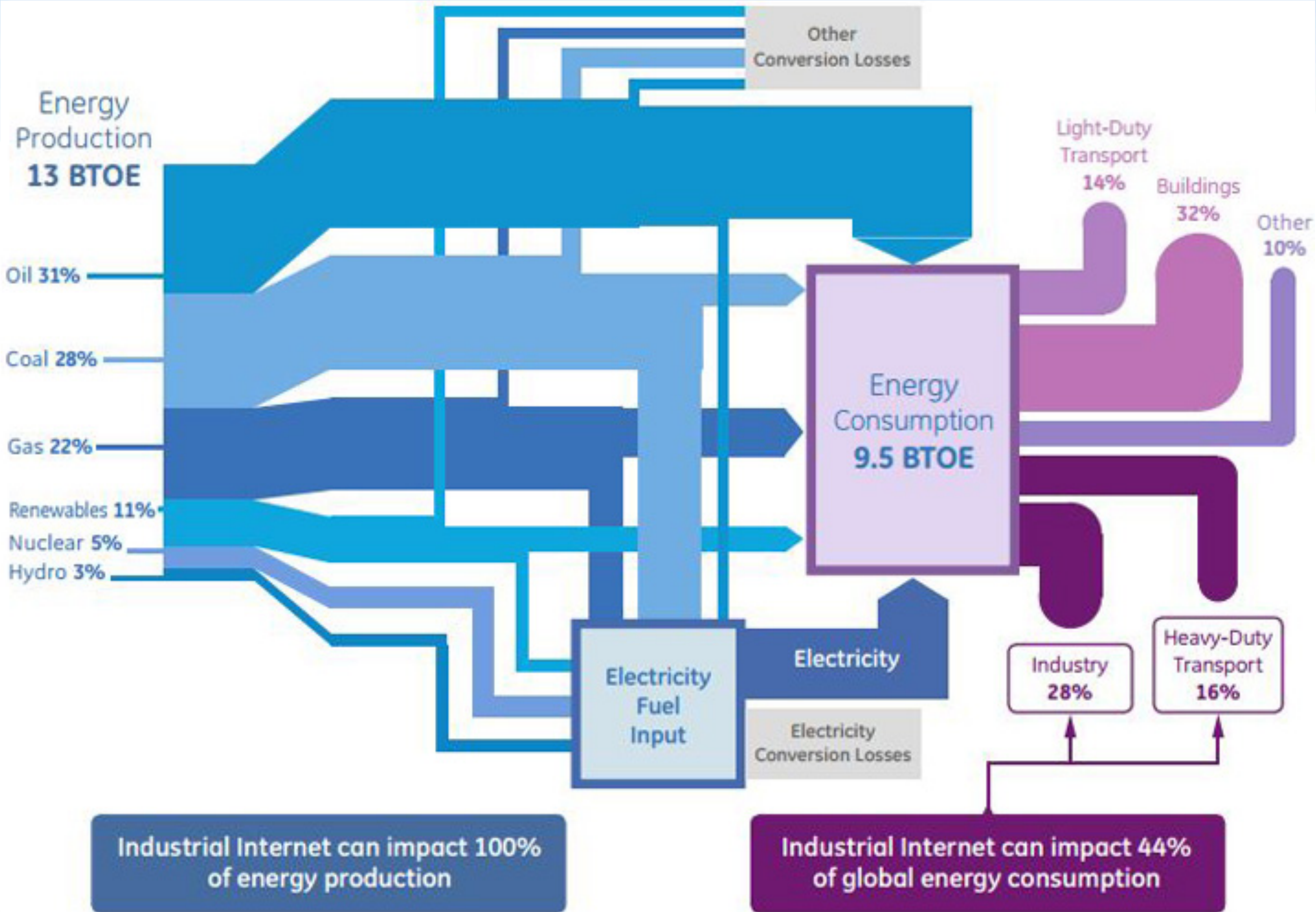
Energy Flow Example



[National Broadband]

M2M Play Central Role

Combination of Networks and Machines Could Add $10 to $15 Trillion to Global GDP



Source: GE, Global Strategy & Planning Estimates, 2011

Why Smart Grid?

European 20/20/20 target for year 2020:
- 20% cut in Greenhouse gas emission
- 20% rise in Renewable energy usage
- 20% cut in Energy consumption

Historical Smart Grid Developments

- EU initiated the smart grid project in 2003 (**10 years back!**)
- Electric Power Research Institute, USA, around 2003
- US DOE (Dept. of Energy) had a Grid 2030 project, around 2003
- National Institute of Standards and Technology (NIST) is responsible as of 2007
- **Obama's "National Broadband Plan" [March 2010] – chapter 12**

Mission of ICT in Smart Grids

- enable energy efficiency distribution and usage
- keep bills at both ends low
- minimize greenhouse gas emissions
- automatically detect problems and route power around localized outages
- accommodate all types and volumes of energy, including alternative
- make the energy system more resilient to all types of failures

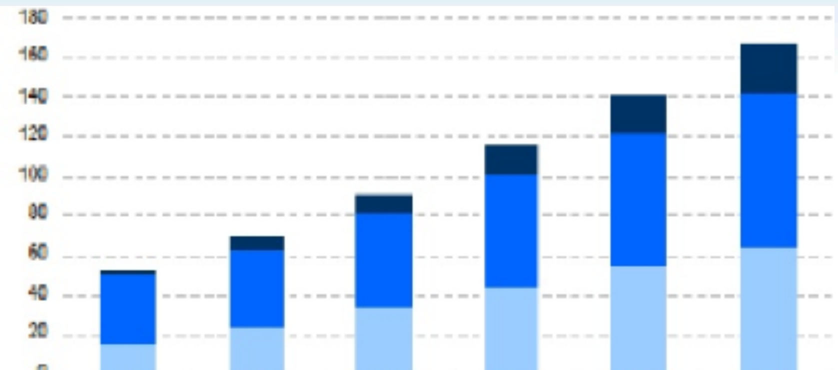
- 234 Million Smart Meters to be deployed worldwide by end 2015
- 35 Million Smart Meters worldwide shipment in 2015

Smart Grid Market Potentials

Smart Grid Wireless **Revenues** expected to reach 166Mln EUR worldwide in 2015 (3% to 4% of wireless M2M)

ROI

- Smart Meters: 5 years
- Smart Grids: add 10 years
- **BUT**
  - Smart Meters and Advanced Metering Infrastructure are first to be deployed
  - This can be done **ONLY** following Government Incentive Plan
    - – REGULATIONS ARE NEEDED



	2010	2011	2012	2013	2014	2015
Rest of World	3.5	6.1	9.6	13.4	18.0	23.4
Europe	34.2	39.2	46.8	56.4	66.8	78.3
North America	15.4	23.8	34.2	45.3	55.3	64.5

EU Regulation on Smart Grid

European Commission Mandates

CEN, CENELEC and ETSI have setup a joint group to coordinate activities on the mandates in the field of energy

- M/441: Smart Metering (ongoing)
- M/468: Electrical Vehicles charges (ongoing)
- M/490: Smart grid. Launched March 1, 2011

« The General objective of this mandate is to create European standards that will enable **interoperability** of utility meters (**water, gas, electricity, heat**), which can then improve the means by which **Customers' awareness** of actual consumption can be raised in order to allow **timely adaptation to their demands** (commonly referred to as '**smart metering**') »

