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Contents

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Summary

Internet-of-Things (IoT) envisions a world of heterogeneous things that have identities as well as physical and virtual attributes, and that are seamlessly and securely integrated into the Internet infrastructure using standard communication protocols. This vision is based on the advances in the fields of, for example, radio-frequency identification (RFID), machine-to-machine (M2M) communication, wireless sensor and actuator networks (WSAN), ubiquitous computing, and web-of-things (WoT). Internet-enabled things will bring various benefits to both organizations and individuals by facilitating or simplifying environment sensing, proximity triggering, automated sensing and actuation, all of which can be utilized in various application domains, ranging from automated home appliances to smart grids and high-resolution asset and product management.

In terms of business, IoT represents a tremendous opportunity for various types of companies, including IoT application and service providers, IoT platform providers and integrators, telecom operators and software vendors. According to some estimates, M2M communications alone will generate approx. EUR714 billion in revenues by 2020, and many IoT vertical segments are expected to experience a double-digit growth in the upcoming years. Among the most prospective vertical application domains are consumer electronics, automotive, and healthcare, as well as intelligent buildings and utilities.

Technologically, connecting things to the Internet can be accomplished with the help of various protocols and standards, either adopted from the traditional Internet and telecommunications fields (WiFi and Bluetooth, Ethernet, 3G and LTE, HTTP), or specifically tailored to meet the constraints of the connected things (ZigBee and Z-Wave, as well as IETF's 6LoWPAN, RPL, and CoAP). Specific requirements of different application domains affect the feasibility of certain technologies.

At the present, the IoT field is characterized by a multitude of co-existing and competing products and platforms, as well as standardized and proprietary communication protocols. The components of the solutions offered by different vendors are barely compatible, keeping the prices of the components high. The IoT field is in the early phase of its evolution, and the competition is yet to start between the traditional HTTP-based and proprietary solutions, on one hand, and the new IETF-based solutions, on the other hand, for the position of the new dominant design in future IoT applications.

The expected widespread adoption of IoT technologies implies the emergence of IoT business ecosystems, each representing a community of interacting companies and individuals along with their socio-economic environment. Within an ecosystem, the companies compete and cooperate by utilizing a common set of core assets related to the interconnection of the physical world of things with the virtual world of Internet. These core assets may be in the form of hardware and software products, platforms or standards that focus on the connected devices, on their connectivity, on the application services built on top of this connectivity, or on the supporting services needed for the provisioning, assurance, and billing of the application services.

For individual companies, the current state and trends of the IoT business can be described by using business model frameworks. Besides the role of the company in its ecosystem, a business model encompasses other components, such as value proposition, revenue model, and cost structure, which reflect how the company creates, delivers, and captures value.

Introduction

As a result of decades of research and industrial efforts in the domain of information and communications technologies (ICT), people are today equipped with fast-speed, (almost) any-time and any-place solutions that allow them to be connected with each other, and to interact with and through the rich world of Internet-enabled applications and services. The next step aims to facilitate the interconnection of the applications and services of the virtual world of the Internet with the physical world of things, allowing us to better sense and control our environment. This is generally referred to as the Internet-of-Things (IoT).

A number of definitions have been provided for the term Internet-of-Things in recent literature; some of them are overviewed in (CASAGRAS 2009, Atzori et al. 2010, Serbanati 2011, Bandyopadhyay and Sen 2011). In general, the following three complementary – and partly overlapping – visions can be distinguished (Atzori et al. 2010, Bandyopadhyay and Sen 2011):

1. The *Things* oriented vision focuses on the things' identity and functionality, which is in line with the original idea presented by MIT Auto-ID Labs for using RFID tags to uniquely identify things. While the original idea was tied to the RFID and Electronic Product Code (EPC), other identification alternatives have emerged, and the concept of an identifiable object has been expanded to include also virtual entities. From this perspective, IoT is defined as:

   > *"Things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts."*

   > *or*

   > *"A world-wide network of interconnected objects uniquely addressable, based on standard communication protocols." (EPoSS 2008)*

2. The *Internet* oriented vision emphasizes the role of the network infrastructure and is concerned with the applicability of the available (and future) Internet infrastructure, including IP protocol stack and Web standards for the purpose of interconnecting smart objects. This perspective is promoted by, for example, the IPSO (IP for Smart Objects) Alliance[1], Internet $\varnothing$ architecture (Gershenfeld et al. 2004), and Web of Things community[2], suggesting that IoT shall be built upon the Internet architecture, by adopting and, when necessary, simplifying the existing protocols and standards. From this perspective, IoT can be defined (following the definition by CASAGRAS project) as:

   > *"A global network infrastructure, linking physical and virtual objects through the exploitation of data capture and communication capabilities. This infrastructure includes existing and evolving Internet and network developments. It will offer specific object-identification, sensor and connection capability as the basis for the development of independent*

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[1] See http://www.ipso-alliance.org/.
[2] See http://www.webofthings.org/.

> *cooperative services and applications. These will be characterised by a high degree of autonomous data capture, event transfer, network connectivity and interoperability."*

3. The *Semantics* oriented vision focuses on systematic approaches towards representing, organizing and storing, searching and exchanging the things-generated information, by means of semantic technologies (Toma et al. 2009; Barnaghi et al. 2012). According to this vision, the application of semantic technologies to IoT

> *"promotes interoperability among IoT resources, information models, data providers and consumers, and facilitates effective data access and integration, resource discovery, semantic reasoning, and knowledge extraction" [through] "efficient methods and solutions that can structure, annotate, share and make sense of the IoT data and facilitate transforming it to actionable knowledge and intelligence in different application domains." (Barnaghi et al. 2012)*

The strategic research agenda for the IoT program combines these three visions within its working definition, according to which IoT represents

> *"a global network and service infrastructure of variable density and connectivity with self-configuring capabilities based on standard and interoperable protocols and formats [which] consists of heterogeneous things that have identities, physical and virtual attributes, and are seamlessly and securely integrated into the Internet." (Tarkoma and Katasonov 2011)*

IoT research has its roots in several domains addressing different IoT aspects and challenges. These research domains include, for example, the radio-frequency identification (RFID), machine-to-machine (M2M) communication and machine-type communication (MTC), wireless sensor and actuator networks (WSAN), ubiquitous computing, and web-of-things (WoT). Furthermore, these technologies have been applied in many vertical application domains, ranging from automotive and machinery to home automation and consumer electronics. Thus, what is today known as IoT represents a convergence of multiple domains, and IoT can be seen as an umbrella term uniting the related visions and underlying technologies (Atzori et al. 2010).

In terms of business, IoT represents a tremendous opportunity for various types of companies, including the *primarily IoT firms*, whose revenues are mostly generated from the IoT technologies and services based on them (IoT application and service providers, IoT platform providers and integrators), as well as the *secondarily IoT firms* with a particular branch or business unit, but not the entire firm, focusing on the IoT technologies and services (OEM, telecom operators, software vendors). According to some estimates, M2M communications alone will generate approx. EUR714 billion in revenues by 2020 (Machina Research 2011).

At the present, the market is in the very early stage, with fragmented solutions targeting specific vertical domains and/or specific types of applications. The current solutions are also characterized by a variety of proprietary platforms, protocols and interfaces, which makes the components of the solutions provided by different vendors barely compatible, while keeping the component prices at a high level. Standard protocols and interfaces are either available or being developed (e.g., by ZigBee Alliance, IPSO Alliance), but no single dominant set of standard protocols, interfaces or platforms has emerged yet. The lack of a generally accepted dominant design and the resulting high costs of the solutions, along with the lack of reference

architectures and vendor-independent guidelines on how to choose among the solutions or components, are currently inhibiting the wider adoption of the IoT technologies (Batten and Wills-Sandford 2012).

Thus, the expected rapid growth of the IoT market is contingent on the emergence of common/dominant standards, platforms and interfaces. Their emergence, in turn, depends on whether the standards and platforms being developed match the requirements of the specific IoT domains. In the extreme case of all application domains having "incompatible" requirements, the resulting solutions are unlikely to share common standards, platforms and interfaces, thereby hindering the development of the IoT market.

Business ecosystems in the IoT field are formed around specific technological solutions, often focusing on a specific application domain, such as RFID solutions in retail, mobile M2M communications in remote automated meter reading (AMR) or ZigBee communications in a smart home. According to some estimates, the service-enabling IoT firms – that is, the providers of IoT platforms – will eventually receive the biggest share of the total IoT revenues in the ecosystem (Schlautmann et al. 2011). At the present, these ecosystems are mainly in their formation stage, where both incumbent firms and new entrants are cooperating and competing in the same market, and where no single firm can be identified as the leader, playing the role of a keystone or a dominator in the ecosystem (Sundmaeker 2010).

The business models of the IoT firms vary depending on whether IoT is the main market for the company (e.g., for a start-up focusing on smart home products) or whether IoT is an extension for the business of an incumbent company (Sundmaeker 2010): the incumbents leverage the economies of scope by offering their customers IoT-related products, while the new entrants focus on individual niches being formed around their competence-destroying innovations. It is believed that the innovative business models (of new entrants) rather than the market power (of established vendors) are likely to induce the major changes in the IoT field.

In this report, we survey the current IoT field from the business and techno-economic points of view. The report reviews the state of the art from three perspectives, with a separate chapter dedicated to each (Table 1).

Table 1. Three perspectives of the state-of-the-art review

Level	Unit of analysis	Issues addressed
Macro	Market, vertical sectors	Market segments; technology adoption; domain-specific application requirements
Intermediate	Ecosystems, value networks, platforms, standards	Ecosystems: functions and roles of the players; platforms and standards
Micro	Companies	Business model elements: value proposition, revenue model, cost structure, resources, partner network

Chapter 1 considers the IoT field from the macro perspective. In particular, we consider the major IoT market segments, their size and expected growth, and analyze the specific requirements of these segments, as well as the available connectivity alternatives.

Chapter 2 views the IoT field from the intermediate-level perspective. With a focus on the IoT business ecosystems of companies sharing certain assets in their products and services,

Chapter 2 identifies the players of the ecosystem and their roles, and considers the value created by different roles.

Finally, Chapter 3 takes the micro-level viewpoint by studying the business models of the IoT companies, their business opportunities, drivers and challenges, as well as the earning logic.

Chapter 1.   Evolution and diffusion of the IoT field

By Oleksiy Mazhelis and Henna Warma

1.1 Main IoT segments and their requirements

This section first considers the IoT market, the main segments and their requirements, and then analyzes the technical alternatives available in these segments (primarily in terms of connectivity) and their match with the segment-specific requirements.

1.1.1   Market segments, their size and growth

Various IoT technologies can be conventionally categorized into tagging things, sensing things and embedded things (ITU 2005). The tagging things provide seamless and cost-efficient item identification, allowing the things to be connected with their records in databases. The sensing things enable us to measure and detect changes in the physical status of our environment. Finally, the embedded things yield information about the internal status of the embedding object.

Over the last decade, these technologies have been developed rapidly in the domains of, among others, the radio-frequency identification (RFID), machine-to-machine (M2M) communication and machine-type communication (MTC), wireless sensor and actuator networks (WSAN), ubiquitous computing, and web-of-things (WoT) (Atzori 2010). The IoT field is relatively young, and still dominated by the silos of vertically integrated solutions based on incompatible technologies, with each having a relatively limited marked penetration (Batten and Wills-Sandford 2011, OECD 2012). However, the adoption of the various IoT technologies is expected to expand rapidly in the upcoming years, and it will be reflected in the number of connected things, expected revenues, and annual growth rates.

In particular, the number of connected devices is expected to grow from 9 billion in 2011 to 24 billion in 2020. As show in Figure 1, the most drastic growth is assumed to take place in M2M connections, from 2 billion at the end of 2011 to 12 billion by the end of 2020 (GSMA 2011). According to Frost & Sullivan, the ratio of M2M SIMs to total mobile subscriptions in Europe exceeded 10% in some countries (e.g., 15.5% in Sweden) in 2009. Cellular technologies are expected to get a 19% share (2.3 billion) of connections by 2020 (GSMA 2011). According to Gartner, already in 2011, the population of connected things comprised over 15 billion permanent and over 50 billion intermittent connections, and these numbers are forecasted to increase to over 30 billion and over 200 billion, respectively, by 2020 (Cearley 2011).

The total revenue generated by connected devices will also grow significantly; according to some estimates, from EUR420 billion in 2010 to EUR1.3 trillion by 2020, excluding the mobile handset revenues (GSMA 2011).

The M2M market is expected to be the largest submarket within the IoT market and M2M is expected to account for the largest proportion of the "connected life" revenue, forecasted to total EUR714 billion in 2020 (Machina Research 2010). Within the M2M submarket, GSMA (2011) expects the main vertical segments to be the following:

- Automotive (revenue opportunity USD 202 billion)
- Healthcare (revenue opportunity USD 97 billion)
- Consumer electronics (revenue opportunity USD 445 billion)
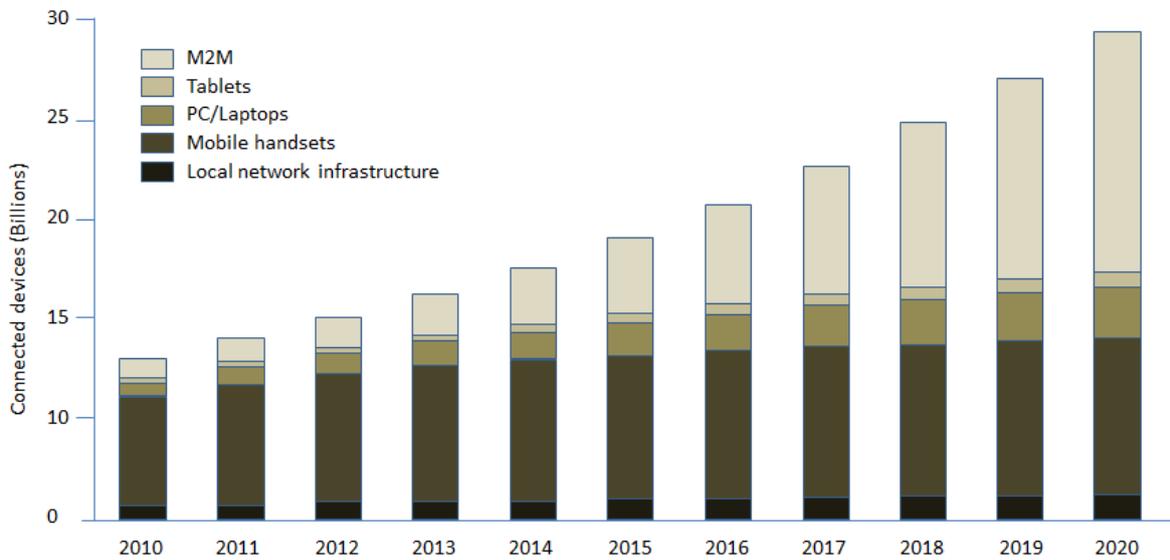- Utilities (revenue opportunity USD 36 billion).

Figure 1: Expected growth in the number of connected devices (GSMA 2011)

Figure 2 portrays the expected revenue growth in different M2M vertical sectors. As can be seen, the consumer electronics, automotive, healthcare, as well as intelligent buildings and utilities are the most promising in terms of both revenues and growth rates.
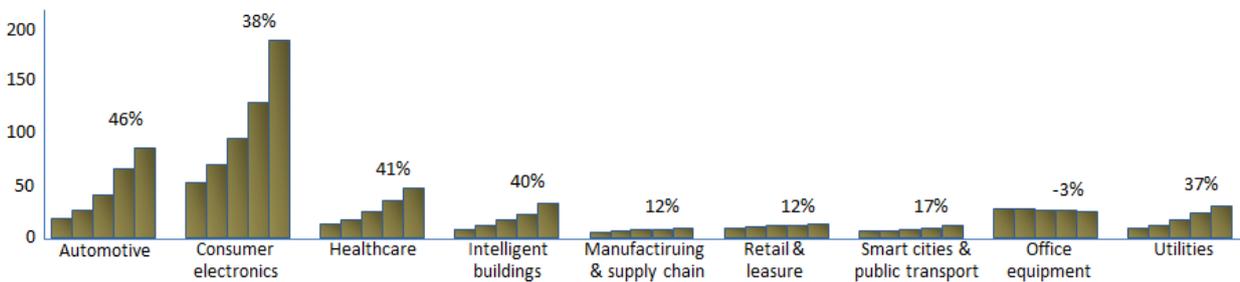
Figure 2. M2M global revenue forecast 2011-2015 in USD billions and CAGR (Machina, M2M Global Forecast & Analysis 2010-20, October 2011)

A study conducted by Ericsson suggests that the automotive sector has so far been the largest user of M2M applications (with over 25 million connections in 2010), followed by the electricity sector (14 million connections), whereas e-Health is identified as a market with "interesting opportunities" (Lehto 2010).