M/490 Services

M/490 defines six high-level services to enable European Smart Grid

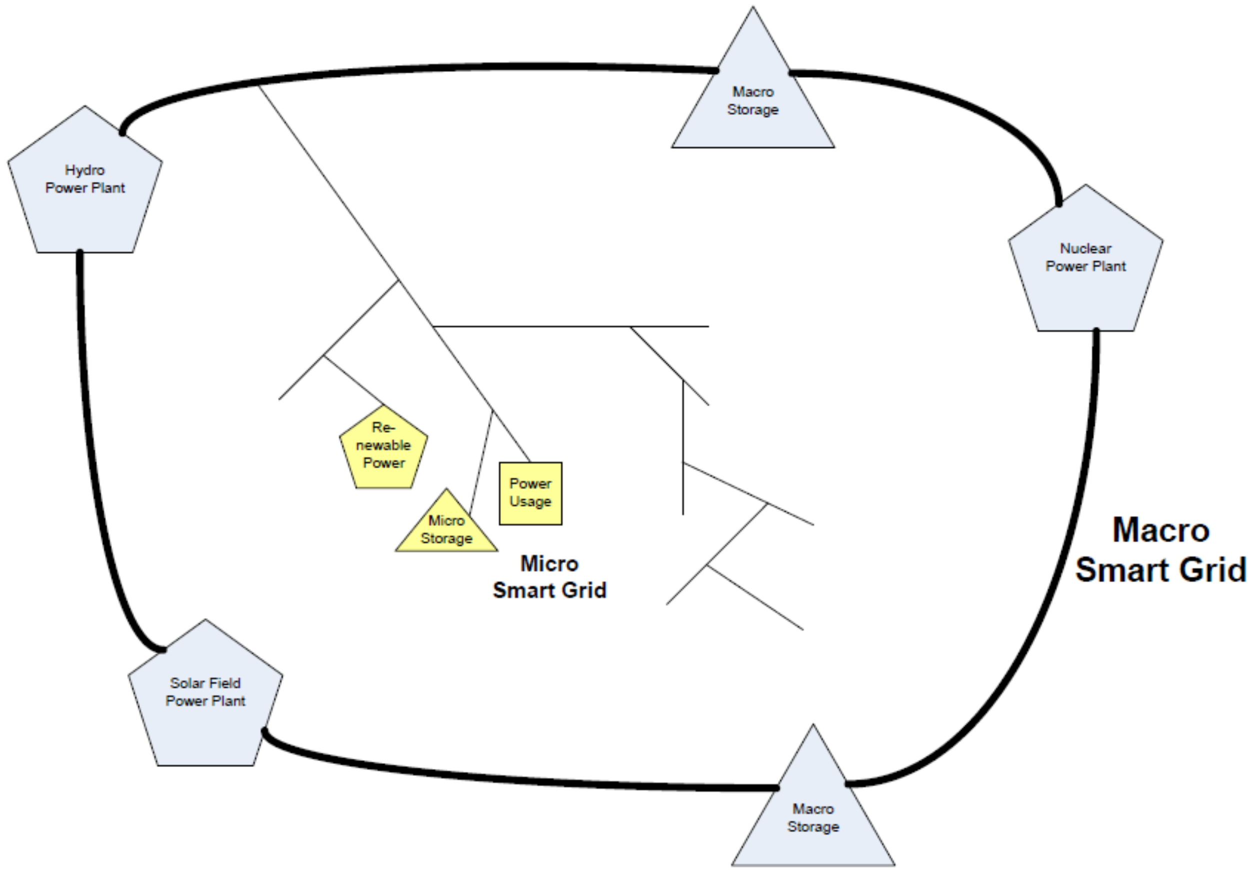
- Enabling the network to integrate users with new requirements
- Enhancing efficiency in day-to-day grid operation
- Ensuring network security, system control and quality of supply
- Enabling better planning of future network investment
- Improving market functioning and customer service
- Enabling and encouraging stronger and more direct involvement of consumers in their energy usage management

A power grid qualifies to become a smart grid if it provides the following functionalities

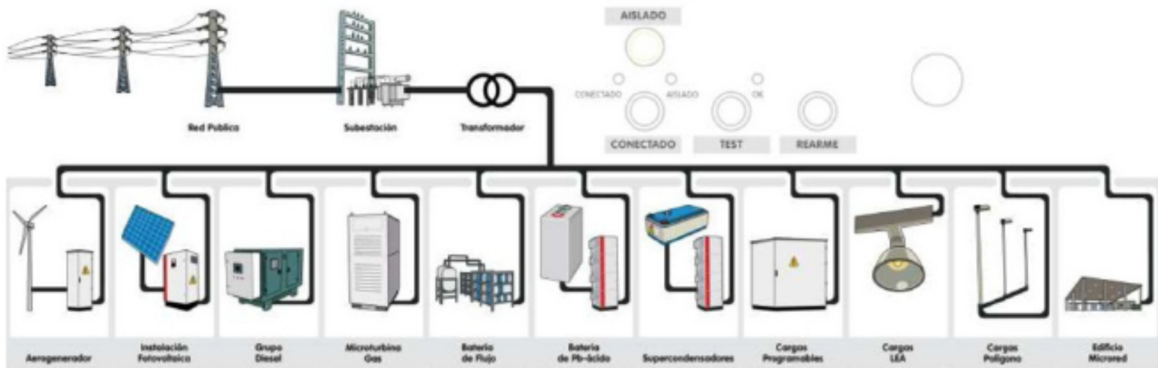
- Self-healing from power disturbance events
- Enabling active participation by consumers in demand response
- Operating resiliently against physical and cyber attack
- Accommodating all generation and storage options
- Enabling new products, services, and markets
- Optimizing assets and operating efficiently

Grid General Structure

1. Local Energy Production
2. Bi-Directional Energy Flow
3. Real-Time Instrumentation



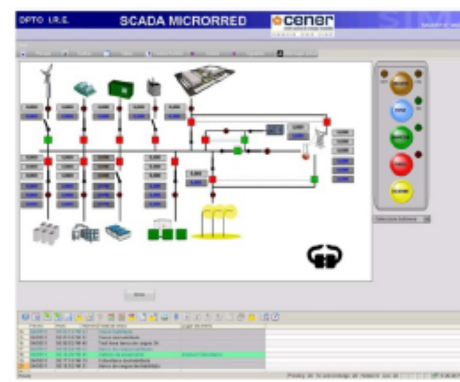
Microgrids Play Central Role



G- Instalación fotovoltaica de 25 kWp

G- Aerogenerador 20 kW tipo full-converter

G- Grupo electrógeno diesel 55 kVA



A- Banco de baterías plomo ácido de gel, 50 kW x 2 horas

EU vs US Smart Grid Strategy

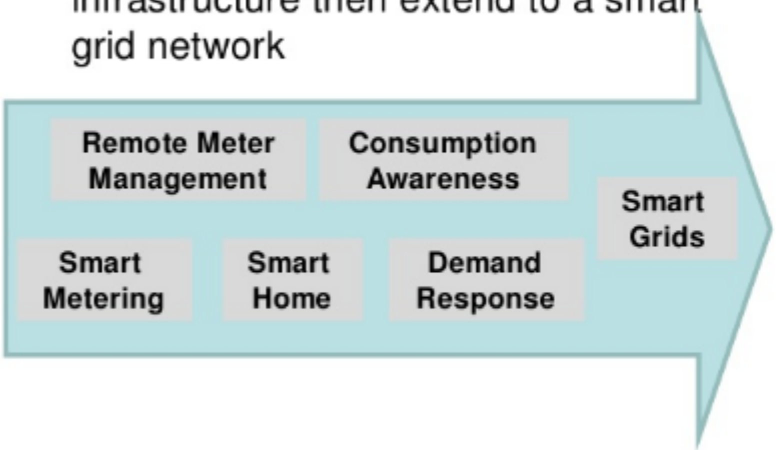
EU

Background: a fragmented electricity market

Deregulation of electricity in some EC states

Vision:

Start with a smart metering infrastructure then extend to a smart grid network

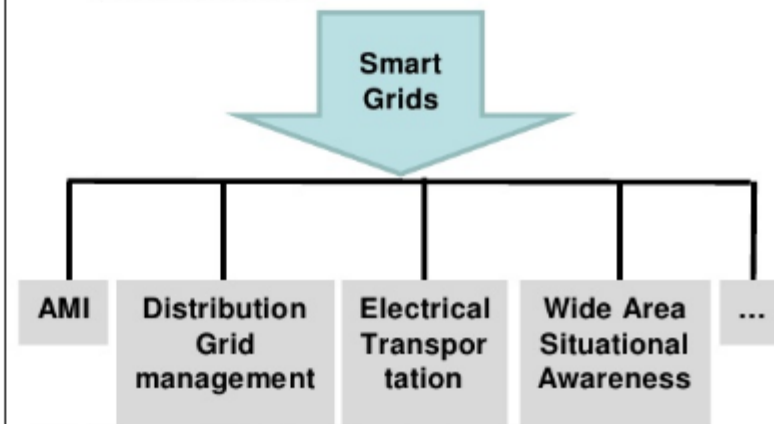


US

Background: an aging power grid

Vision:

Smart meters and AMI are part of the toolbox that allows to build a smart grid infrastructure



AMI: Advanced Metering Infrastructure

Need for a global (architecture) approach and for regional implementation
ETSI, as a global and EU based ICT standards organization, is ideally placed

Smart Meter Benefits

Demand Side Management and reduction of CO_2:

- Reduction of peak load by consumers information
- Easier connection for distributed generation Soft shedding systems
- Better network observability
- Demand side management and better fraud detection in small isolated system will limit tariff compensation

Automated Meter Management:

- Data storage
- Events storage
- Remotely managed

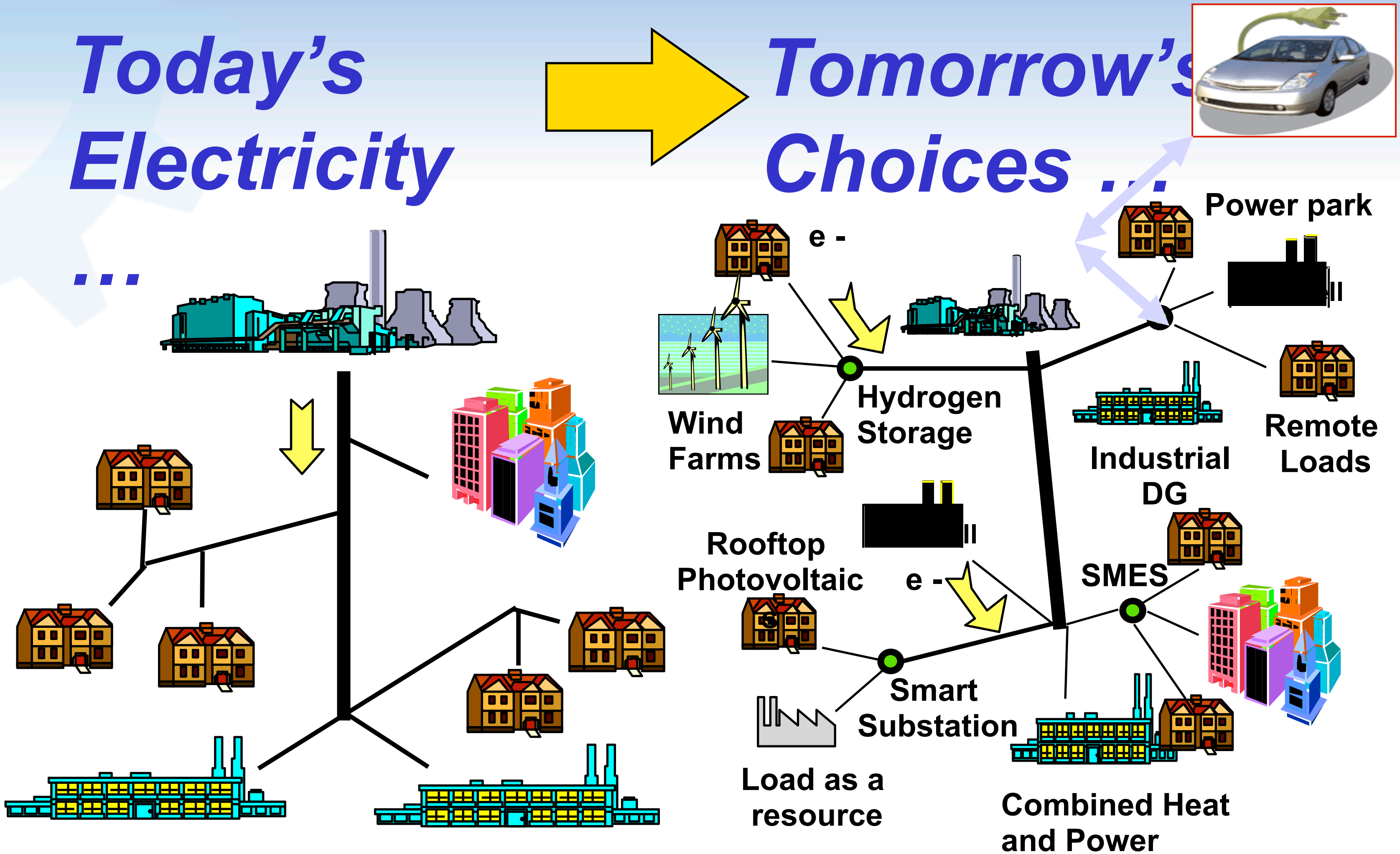
Well-functioning internal Market:

- Better consumers information
- Better frequency and quality of billing data
- Assist the participation of consumers in the electricity supply market
- Easier access to data (IS or TIC)
- Reduction of cost and delay of interventions

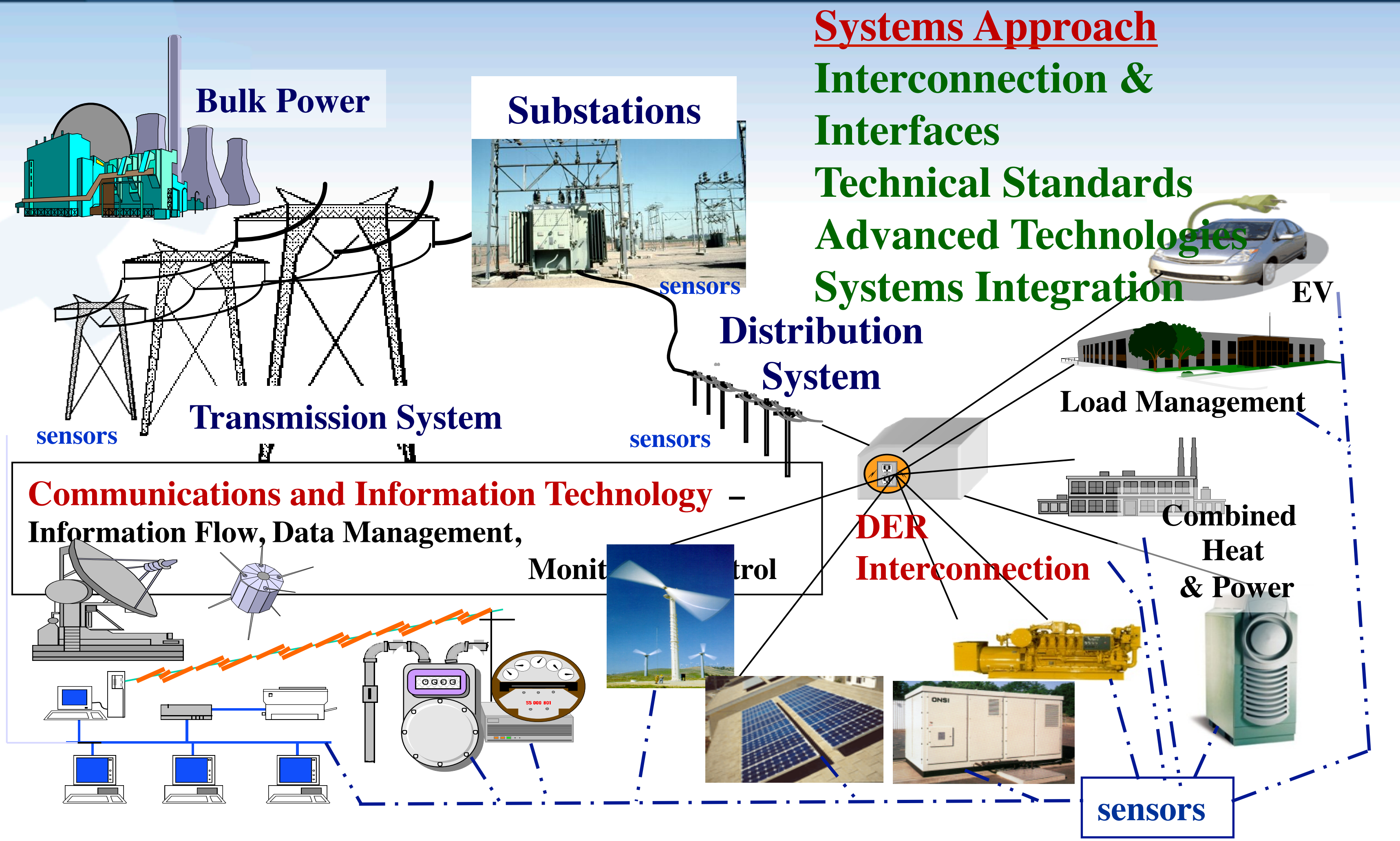
Reduction of operating system costs:

- Reduction of reading and interventions costs
- Reduction of “non technical losses”
- Reduction of treatment of billing claim
- Easier quality of supply management
- No need of user presence to do simple operations

IEEE P2030 Interoperability Concept



Interoperability Smart Grid Concepts



ETSI M2M Smart Grid

ETSI M2M

3GPP and ETSI

- Use-case-driven approach as a means with which to derive the set of requirements that further define the service architecture

ETSI has adopted a more formal way of describing the use cases

- As an addition to the use-case-driven approach
- Addresses network optimization matters
    - Equipment features
    - Operational networks design
        - By taking into account fundamental characteristics of M2M-generated traffic and growth patterns
- Hence ETSI provides new and particularly challenging requirements on the access and core network

ETSI M2M SG

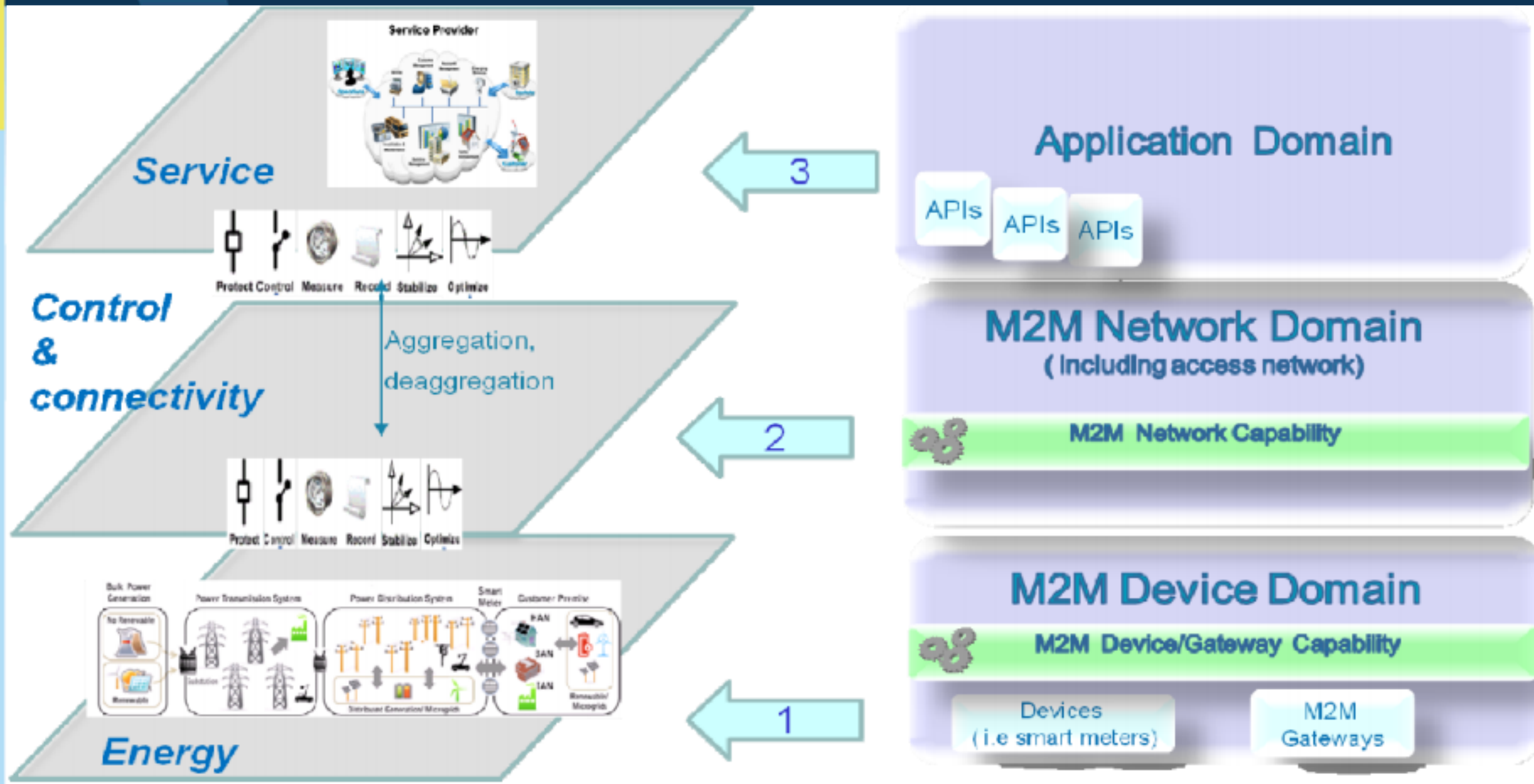
ETSI TR 102 935 V2.1.1 (2012-09) Machine-to-Machine communications (M2M); Applicability of M2M architecture to Smart Grid Networks; Impact of Smart Grids on M2M platform

- Develops the most relevant Smart grids use cases, used to derive high level requirements
- Provides a standard gap analysis (applicability of M2M APIs for Smart Grid applications, mechanisms to manage energy for end users, etc), and derives a set of recommendation for the work of ETSI M2M

ETSI TR 102 966 V0.2.0 (2012-03) Machine to Machine Communications (M2M); Interworking between the M2M Architecture and M2M Area Network technologies

- Explores the specific mappings recommended for interworking with other M2M technologies, such as ZigBee
- Each implementation profile is evaluated against deployment scenarios and applicable technologies in order to identify the most suitable for the specific conditions

ETSI M2M : Smart grids concepts & M2M architecture



ETSI M2M : Smart grids concepts & M2M architecture

Energy Layer

- Handles the energy (production/generation, distribution, transmission and consumption), i.e. sensors, electricity generation, storage and interconnection, transmission and distribution power systems
- Needs M2M sensors for controlling of production, distribution, transmission and consumption