Given the forecasts, the following vertical segments appear to have the greatest market potential:

- *Automotive/Transportation*: in-vehicle infotainment, eCall, parking meters, information sharing about road conditions and traffic density, road pricing, toll collection, taxation, pay as you drive (PAYD) car insurance;
- *Digital home*: (home) consumer electronics, home automation, automated meter reading (AMR), residential security;
- *Healthcare*: monitoring solutions to support wellness, prevention, diagnostics or treatment services.

A number of forecasts for the growth of IoT and its subdomains are available in the trade literature. In the tables below, the forecasts on the number of items available, shipped or sold, the associated revenues, and the growth thereof (expressed as the Compound Annual Growth Rate, CAGR) are aggregated from different sources. In the literature forecasting the growth of the IoT field, the tags (RFID) and the other smart objects (also referred to as connected devices) are considered separately[3], and consequently, they are treated separately here as well.

Table 2: Number of "things" available, in billions

Number of items, billion	2010	2011	2012	2013	2014	2015	2016	2017	2020	CAGR (%)
RFID tags										
Passive tags	**0.06**	0.08	0.10	0.13	0.17	0.22	0.28	0.37	**0.80**	29.57
Active tags	**2.30**	3.43	5.11	7.61	11.33	16.89	25.16	37.49	**124.00**	48.99
Tags, total	**2.40**	3.56	5.29	7.86	11.67	17.32	25.72	38.19	**125.00**	48.48
Connected devices										
Connected M2M devices	1.64	**2.00**	2.44	2.98	3.63	4.43	5.41	6.60	**12.00**	22.03
Connected devices, total	8.04	**8.99**	10.05	11.23	12.55	14.02	15.67	17.52	**24.45**	11.76
Total tags and connected devices	10.44	12.55	15.34	19.08	24.21	31.34	41.39	55.70	149.45	31.68

Table 3: Number of connected devices shipped or sold, by type of communication and by vertical segments, in billions

Number of items, billion	2010	2011	2012	2013	2014	2015	2016	2017	2020	CAGR (%)
Type of communications										
Modules	0.19	0.27	0.39	0.56	**0.80**	1.16	1.67	2.41	7.22	**44.20**
WPAN	0.06	0.10	0.17	0.29	**0.48**	0.80	1.35	2.26	10.70	**67.80**
WWAN (GSM, CDMA, satellite, etc.)	0.05	0.07	0.09	0.12	**0.15**	0.19	0.25	0.32	0.69	**29.00**
Wireline	0.03	0.04	0.05	0.06	**0.07**	0.09	0.11	0.14	0.25	**22.80**
Vertical segment										
Consumer electronics	**0.16**	**0.24**	0.31	**0.50**	0.59	**0.78**	1.14	1.58	**4.20**	38.56
Healthcare	**0.04**	0.05	0.07	0.10	0.13	0.18	0.24	0.32	**0.77**	34.48
Automotive/Transportation	**0.09**	0.12	0.16	0.21	0.27	0.35	0.47	0.61	**1.40**	31.58
Utilities	0.07	**0.10**	0.14	0.18	0.25	0.33	0.45	0.61	**1.50**	35.11

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[3]See e.g.
http://www.dfwatw.org/uploads/Ericsson_2020_presentation_Marketing_A_shashi.pdf

Table 4: Revenues from tags and connected devices (by level and vertical segment)

Revenues, USD billion	2010	2011	2012	2013	2014	2015	2016	2017	2020	CAGR (%)
RFID tags										
Tags	**2.1**	2.5	2.9	3.3	3.9	4.6	5.3	6.2	**9.9**	16.8
Other (e.g. integration services)	**3.5**	4.0	4.5	5.1	5.7	6.5	7.3	8.3	**12.0**	13.1
RFID tags, total	**5.6**	6.4	7.4	8.4	9.7	11.1	12.7	14.5	**21.9**	14.6
Connected devices										
Connected devices - by level										
Devices	5.2	6.2	7.4	8.9	**10.7**	12.8	15.4	18.5	32.0	**20.0**
Network Services	24.5	32.1	42.0	54.9	**71.8**	93.9	122.8	160.7	359.6	**30.8**
Horizontal System Applications	18.1	23.1	29.6	37.9	**48.5**	62.1	79.5	101.7	213.3	**28.0**
Vertical Value-Added Applications	68.0	89.6	117.9	155.1	**204.1**	268.6	353.5	465.2	1060.2	**31.6**
Connected devices - by vertical segment										
Consumer electronics	315.0	**332.0**	349.9	368.7	388.6	409.5	431.5	454.7	**532.2**	5.4
Healthcare	1.4	2.0	3.1	**4.5**	**6.9**	**10.2**	**15.4**	**23.0**	**91.8**	50.4
Automotive/Transportation	**13.3**	17.5	23.1	30.4	40.0	52.7	69.4	91.4	**208.9**	31.7
Utilities	**6.7**	7.9	9.5	11.3	13.4	16.0	19.1	22.8	**38.6**	19.2
Connected M2M devices, total	**121.0**	148.7	182.7	224.5	275.9	339.0	416.6	512.0	**950.0**	22.9
Connected life, total	**560.0**	629.4	707.3	794.9	893.4	1004.0	1128.3	1268.1	**1800.0**	12.4

Due to the limited numerical data reported in the publicly available sources, the missing values were derived from the reference figures found in the literature by assuming a constant CAGR. In the tables, the reference figures are in bold and the estimates in normal font.

As can be seen, the tags are expected to exhibit the largest growth in the number of items, which is associated with a gradual decline in the cost per tag, dropping to roughly 2 cents per tag for chipless tags. The base of other connected devices in the M2M category (excluding PCs, laptops, smartphones) is also likely to exhibit a significant growth, although the total number of devices by 2020 is predicted to be less than the originally envisioned 50 billion. It is also worth noting that, of the different types of connections, the connected WPAN devices will probably grow fastest.

Tags-related revenues will likely be a tiny fraction of the revenue generated by the connected devices. Of various connected devices, the largest revenues will come from the consumer electronics and automotive/transportation verticals. The figures in the tables may be slightly misleading, however, since the predicted revenues as presented in the table include the revenues from the devices sold through telco channels (including USB modems, tablets and PC/laptops, but excluding mobile handsets).

The revenues are likely to show a more modest growth, both for the tags and for the other connected devices (CAGR of 14.6% and 22.9%, respectively), reflecting the eventual decline in the unit prices of the tags/devices. As regards the different levels in the value/supply chain, the greatest revenues are expected for the vertical value-added applications, followed by the network services and horizontal applications, whereas relatively modest revenues are expected for the device/module suppliers (although the latter revenue estimate may exclude the revenues from the M2M enabled consumer electronic devices). The latter is also expected to

grow more slowly (20%), as compared with the network services, and horizontal and vertical applications (approx. 30%).

1.1.2   The "things" in IoT

According to the IoT Clusterbook SRA (Sundmaeker et al. 2010), a "thing" in the Internet-of-Things can be defined as a physical or virtual entity that exists in space and time and is capable of being identified. In line with the vision of "anything connection" (ITU 2005), practically any *smart object*, either physical or virtual, could become a connected thing in IoT. These things are expected to sense their environment and to react to the sensed information by triggering certain actions and exchanging information among themselves as well as with the external computing entities and humans (Sundmaeker et al. 2010).

To become a part of IoT, the object shall have both *processing* and *communication* capabilities, either embedded in itself or offered by an attached component (Smith et al. 2009). Depending on their functionality, these things generate, relay and/or absorb data.

Based on their primary functionality, the IoT objects can be divided into the following three categories (ITU 2005):

- Identifying things assign a (unique) identity to an object.
- Sensing things transduce the physical state of the object and/or its environment into the (digital or analog) signal for storage and further processing.
- Embedded-systems things have an immediate access to the data sensed and processed by the systems.

The categorization is non-exclusive; for example, sensors may have identities and embedded systems may include both identifiers and sensors.

Different taxonomies are available for classifying the things in IoT; Table 5 summarizes the dimensions found in literature to characterize or classify the IoT things (Smith et al. 2009; Chaouchi 2010; OECD 2012).

Table 5. Taxonomies for the things in IoT.

Dimension	Characteristics
Mobility	Moveable vs. fixed
Size	From tiny microchips to large vessels
Complexity	Dumb vs. smart
Dispersion	Concentrated vs. dispersed
Power supply	Externally powered vs. autonomous
Placement	Attached vs. embedded
Connectivity patterns	Sporadic vs. continuous communication, narrow vs. broadband
Animateness	Non-animate vs. animate

These and other properties of the connected things impose some restrictions and requirements on the networking infrastructure and the applications utilizing them.

The interconnection with the physical world through the help of smart things is expected to bring numerous tangible benefits (Sundmaeker et al. 2010):

- Enhanced identification capabilities enable high-resolution asset and product management, high-granularity lifecycle management, and more dynamic inter-enterprise collaboration.
- Sensing and processing at the edges will facilitate the distribution of the business processes towards the edges, thus enabling improved performance and scalability.

Fleisch (2010) identified several generic IoT value drivers based on the analysis of a hundred existing and emerging IoT applications. Some of these drivers originate from the M2M communication capabilities:

- *Simplified manual and automatic proximity triggering.* The things are able to communicate their identity in a fast and robust way when in the proximity of a sensor/reader. This enables a manual or an automatic triggering of various transactions (e.g. entry records, payments). For consumers, this enables convenient self-service and hence cost-reduction and saving of time. For businesses, automatically triggered record updates in bookkeeping are advantageous e.g. in production and the supply chain management environment; such automatic functions allow for faster and more accurate tracking of assets as well as support the firms in gathering data for process optimization. A number of other applications of proximity triggering are identified, e.g. automatic door opening.
- *Automatic sensor triggering*. Based on their ability of sensing the state of their environment, the smart things are able to process the gathered information about the environment and use e.g. rule-based logic to trigger processes and/or actions. The use of smart sensors allows the decisions to be done locally and in a prompt manner, thus enabling more efficient, dynamic, and higher quality processes in a variety of application domains, from smoke detection to remote patient monitoring. For businesses, this brings both higher process efficiency and new data for further process optimization, while for the consumers the benefit lies in the enhanced quality of goods and services.
- *Automatic product security*. Using their unique identities, the past behavior of the things can be traced and documented in a unique log (at a website). The uniqueness of the log (and hence the thing) can be automatically verified, thus making it much easier to spot (multiple) counterfeiting copies that attempt to direct to a same log.

The other benefits are attributed to the interaction between the things and their users:

- *Simple and direct user feedback*. A thing can provide the user with direct feedback in the form of beeping, flashing or otherwise, which increases the accuracy of the processes and may improve their attractiveness/appeal (entertainment value).
- *Extensive user feedback.* Provided through a gateway (e.g. smartphone),the user will gain rich information about the properties of the thing (or the object to which it is attached). This may be useful in a range of convenience-increasing informational applications, varying from shopping advice to tourist services.
- *Mind-changing feedback.* Monitoring of consumer behavior (e.g. driving style or electricity consumption) and provision of information are aimed at changing the behavior towards a desired outcome (such as safer driving or more conservative use of electricity).

1.1.3 Domain-specific applications and the related requirements

The IoT technologies can be applied in a variety of domains of which the following will be discussed in this section:

- *Automotive/Transportation* applications, e.g., in-vehicle infotainment, eCall, parking meters, information sharing about road conditions and traffic density, road pricing, toll collection, taxation, pay as you drive (PAYD) car insurance
- *Digital/Connected home* including (home) consumer electronics, home automation, utilities/automated meter reading (AMR), and residential security
- *Healthcare* solutions including the monitoring solutions to support wellness, prevention, diagnostics, or treatment services.

These three domains are expected to bear the greatest potential within IoT market.

For a technical IoT solution to be accepted in an application domain, the solution should be in line with the specific requirements of the application domain. It is therefore important to consider the match between the application domain-specific requirements and the available technological alternatives. For this purpose, a number of dimensions shall be analyzed, among which are e.g. (Mendyk and Kridel 2010, OECD 2012):

- Connectivity needs
- Obsolescence period
- Coverage
- Local vs. global use
- Service level objectives including delays, robustness, durability, reliability, availability
- Need for easy roll-out and/or autonomous operation
- Energy-efficiency
- Security and privacy
- Cost of components and communications

In the following, these dimensions will be used for considering the specific requirements of the transportation, healthcare, and the connected home application domains. Further dimensions to consider would include failover capabilities, the control over the technology and customer interface (and charging for that), proven track of successes at large scale, and the availability of vendor solutions and suppliers in the market (Mendyk and Kridel 2010, OECD 2012); however, for the sake of simplicity, these dimensions are excluded from the analysis.

1.1.3.1 Transportation

Connectivity/service level. It is predicted that, by 2025, all vehicles will be equipped with either embedded or tethered connectivity (SBD 2012). This connectivity will enable a number of applications and services to be provisioned to the drivers, including telematics and navigation services (GSMA 2012b), as summarized in the table below.

Table 6: Examples of telematics and infotainment services (GSMA 2012b)

Telematics services	Infotainment
Navigation/Journey times/Augmented reality/Points of Interest	Radio - music, news: on-demand real time content
Travel and traffic assistance (assisted traffic regulation, access control/parking zone management/eco-driving)	Video: : on-demand real time content
Traffic sign warning	Multimedia, Internet services and more
Remote control of vehicle environment/Car features/Restricted drivers	Other infotainment applications (passenger gaming)
Remote diagnostics	
Breakdown services (bCall)	
General eCall (not EU specification)	
Insurance/Stolen vehicle tracking	
Fleet management	
eFreight/Tracking and tracing	
Payment/Ticketing/Metering/Tolling	
Electrical Vehicles: battery charge monitoring/control/navigation to recharge points	

As listed in Table 7, three main connectivity alternatives are available for in-vehicle solutions (GSMA 2012b): 1) embedded solutions (with connectivity and intelligence embedded into the vehicle's components), 2) tethered solutions (with connectivity relying on an external modem, keeping the intelligence embedded in the vehicle's components), and 3) integrated solutions (with intelligence and connectivity integrated into a gateway device, e.g. smartphone).

Table 7. In-vehicle connectivity alternatives (GSMA 2012b)

Connectivity	Embedded	Tethered	Integrated
Modem	Embedded	Brought-in	Brought-in
UICC	Embedded	Embedded or Brought-in	Brought-in
Intelligence/Application	Embedded	Embedded	Brought-in
User interface	Vehicle HMI	Vehicle HMI	Projection (on vehicle display or on phone) or phone-based

The *embedded* connection is used whenever the services need to be highly reliable and available – such as in security and safety-related applications. If they are not generating much communications traffic, the vehicle manufacturers may prefer charging a single upfront payment for the whole lifetime of the car. Otherwise, at the present, the difficulty of splitting the costs between services and the complexity of roaming agreements make it difficult to use these services for a wider range of applications.

The *tethered* solution mitigates the billing and roaming agreement problem of an embedded connection, but gives only a marginal cost advantage (if an embedded modem is used), and requires the user to have a separate SIM or a separate modem (whose quality may not be up to the needs). Furthermore, it requires the telematics control software to be customized/revised for interfacing and interoperating with different types of mobile phones (likewise, all mobile phones shall support the interfaces). It is used in less critical and more traffic generating applications, such as infotainment. Both tethered and embedded connectivity

may require interventions in order to cope with technological evolution during the vehicle's lifetime.

The *integrated* connectivity, as the tethered solution, allows the communication costs to be fully allocated to the vehicle owner while minimizing the hardware costs. Still, the interaction with vehicle systems is difficult, and connectivity is not guaranteed. The likely use scenario for the integrated connectivity is thus infotainment.

According to the study by GSMA (2012b), the requirements for the connectivity depend largely on whether or not telematics or infotainment services are provided. The *telematics applications* (travel and traffic assistance, remote control and diagnostics, bCall and eCall, insurance, tracking, ticketing, etc.) require the following:

- *Wide coverage* of the connection
- *Low latency*
- *High degree of security, reliability and privacy*
- Relatively *low bandwidth* (below 1 Mb per user).