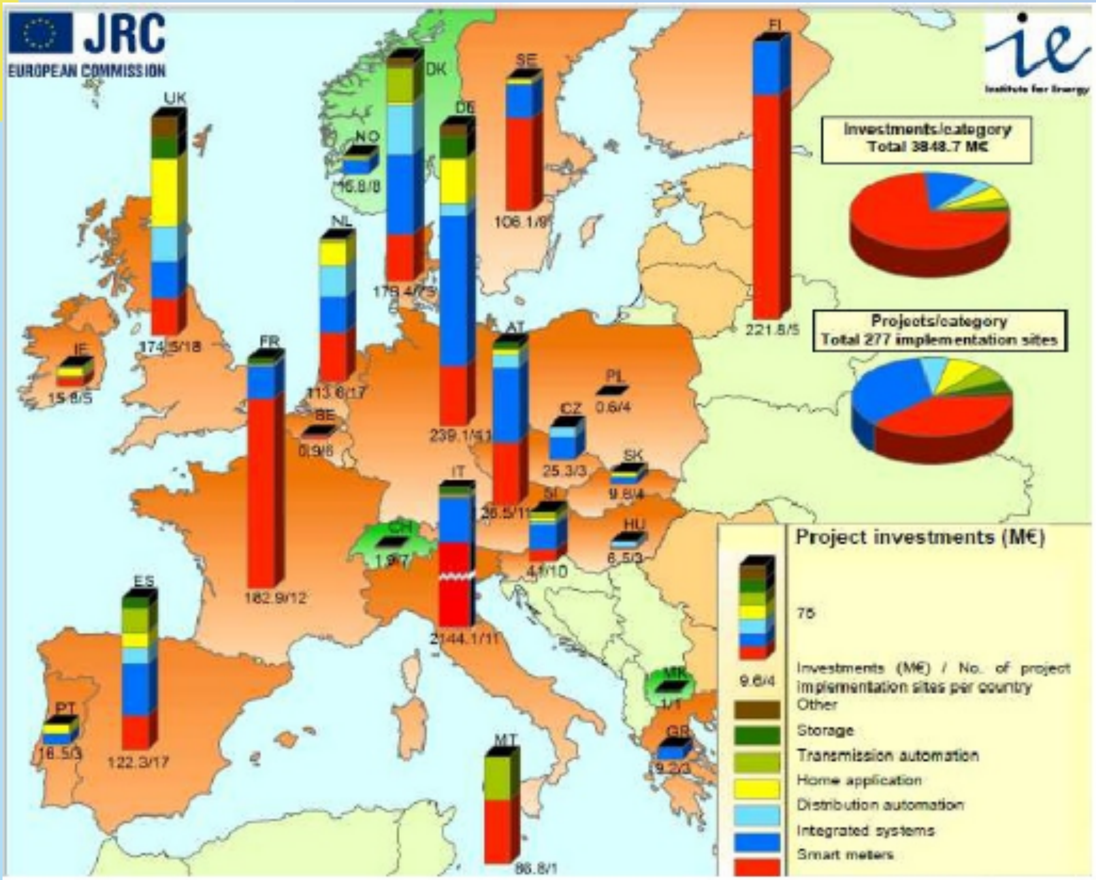
Control and Connectivity Layer

- Ensures energy control and connectivity including management functions such as substation automation, condition, monitoring/diagnosis, supervision and protection, metering, traffic engineering, protection
- restoration, virtualisation, routing M2M core and M2M capabilities shall provide coverage and accessibility, quality of service, security, privacy and reliability

Service Layer

- Provides all services related to the Smart grids use (billing, e-commerce, subscription management etc), and a M2M Application server with sufficient APIs for Smart grids network is applicable

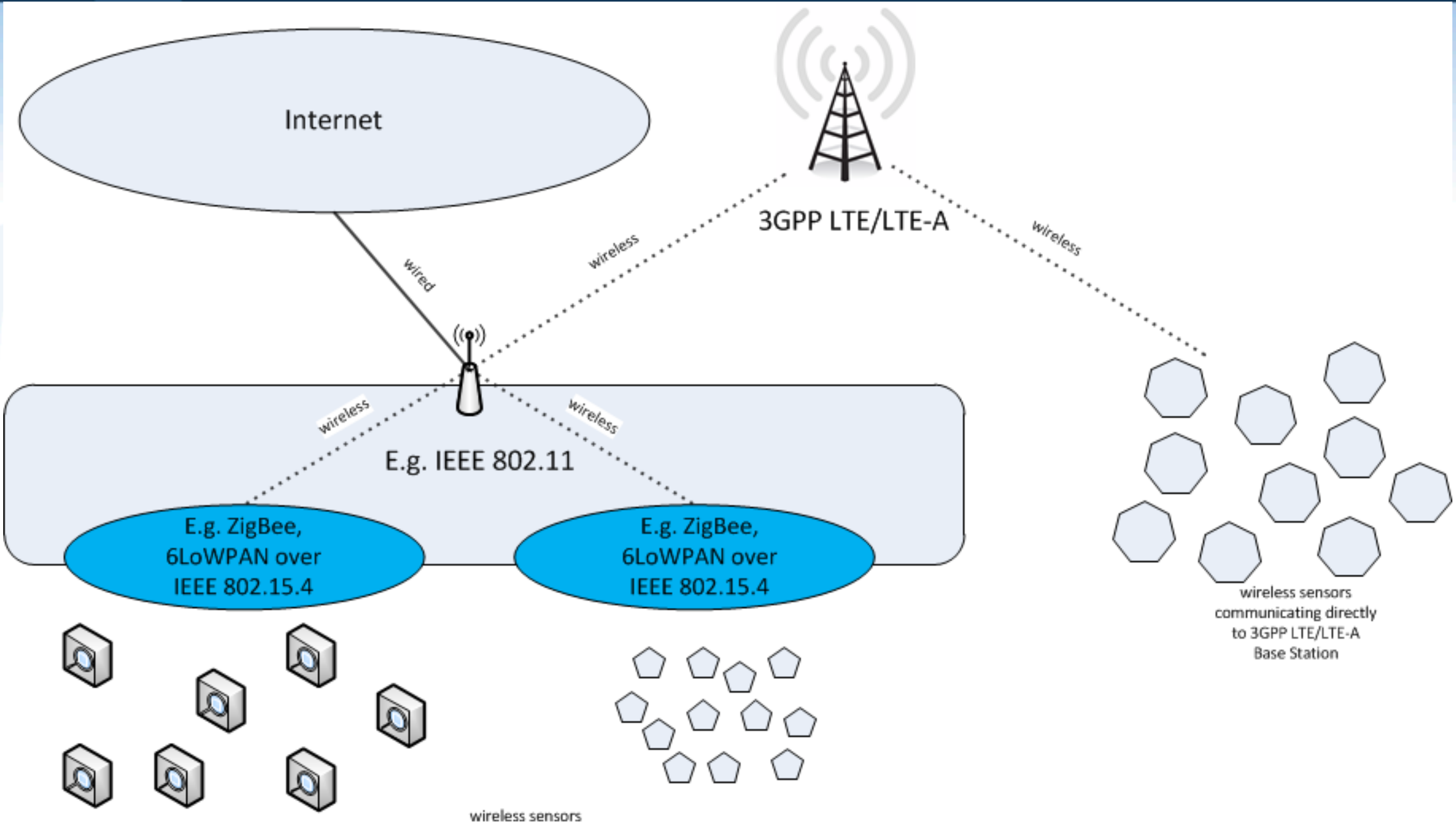
EU Status on Smart Grid: Early Stage



- **Over €5.5Billion invested in 300 Smart Grids projects**
  - € 300Million coming from EU budget
- 10% EU Households have some sort of smart meters, BUT w/o providing full scale of services
- ➔ monitored **energy consumption reduction by as much as 10%**
- Smart Household appliances market
  - 2011: $3 Billion
  - 2015: $15 Billion
- **Investments needed**
  - Smart Meters: 15%
  - Smart Grids (rest of system): 85%