On the other hand, the *infotainment* applications (and, to some extent, navigation services) require the following:

- *Higher bandwidth* (often exceeding 1 Mbps)
- *Low latency*
- *High reliability* or *privacy*
- *Wide coverage* was not reported as critical in this application domain.

Obsolescence period. While mobile networks and other IoT-enabling technologies are evolving rapidly, the automotive industry features both relatively long product development cycles (3-5 years) and relatively long times of active use (7-10 years). Accordingly, the connectivity solutions should be *robust* and *durable*, require *minimal hardware upgrades*, and rely on *over-the-air updates for the software*. For embedded solutions, this has two implications: 1) the networks shall be sufficiently future-proof to cover the lifetime of the solution (some 2G networks may soon be obsolete) and 2) services with conservative data communication needs (diagnostics, navigation) could be cost-efficiently provided with an embedded SIM card (remotely managed) for a single upfront payment throughout the whole lifetime of the car (GSMA 2012b). Another implication of the specific requirements is the higher average price for the automotive communication modules, as compared with those in consumer electronics (Sanders et al. 2010).

Coverage/mobility. Seamless mobility is generally required for the applications. For telematics applications, global coverage is essential, whereas for the infotainment, regional coverage is likely to be sufficient.

Energy-efficiency. The power consumption of all in-vehicle electronic units should be minimized, especially when the engine is off. This can be achieved, e.g., by shutting down the electronic units when the vehicle is parked and no activities are detected in the vehicle (Kohn 2010).

Costs of components and communications. As found by Analysis Mason (Sanders 2010), the TCO of in-vehicle devices varies from USD 300-400 for private vehicle theft detection and infotainment solutions to USD 2000 for commercial vehicle management, information, diagnostic, and control systems. Accordingly, the share of the communication module in the TCO varies between 2% (commercial vehicles) and 14% (private vehicles). Private consumers in Europe are reluctant to pay a subscription fee for the telematics services and quite sensitive

to the costs of the telematics, whereas a higher tolerance is expected towards the costs of the infotainment solutions (GSMAb 2012). The telematics services targeting commercial vehicles are generally less sensitive to the costs of the components and communication, given their relatively small share in the TCO.

Since a vehicle's owner and/or region of usage may change during its lifetime, the connectivity shall be flexible to allow the change of the owner and the country/region of operation without inflicting costly changes to the solution.

Finally, the connectivity solution shall be in line with the regulatory provisions (such as eCall from 2015 and upcoming roaming requirements), and with the prevailing automotive sector business models (such as the customers' reluctance to pay subscription fees for the telematics, except in the USA).

1.1.3.2 Healthcare

IoT-related healthcare applications and services include the so-called telehealth and telecare solutions, allowing medical services to be delivered remotely and/or over electronic media. In particular, the m-Health (mobile health) services rely on using mobile terminals and networks in gathering, aggregating, and communicating the information about a patient's state. Such (mobile) health services are categorized into patient pathway solutions (wellness, prevention, diagnostics, treatment, and monitoring) and healthcare strengthening services (Vishwanath et al. 2012). Among these, only monitoring requires technical capabilities beyond a smartphone with a broadband connection enabled. Coincidentally, the monitoring services are expected to generate the greatest portion of the revenues in the developed markets (such as Europe or North America).
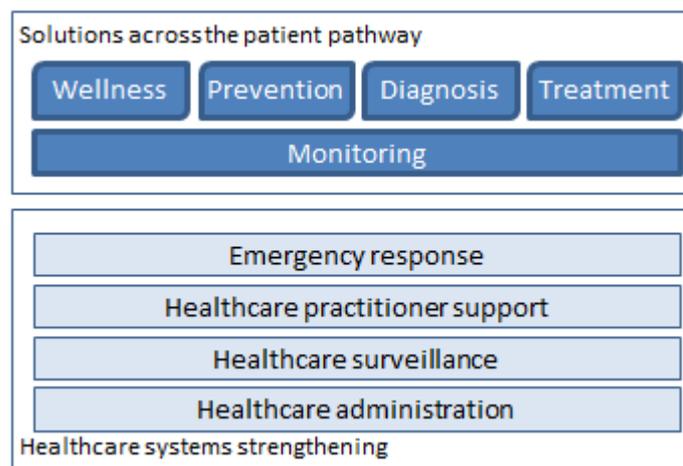

Figure 3: Categories of mobile health services (Vishwanath et al. 2012)

Monitoring services support the other healthcare activities, such as prevention, diagnosis, treatment, and after-care. These services focus on "monitoring patients to identify and confirm underlying illnesses and monitoring of the vital parameters of at-risk patients to track underlying conditions and take action in order to prevent exacerbation" (Vishwanath et al. 2012). Examples of the solutions include body and heart monitors, remote hypertension monitors to monitor patients' blood pressure, monitoring of the body parameters and activities of senior citizens (fall detection, location tracking).

Table 8 summarizes the connectivity options of contemporary monitoring devices. Of the 200 devices listed, a vast majority are connected (mainly over the Bluetooth) to a smart device or a dedicated gateway which will further relay the information.

Table 8. Connectivity available in (mobile) health devices (GSMA 2012a)

Connection Type	Count	Percent
Embedded	33	16.5 %
Gateway	33	16.5 %
Connects to Smart Devices	103	51.5 %
Connects to Gateway/Smart Devices	31	15.5 %
Total	**200**	**100.0 %**
Short-range connectivity		
Bluetooth	108	54.0 %
USB	16	8.0 %
Wi-Fi	4	2.0 %
Infrared	8	4.0 %
ZigBee	8	4.0 %
Mobile network connectivity		
GSM	40	20.0 %
WCDMA HSPA	7	3.5 %
WCDMA UMTS	5	2.5 %

A reference architecture for (mobile) health services has been introduced by GSMA (2012a). The main building blocks of the reference architecture include the mobile health connected device, the clinical device, and the mobile health platform responsible, e.g., for the conversion, aggregation and analysis of the data. In addition, the architecture includes some of the MNO elements (responsible e.g. for billing and authentication) and the hospital systems, such as Personal Health Record (PHR) and Electronic Health Record (EHR). The architecture focuses on m-Health services. According to GSMA (2012a), the main difference between e-Health and m-Health lies in the connectivity: while e-Health uses the existing landline communications network, m-Health uses the mobile telecommunication network. Therefore, the reference architecture presented in the figure below can be generalized to cover e-Health services as well.
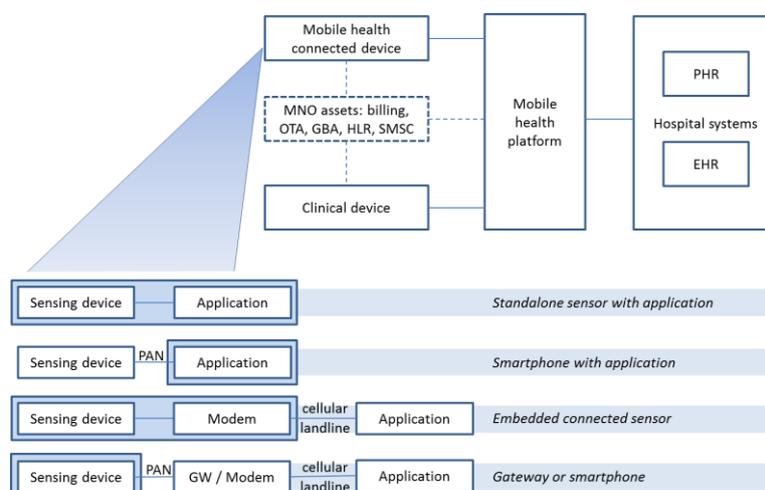

Figure 4: Reference architecture for m-Health/e-Health (GSMA 2012a)

Three types of m-Health connected devices are envisioned by GSMA (2012a):

- *Embedded sensors* with embedded connectivity.
- *Gateway devices* using a short-range technology to connect to a router, which will further relay the information.
- *Smartphones with application* using devices that either connect via a short-range technology or plug into the smartphone.

The second and the third type of devices are merged in the figure above. For completeness, we shall add to this list also the "sensor with application" type of device. Of these types, "sensor with application" and "smartphone with application" are self-sufficient, i.e., do not benefit from Internet connectivity, and therefore are not considered in this document.

While the GSMA report focuses on cellular connectivity, we include also landline connectivity as an alternative for connecting the device or gateway with the platform.

Several standards are applicable for these solutions:

- Industry healthcare standards (HL7 and IHE PCD profiles) are used for exchanging the patient information between the platform and a patient's PHR or a healthcare provider's EHR.
- Both the sensor device and the application may use data semantics defined by the healthcare messaging standard, such as IEEE 11073, IHE PCD-01, or DICOM.

The requirements are summarized in the following.

Connectivity. The needs are application-specific and depend on criteria such as whether the application is required to transfer images, video, and/or sound samples, or whether only sensor readings and/or alerts are communicated, or how often the communication takes place. Overall, bandwidth requirements are relatively modest, generally below 2Mbps (Batten and Wills-Sandford 2011).

Obsolescence period. Depending on the application, the lifetime of a solution may range from 5 to 20 years.

Coverage/mobility. Seamless mobility is generally required for the applications, although some solutions (e.g. a connected weight scale) can be used at home or another fixed location.

Local vs. global use. Global coverage would make the solutions attractive for those travelling abroad, but otherwise local/regional coverage may be sufficient.

Reliability and availability. If a monitoring solution focuses on wellness services, occasional failures and unavailability cases may be tolerated. However, whenever the monitoring is a part of prevention, diagnostics, or treatment services, high-level of reliability and availability is required end-to-end (Batten and Wills-Sandford 2011).

Roll-out and operation. The service provider often needs the capability for remote management of the mobile health connected device, the smartphone/gateway device (when involved), and the applications. It is also important to make the provisioning process (device delivery, plugging, configuration) streamlined, both in order to improve the customer experience and to minimize the costs of the service.

Energy-efficiency. The sensing devices and the smartphone (when involved) often run on batteries and hence are energy-constrained; therefore, conservative consumption in such cases is important.

Security and privacy. Integrity and confidentiality of patient data, while on the device, in transit, and on the platform, are vital in healthcare solutions (GSMA 2011). To avoid life-threatening situations caused by security incidents (e.g. hacking insulin dosage (Marshall 2012)), user and device authentication and other security mechanisms are necessary. The security requirement may be somewhat less stringent for some of the wellness-supporting monitoring services.

Costs of components and communications. According to the report by Sanders et al. (2010), in the patient monitoring and diagnostics domain, the TCO of the devices is under USD 200, of which the communication module costs USD 21, i.e. approx. 12%[4]. Overall, the monitoring solutions focusing on wellness services are likely to be closer in nature to consumer/household devices, and therefore their adoption is assumed to be sensitive to the solution costs. However, for monitoring solutions that support the prevention, diagnostics, or treatment services, moderate and even high costs may be acceptable, under the assumption that the benefits received from the service exceed these costs.

Being MNO-driven, GSMA promotes the use of 3G, 2.5G and 2G networks and other MNO assets as building blocks for the mobile healthcare solutions. However, other connectivity alternatives can be employed as well: for instance, the Sana Mobile Health Platform supports the transfer of data over multiple interfaces, including GPRS, WiFi, SMS, and USB tether[5].

1.1.3.3 Connected home

Connected home has been a subject of interest for both researchers and practitioners for several decades. Known under different names – Domotica, smart home, smart living, digital home – the connected home concept can be broadly defined as a "a residence equipped with computing and information technology which anticipates and responds to the needs of the occupants, working to promote their comfort, convenience, security and entertainment through the management of technology within the home and connections to the world beyond" (Aldrich 2003). As such, the connected home encompasses a variety of applications from multiple vertical sectors, including media, energy, healthcare, home automation, security, education and eGovernment (Batten and Wills-Sandford 2011). The healthcare sector has already been considered above. Education and eGovernment applications are excluded from the analysis since they rely on traditional computers without the need to connect and interoperate with new smart devices and/or physical world, and as such, appear less relevant within the scope of IoT.

Thus, we focus our attention on the following connected home subdomains:

Connected media and entertainment. By adding connectivity to consumer electronics, the applications in this domain allow the users not only to capture and store, but also to communicate and share the media/entertainment content across devices and people as well as

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[4] http://www.gsma.com/documents/the-total-cost-of-ownership-for-embedded-mobile-devices/22770/
[5] http://sana.mit.edu/platform/, see also http://www.gsma.com/documents/sana-mobile-health-platform-case-study/21317

locations. The connected devices in this category include TVs, game consoles, e-book readers, digital and video cameras, digital photo frames, etc.

Remote metering allows the utility companies to automatically and remotely measure the electricity, gas and water consumption. This will reduce the costs of measuring and resulting disputes, and is also expected to deliver significant reductions in consumption patterns due to the possibility to remotely switch on the home appliances at off-peak times with lower tariffs.

Home automation allows remote control of home systems, including heating, ventilation, and air conditioning (HVAC) systems, lighting, and home appliances, such as washing machines and dish washers. Home automation promises its users the possibility to reduce the time spent on routine tasks, accompanied by the convenience, cost reduction and peace of mind.

Home security can be exemplified with the access control and video surveillance solutions. By adding the connectivity to door locks, motion sensors, video cameras, etc., the domestic security incidents can be avoided or, at least, detected quickly. Another set of applications may trigger an alarm whenever a valuable object (wallet, laptop) leaves the home without authorization.

These domains attract significant attention from the industry, as evidenced by numerous innovative connected devices shown at CES 2012[6]. In particular, smart TVs enable screen-to-screen sharing of media over DLNA/UPnP (Panasonic Smart Viera [7]). Besides media, applications such as Email, Facebook, Google Maps or PowerPoint can be shared using a software client pre-installed on the devices (iRevo Multimedia[8]). Consumer electronics products, such as cameras and camcorders, are getting connected over Wi-Fi[9]; home appliances such as fridges, washing machines, dishwashers are getting connected as well[10].

Innovative home automation products are being introduced, with the focus on energy saving applications. For instance, GreenWave Reality offers a platform for cloud-based monitoring and control of a connected home by providing, in particular, Energy Management, Connected Lighting, and Home Monitoring services[11]. Other examples of energy monitoring systems present at CES 2012 include Energy Buddy by FutureDash[12], e-Sense Home Energy Monitor by Reliant[13], Marvell's Smart Energy Platforms[14], as well as Savant, Tendril, ThinkEco, and other platforms. Many of the new products fall into the category of home security solutions: for instance, Kwikset solution allows the residents to use their smartphones for remotely controlling the Wi-Fi-connected door locks[15], and Yale demonstrates how the smartphone can be used for controlling the locks over the near field communication (NFC).

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[6] http://www.slideshare.net/Greenwich-Consulting/2012-international-ces-review-of-innovative-products-and-services
[7] http://www.panasonic.co.uk/html/en_GB/7420871/index.html
[8] http://www.irevomm.com/
[9] http://www.pcworld.com/article/247983/ces_2012_camera_and_camcorder_trends_connected_compact_and_complex.html
[10] http://plassapplianceblog.com/2012/01/21/smart-appliances-steal-the-show-at-ces-2012/
[11] http://www.greenwavereality.com/
[12] http://futuredash.com/sites/default/files/EnergyBuddyPressRelease.pdf
[13] http://www.azosensors.com/news.aspx?newsID=3688
[14] http://www.marvell.com/ces-2012/
[15] http://kwiksetpresskit.com/events/ces/

Devices and appliances can be connected with each other and with Internet in multiple ways:

- Directly to WAN using an embedded on-dongle 2G/3G/LTE modem.
- Through a gateway, more specifically
    - a gateway device equipped with 2G/3G/LTE modem
    - a residential landline gateway which is further connected to a WAN, e.g., over xDSL or FTTH
    - a smartphone acting as a gateway.
- Devices may communicate with each other using either proprietary protocols (cf. the case of an LG fridge communicating with an LG oven[16]), industry standards (cf. the case of Samsung AllShare product using DLNA/UPnP for sharing media[17]) or using third-party client software (iRevo Multimedia).

At the present, the interoperability between the connected devices is a responsibility of a single vendor that ensures the interoperability either through using proprietary interfaces and protocols, through installing add-on software clients on the devices, or through the use of a gateway device (Katasonov 2012).