M2M Wireless technologies

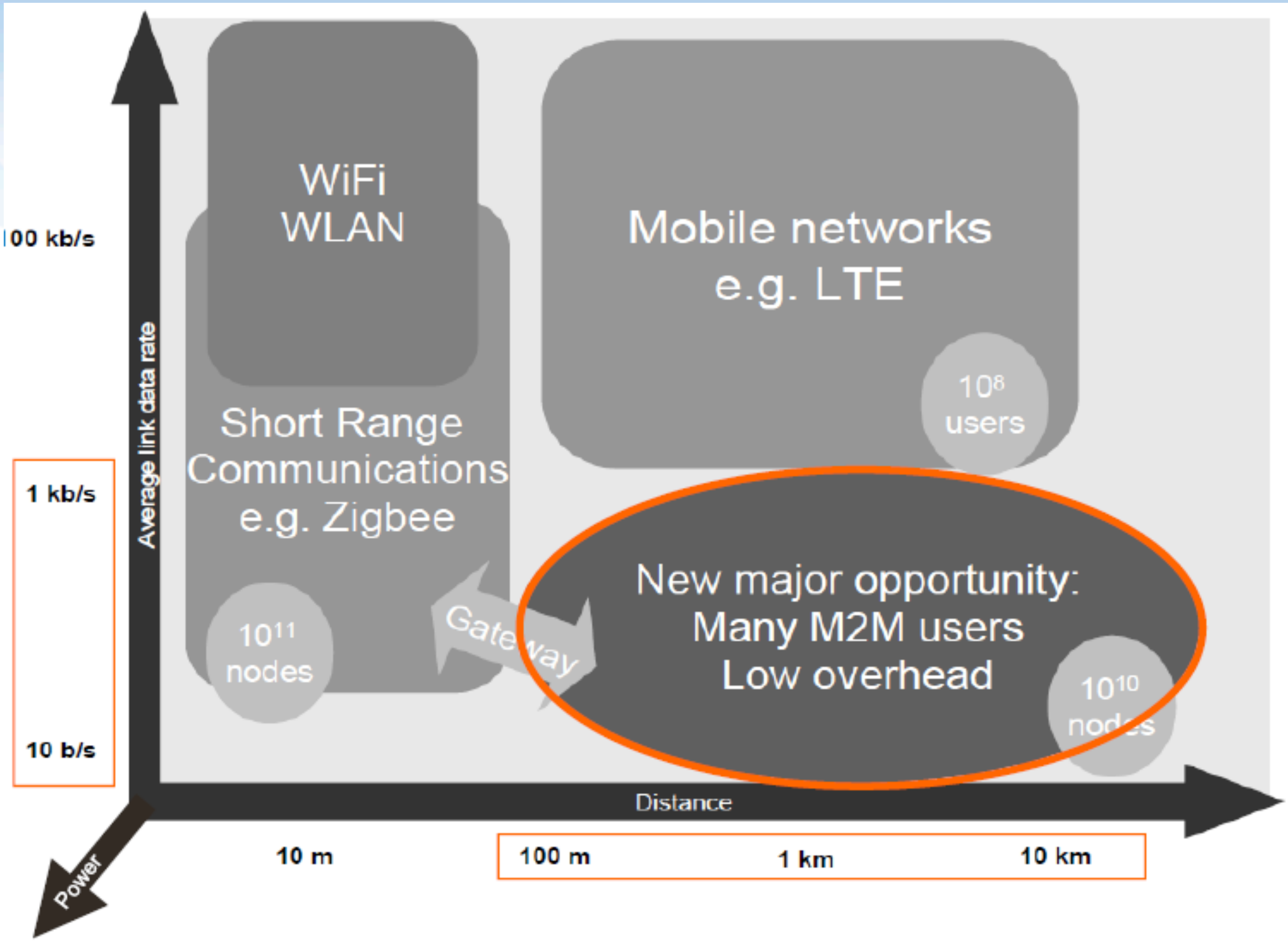
General Network Architecture to support M2M



Available Wireless Technologies

Standard	Area	Rate	Energy-constrained	Typical applications	Data Type
Zigbee	Personal area	Low	Yes	Automatic control	Sensors, monitoring, smart grid
Bluetooth	Personal area	Low	Yes	Music sharing	Voice, low-rate data, music
UWB	Personal area	High	No	Video, file sharing	Video, high-rate data, files
802.15.6	Body area	Low	Yes	Healthcare	Biomedical data
WiFi	Local area	High	No	Home thermostats, water metering	VoIP, data, video
Femtocell	Local area	High	No	Cellular phones	VoIP, data, video

M2M Place 1/2


WiFi
WLAN
Mobile networks
e.g. LTE
10^8
users
Short Range
Communications
e.g. Zigbee
10^{11}
nodes
Gateway
New major opportunity:
Many M2M users
Low overhead
10^{10}
nodes
100 kb/s
1 kb/s
10 b/s
Average link data rate
Distance
Power
10 m
100 m
1 km
10 km

M2M R&D Challenges

- Mass Device Transmission
- High Reliability
- Enhanced Access Priority
- Extremely Low Power Consumption
- Small Burst Transmission
- Low/No Mobility
- Addressing Large Number of Devices
- Group Control
- Security
- Time-Controlled/Time-Tolerant Operation
- One-way Data Traffic
- Extremely Low Latency
- Infrequent and disruptive traffic

Conclusions 1st Day

- IoT is a strategic cross-discipline development
  - Introduces new paradigms of communications and Internet usage
- IoT increases the role of machine-generated traffic
- Utmost important technology for upcoming decade
- Will provide a significant societal impact
- Technology-wise the research agenda is open in many disciplines
- IoT/M2M is certainly one of the major driving forces for ICT arena
  - Many new challenging services and applications
- Smart Grid applications have obvious business model and will bring significant savings in energy and CO_2 emissions
  - Change in energy supplying paradigm
  - Electric cars will contribute
- M2M global standards are needed
  - PHY, MAC, Network, Service abstraction

Internet of Nano Things

Nano-level Cyber Physical Systems (NL-CPS)

- Nanotechnologies promise new solutions for many applications in biomedical, industrial and military fields
- At nano-scale, a nano-machine can be considered as the most basic functional unit
  - Nano-machines are tiny components consisting of an arranged set of molecules, which are able to perform very simple tasks
  - Nanonetworks, i.e., the interconnection of nano-machines are expected to expand the capabilities of single nano-machines by allowing them to cooperate and share information
- Accomplishment can lead **to extremely high societal impact**
- A nanosensor is not necessarily a device merely reduced in size to a few nanometers, but a device that makes use of the unique properties of nanomaterials and nanoparticles to detect and measure new types of events in the nanoscale
  - The Internet of Nano-things [I.F. Akildiz "The Internet of Nano-Things", ComMag, Dec 2010]

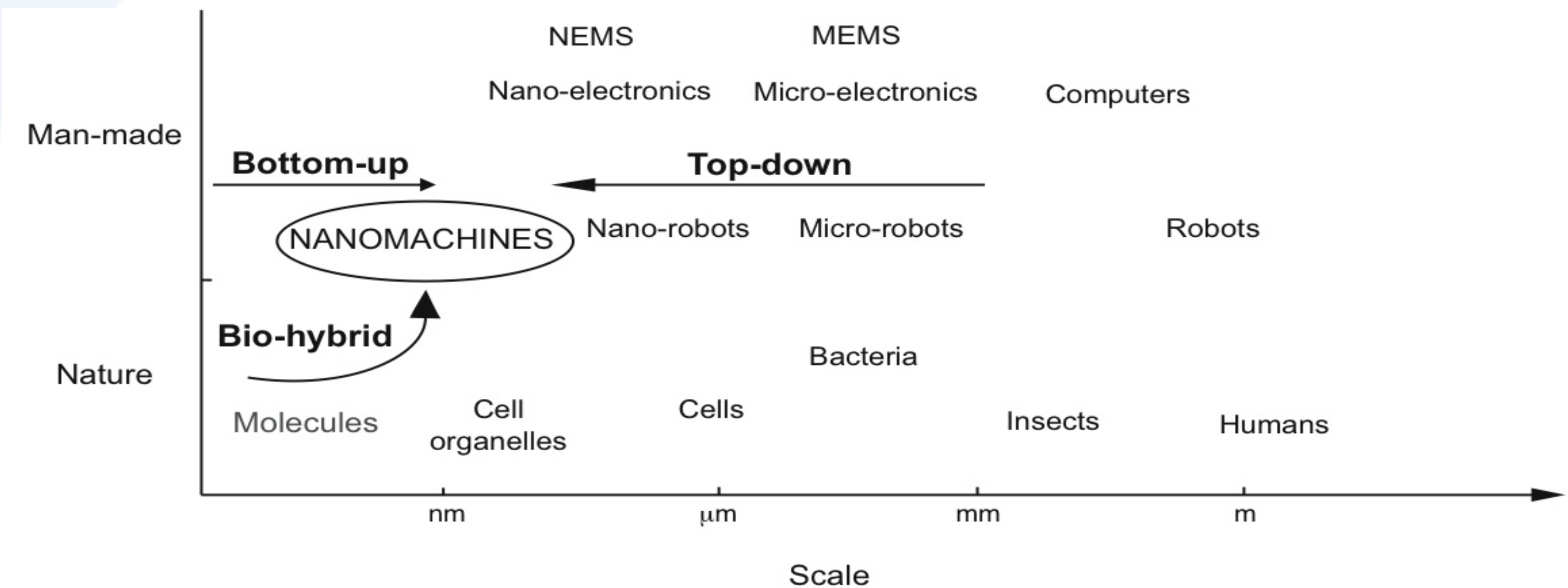
Communication types in NL-CPS

- Traditional communication technologies are not suitable for nanonetworks
  - Mainly due to the size and power consumption of transceivers, receivers and other components
- The use of molecules, instead of electromagnetic or acoustic waves, to encode and transmit the information represents **a new communication paradigm** that demands novel solutions such as molecular transceivers, channel models or protocols for nanonetworks

- Nanonetworks for **short-range** communication
  - Transmission is based on electromagnetic principles
  - Transmission is based on calcium signaling and molecular motors
- Nanonetworks for **long-range** communication
  - Transmission is based on pheromones

Nano-Machine Development

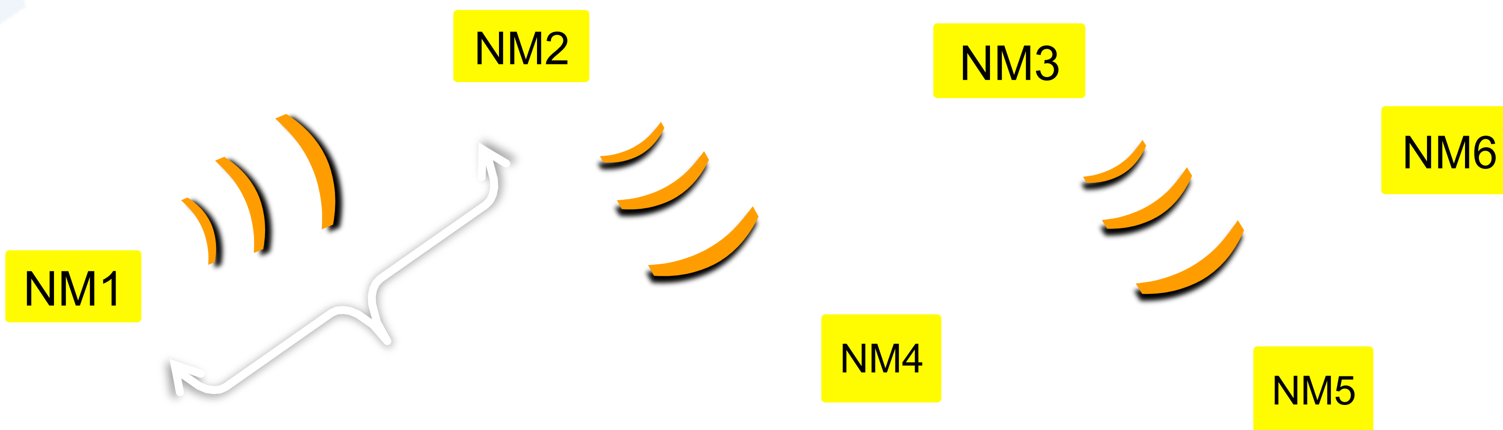
- Approaches for the fabrication and integration of nanosensors
  - Source: I.F.Akyildiz et al "Nanonetworks: a new communication paradigm", Computer Networks, 52 (2008)



IoNT: the Internet of Nano Things

Networks of nano-things

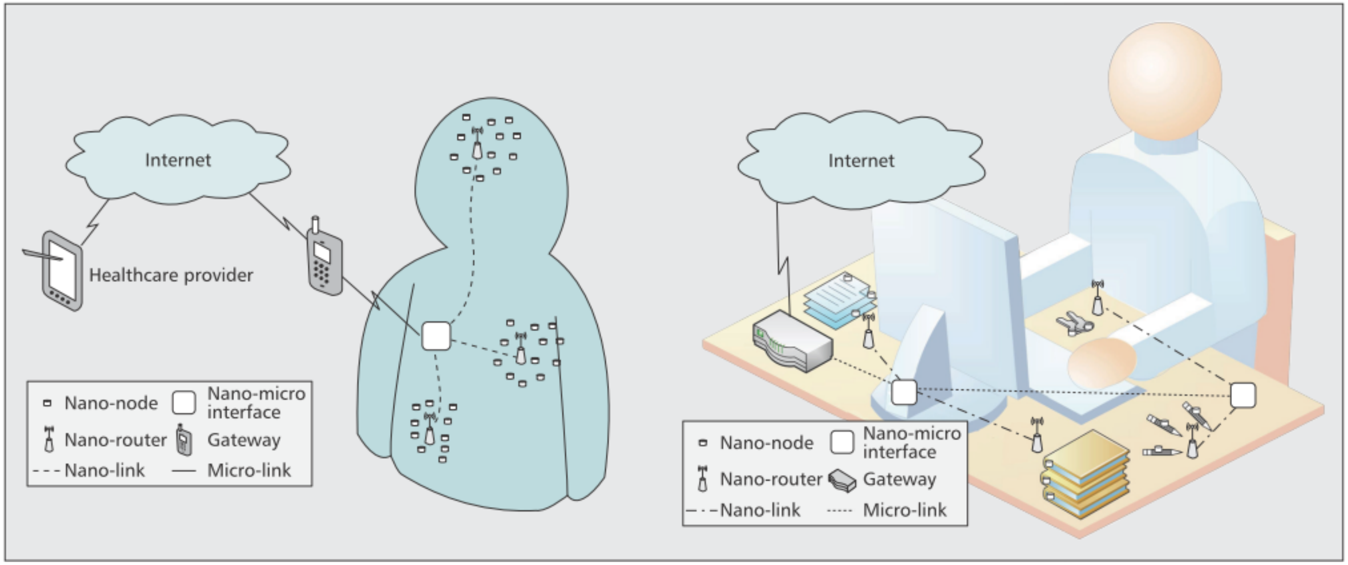
- will enable novel applications of nanotechnology in many fields



Source: Ian F. Akyildiz Internet of Nano Tings

NL-CPS Nanonetworks: short range

- Transmission is based on nano-electro-magnetic communication
- Applications and scenarios
  - Biomediacal: health monitoring, drug delivery
  - Environmental: various monitoring systems
  - Industrial and consumer: touch interfaces, haptic interfaces, interconnected office
  - Military nuclear, biological and chemical defenses, etc.