According to the CES 2012 panelists, in the future, the devices can be expected to gain intelligence sufficient for interoperating directly, without the need for dedicated gateways. Currently, however, such direct interaction is only available for the UPnP/DLNA-based media sharing applications. The gateway is thus the state-of-the-art solution for connectivity and interoperability.

As stated in the Home Gateway Initiative (HGI 2011), the home gateway is often also a critical element in integrating home devices and appliances to the WAN infrastructure and application services. The variety of technologies to interact with (both the hardware/software components of the devices and the communication capabilities they have) necessitates/calls for flexibility in gateway functionality. This flexibility can be achieved either by changing the gateway firmware (which is rather challenging due to the multitude of firmware versions to develop, test and maintain) or by deploying a modular software platform on the gateway, whereby necessary software modules could be started or stopped without the need to change the firmware.

Contemporary gateways are controlled by individual companies, which charge a premium for solving the interoperability with other devices at home. For example, the home automation and energy management gateway recently introduced by Motorola, based on its 4Home platform, comes with a (free) application to control the connected home devices; however, the customers are charged USD 20 or 30 for adding each new connected device, in addition to paying USD 70 in service fees to Verizon[18].

The requirements for connected home solutions are summarized in the following.

Connectivity. The needs are generally higher for the media/entertainment subdomain; some experts estimate the required bandwidth to be up to 4Mbps (Batten and Wills-Sandford 2011). Dealing with video streams, video surveillance may also have high (uplink) bandwidth

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[16] http://www.lgnewsroom.com/ces2012/view.php?product_code=95&product_type=95&post_index=1828
[17] http://www.androidathome.com/?p=687#more-687
[18] http://www.treehugger.com/gadgets/ces-2012-connected-home-leads-popular-theme-in-consumer-electronics.html

demands; however, often the cameras use compression and stream only when a motion is detected, thus reducing the required bandwidth below 1Mbps (Mendyk 2010). The home automation and remote metering solutions are generally conservative in their bandwidth demands, and even a low-bandwidth GPRS connection may be sufficient.

Obsolescence period. The media and entertainment devices are consumer electronics whose average lifetime is relatively short and varies from 18-24 months (for handsets) to 4-6 years (for TVs) or 7-8 years (for appliances)[19]. On the other hand, for the metering and security solutions, it is common to have a rather long replacement cycle of 15 and 10 years, respectively (Mendyk 2010). Depending on the application, the lifetime of home automation solutions follows the lifetime of home HVAC systems and may be from 8 to 30 years[20].

Coverage/mobility. Most of the devices in a connected home are either fixed (e.g. meters, washing machines) or used at home (game consoles, book readers). Seamless mobility is thus generally not needed for the connected home, although some of the media/entertainment devices may offer added value to their users by being connected while outdoor or travelling.

Local vs. global use. While local (or even fixed point) coverage is sufficient for many connected home applications, global coverage would make some of the media/entertainment solutions more attractive to use while travelling abroad.

Reliability and availability. These requirements are more stringent for the home security subdomain (Backer 2007). High reliability (and durability) is critical also for the metering and home automation solutions; however, temporal unavailability of these solutions might be tolerated. On the other hand, the media and entertainment solutions have somewhat lower reliability and availability needs: while lowering customer experience, temporal outages are likely to be tolerated by the customers. For instance, the technical requirements published by the HGI devote limited attention to the reliability and availability issues, with the exceptions of the (non-quantified) need for reliable gateway software modules[21] and the need for a reliable common power supply to have expected lifetime of at least 10 year with a yearly failure rate of 2.9%[22].

Roll-out and operation. The systems are used by non-experts; therefore, easy installation and remote management functionality are needed, including:

- Ease of installation and configuring (zero-touch), implying the need for appropriate tools for end users and operators (HGI 2008)
- Remote management support for remote operations, customer care procedures, managed services provisioning (HGI 2008)
- Remote performance monitoring and diagnostics, in response to a problem report by a customer (HGI 2008)

Energy-efficiency. Some of the devices and the smartphone (when involved) run on batteries and hence are energy-constrained; therefore, conservative (resource) consumption in such cases is important.

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[19] See http://www.assocham.org/prels/shownews.php?id=2159
[20] See http://www.oldhouseweb.com/how-to-advice/life-expectancy.shtml
[21] HGI-RD008-R3, at http://www.homegatewayinitiative.org/documents/release_3.asp
[22] HGI-RD015-R3, at http://www.homegatewayinitiative.org/documents/release_3.asp

Security and privacy. Confidentiality of private data stored at home or communicated over home network, as well as restricted access to the control of home devices and appliances are necessary requirements (Backer 2007). Arguably, ensuring data confidentiality and enforcing access control have higher priority for home security and home automation solutions, whereas the integrity of data is of utmost importance for metering applications.

Costs of components and communications. In general, the media/entertainment subdomain, being related to the consumer electronics, is the most sensitive to the TCO, and therefore to the choice of an inexpensive connectivity mode. The other subdomains of the connected home are arguably more tolerant to the higher connectivity costs, as soon as the solution provides noticeable added value. According to Sanders et al. (2010), the TCO of the connected solutions is as follows:

- Consumer devices and home automation: under USD 200 (communication module costs USD 26, i.e. circa 13%)
- Utilities / metering: above USD 300 (communication module costs USD 20, i.e. circa 6%)
- Domestic security: under USD 400 (communication module costs USD 25, i.e. circa 6%)

As shown by these figures, the proportional share of connectivity in the TCO is largest in the consumer devices and home automation subdomains, whereas in the other two domains it is rather small and may thus tolerate a more expensive embedded cellular connectivity.

1.1.3.4 Domain-specific requirements

The requirements in different domains are summarized in Table 9.

Table 9: A summary of domain-specific requirements

Dimension	Transportation	Healthcare	Connected home
Connectivity needs	**Telematics:** relatively modest bandwidth needs (< 1 Mbps per user) **Infotainment**: high downlink bandwidth (often > 1 Mbps)	Relatively modest, generally < 2 Mbps	**Media & Electronics (TV):** downlink up to 4 Mbps, small uplink **Media & Electronics (cameras), Security**: uplink of some Mbps, small downlink **Utilities/AMR, home automation:** low bandwidth, often one-directional data flow
Obsolescence period	10-15 years for in-vehicle solutions; for infrastructure solutions, the expected lifetime may be even longer	5-20 years	**Media & Electronics**: 18-24 months (4-6 years for TVs and 7-8 years for appliances) **Security**: 10 years **Utilities/AMR**: 15-30 years **Home automation**: 8-30 years
Coverage	**Telematics**: global **Infotainment**: regional	Regional use is sufficient in many cases.	Local use is sufficient in many cases, except for some moveable (**Media & Electronics**) things.

Dimension	Transportation	Healthcare	Connected home
Mobility	Seamless mobility is generally needed.	Seamless mobility is usually needed.	For moveable (**Media & Electronics**) things, seamless mobility may be needed. **Other** things are fixed or used at home, and local coverage is sufficient.
Service level objectives (delays, reliability, availability, robustness, durability)	**Telematics:** 1) *eCall and other safety-related solutions*: low delays; high reliability; high availability. 2) *Parking meters, road pricing, toll collection, taxation, pay as you drive car insurance*: high integrity; relatively high reliability and availability **Infotainment**: low delays, best effort or high reliability and availability (depends on the service)	**Wellness**: occasional failures and unavailability tolerated **Prevention, diagnostics, or treatment**: high end-to-end reliability and availability	**Media & Electronics**: low delays, best effort or high reliability and availability (depends on the service) **Security**: low delays; high reliability; high availability **Utilities/AMR, Home automation**: high reliability; high durability
Energy-efficiency	Important for vehicles when the engine is off; otherwise, energy source is not a strong constraint.	Often devices are battery-powered, i.e. energy-efficiency is critical.	**Media & Electronics**: Energy-efficiency is important for battery-powered devices. **Security, Utilities/AMR, Home automation**: Usually are not constrained.
Security and privacy	**Telematics**: High security is vital. **Infotainment**: Strong privacy is needed.	**Wellness**: Privacy of user data is important. **Prevention, diagnostics, or treatment:** Both security and privacy are vital and often stipulated by legislation.	**Media & Electronics**: need for confidentiality of private data **Security**: strong need for confidentiality, integrity, and availability (with access control) **Utilities/AMR**: strong need for integrity of data **Home automation**: strong need for the integrity and access control
Cost of components and communications	**Telematics**: low tolerance **Infotainment**: high tolerance	**Wellness**: sensitive to the costs **Prevention, diagnostics, or treatment:** Moderate and even high costs may be acceptable.	**Media & Electronics**: low tolerance **Security, Utilities/AMR, Home automation**: higher tolerance

1.2 Technical alternatives, cost structure and bottlenecks

A number of architectural solutions have been proposed for IoT as a result of public research projects (SENSEI, CASAGRAS, CUBIQ, IOT-A), commercial initiatives (ZigBee, SunSPOT) and standardization activities (EPCglobal, ETSI TC M2M, IETF 6LoWPAN, ROLL and CoRE charters); a detailed analysis of these solutions is available e.g. in (Bui 2011, IoT-A D1.1).