NL-CPS Nanonetworks: short range

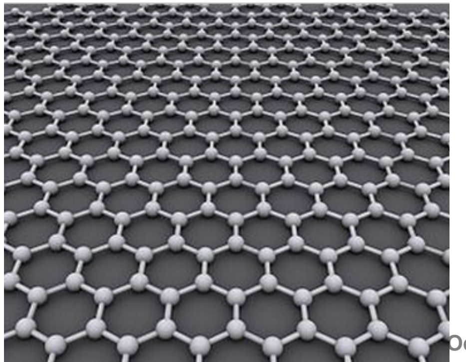
- Nano-electromagnetic communication
  - This is defined as the **transmission and reception of electromagnetic radiation** from components based on novel nanomaterials
  - **Recent advancements in molecular and carbon electronics have opened the door to a new generation** of electronic nano-components such as nanobatteries, nano-memories, logical circuitry in the nanoscale and even nano-antennas
  - **From a communication perspective**, the unique properties observed in novel nano-materials will decide on the **specific bandwidths** for emission of electromagnetic radiation, the time lag of the emission, or the magnitude of the emitted power for a given input energy
  - All these entail a **fundamental change** in the current state of the art of analytical channel models, network architectures and communication protocols

NL-CPS short range comm challenges

- Communication unit
  - Nano-antenna
  - Nano-transceiver
- Medium
  - Upper Megahertz / Terahertz channel

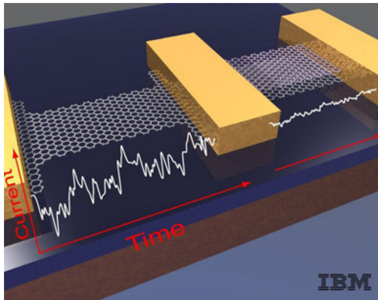
NL-CPS short range comm challenges

- Nano-antenna
  - Reducing the antenna of a classical sensor device down to a few hundreds of nanometers would require the use of **extremely high operating frequencies**, compromising the feasibility of electromagnetic wireless communication among nanosensor devices
  - A few initial antenna designs based on graphene have been already proposed
  - For example, in * nano-patch antennas based on GNRs and nano-dipole antennas based on CNTs are quantitatively compared, illustrating that a graphene nano-antenna 1 μm long can efficiently radiate EM waves in the terahertz band (0.1–10.0 THz)
    - * J.M. Jornet, I.F. Akyildiz, Graphene-based nano-antennas for electromagnetic nanocommunications in the terahertz band, in: Proc. of 4th European Conference on Antennas and Propagation, EUCAP, April 2010.



NL-CPS short range comm challenges

- Nano-transceiver
  - A challenging task, mostly addresses graphene-based solutions
  - Several graphene-based Field-Effect Transistors (FET) operating in the sub-terahertz and lower part of the terahertz band have been demonstrated so far
  - Feb 2010 - IBM Corp. has demonstrated 100 GHz graphene-based transistor
    - The transistor prototypes were made from sheets of carbon just one atom thick that could switch on and off at 100 billion times per second
    - The 100-gigahertz speed is about 10 times faster than any silicon equivalents
    - This work IBM conducted under DARPA programme to develop high-performance RF (radio frequency) transistors
    - Next target is 1 TGz
  - This is not only for nano-communications, but also for multimedia services



NL-CPS short range comm challenges

- Current achievements on graphene-based RF
  - RF performance of epitaxial graphene-based FET transistor was measured, thus potentials are shown
    - J. Moon, D. Curtis, M. Hu, D. Wong, C. McGuire, P. Campbell, G. Jernigan, J. Tedesco, B. VanMil, R. Myers-Ward, C. Eddy, D. Gaskill, Epitaxial-graphene RF field-effect transistors on si-face 6h-sic substrates, IEEE Electron Device Letters 30 (6) (2009) 650–652.
  - Shown that graphene is suitable for fabrication of oscillators beyond 1 THz
    - M. Dragoman, A. Dragoman, D. Muller, High frequency devices based on graphene, in: International Semiconductor Conference (CAS), vol. 1, 15 Sept. 2007, pp. 53–56.
- Graphene research challenges in RF
  - Understanding of features of graphene-based RF schemes
    - For building of models and simulators
  - Developing of modulation schemes

NL-CPS short range comm challenges

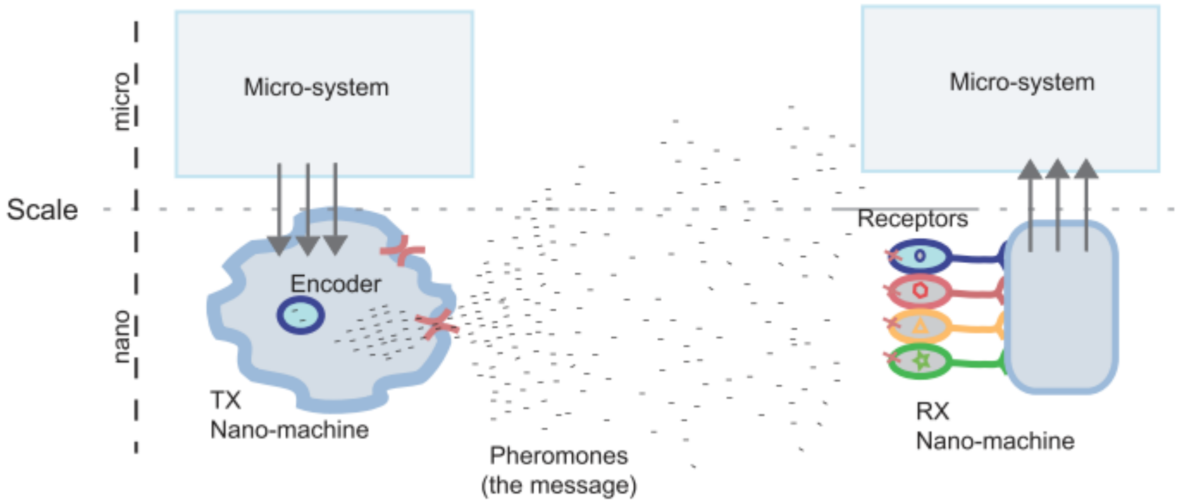
- PHY
  - Upper Megahertz / Terahertz
    - Will be enabled by nano-antennas and nano-transievers
    - Is under investigation by many research groups
    - Can be implemented as pulse-based communications
  - Channel modeling is extremely challenging for this
    - A number of interesting studies already available
- MAC
  - Carrier sensing protocols cannot be used for pulse-based communications
  - Need to be investigated and adjusted

NL-CPS Nanonetworks: short range

- Transmission is based on **molecular interaction**
  - The transmission and reception of information encoded in molecules
  - Molecular transceivers will be easy to integrate in nano-devices due to their size and domain of operation
    - These transceivers are able to react to specific molecules and to release others as a response to an internal command or after performing some type of processing
    - The released molecules are propagated either
      - Following spontaneous diffusion in a fluidic medium (diffusion-based)
      - Through diffusion in a fluidic medium whose flow is guided (flow-based)
      - Through active carriers that transport them through pre-defined pathways (walkway-based)
- This radically different communication paradigm call for novel
  - Channel models, network architectures, and communication protocols

BI-CPS Nanonetworks: long range

- Transmission is based on pheromones
  - Only members of the transmitter group can decode the transmitted message
  - Propagation speed is much slower than in electromagnetic communications
  - Low power transmission since it's about chemically driven processes
  - Information i.e., molecules, has to be physically transported from the transmitter to the receiver
  - Molecules can be subject to random diffusion processes and environmental conditions, such as temperature, which can affect the propagation of the molecular messages



Grand challenges of communication tasks in BI-CPS

- A lot of synthetic pheromones are in production for pretty long time already
  - New communication-oriented pheromones are needed
- Design of a receiver is a key task to solve to enable pheromone-based communications
- MAC questions
  - Have not been treated yet from communications point of view