The majority of the architectural solutions focus on a particular sub-domain of IoT. For instance, IETF and SENSEI focus on wireless constrained/sensor networks, EPCglobal deals with RFID-related technologies, and ZigBee's scope covers personal area network communications. The work by ETSI TC M2M represents a notable exception (see Figure 5). In addition to the issues pertaining to the local/personal area networks and their interconnection with the Internet, it also offers an end-to-end architectural view, including application-level interfaces and their service capabilities, as well as application-level gateways facilitating the inter-work between different networks using URIs/RESTful approach (Hersent et al. 2012).

In this section, we focus on technologies that have been developed so far for the M2M communication and deployed for commercial applications. First, we take a look on short-range protocols, both proprietary and standardized, their key characteristics and application areas. Thereafter, we provide a brief introduction to wide-range protocols in the field.
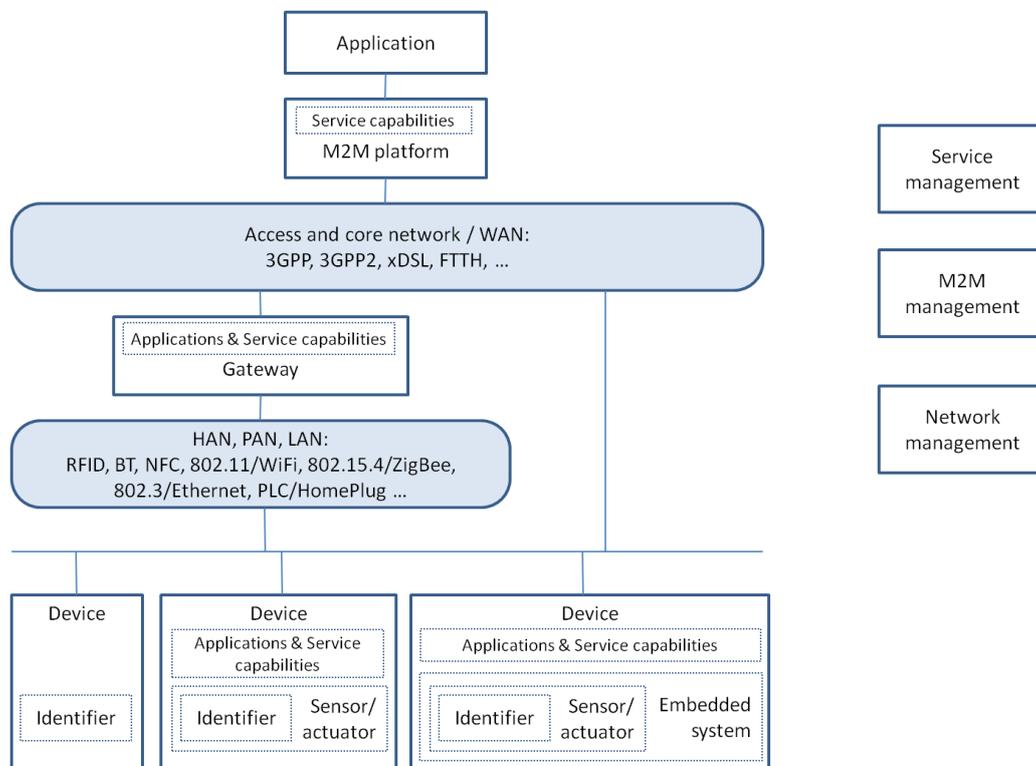

Figure 5. A generic high-level end-to-end architecture based on ETSI TC M2M (adapted from Hersent et al., 2012)

1.2.1   Short-range protocols

Sensor networking and M2M communication have become subject to special interest during the past few years, but the protocol development has been ongoing for decades. This section provides an introduction to the existing short-range protocols. A short introduction to long-range wireless technologies is provided in section 1.2.2. A more thorough technical evaluation of radio technologies in the IoT context is available in the deliverable D1.1.4 (Comparison of Radio Technologies for IoT) issued by the WP1. We present here both proprietary and standardized solutions, which have commercial deployments, and compare their characteristics. We concentrate on protocols that are being used for user/device monitoring, home and building automation and automotive applications.

Table 10 shows a mapping of different short-range protocols into different application areas of interest. The list is not exhaustive, but it aims to list technologies which currently have or will have a major impact on the market. The presented technologies may have applications in other areas as well but they are not listed in this document. Since we believe that, in order to become widely deployed, M2M applications need to rely on wireless technologies, we do not go deeper into the wired technologies either.

Table 10. Use of short-range protocols in different application areas

	User/device monitoring	Home automation	Large building automation	Automotive
ZigBee	X	X	X	
Z-Wave		X		
Insteon		X		
EnOcean		X	X	
ONE-NET		X		
KNX		X	X	
LonWorks		X	X	
BACnet			X	
Modbus			X	
IEEE 802.11x (e.g. WiFi)	X	X	X	X
DASH7				X
IEEE 1902.1 (RuBee)	X			
Bluetooth (LE)	X			X
ANT/ANT+	X			
Infrared	X	X		

The mapping areas include user or user device monitoring, home automation, large building automation and automotive applications. User monitoring means applications where sensors, such as pulse meters, are used for sending data to a receiver. Alternatively, user device monitoring means applications where a device is identified on the basis of a tag whereby the user will gain access to a particular place or service. Travel cards used in public transportation are an example of such applications. Home automation means connecting and automating the functions of different devices within home environment. Current commercial solutions include automated and/or remote lightning control and security systems, which can monitor the home and send the resident alarms and status messages, for example, via text messaging or email. Office or factory buildings have often different requirements from those of residential buildings, although similar services are needed in both environments. Therefore, home automation technologies have here been separated from those being used in large buildings. Typical applications seen in the office buildings today are automated HVAC (heating, ventilation and air conditioning) systems. Automotive category includes applications for in-vehicle services, such as navigation, but also analysis of remote sensor data from the vehicle.

In the following, we discuss each of these technologies in more detail. We describe the origins of each protocol and the companies and organizations behind their development. We also review the standardization activities related to each technology and analyze their compatibility with the regular Internet technologies. Where possible, we elaborate on the protocol's status in the market.

ZigBee

The development of ZigBee technology began in 1998 at Motorola. At that time, Motorola was researching technologies for low-power mesh networking, which eventually became the basis of the IEEE 802.15.4 standard published in 2003. ZigBee Alliance was formed in 2002, and the original members were Motorola, Philips, Invensys, Honeywell and Mitsubishi. Since then, several companies have joined the Alliance, and currently, it has 13 promoters (e.g., Philips, Texas Instruments, Schneider Electric) with representation in the Board of Directors and full voting rights, as well as 170 participant members (e.g., British Telecom, Huawei, Cisco) that carry voting rights and play an active role in the development of ZigBee protocols (Zigbee Alliance 2012). In addition, ZigBee technology has 230 adopter companies, including ABB, Fujitsu and Motorola, which have access to completed protocol specifications.

ZigBee Alliance calls itself an open association and welcomes businesses, universities as well as government agencies to join. However, the current list of members only includes two academic partners, and the current membership fees are USD 50 000 per year for promoters and USD 9500 per year for participants (ZigBee Alliance 2012). Adopters pay USD 3500 per year for their membership. Therefore, ZigBee is a de facto rather than an open standard in the market.

The original specifications of ZigBee protocol were developed for home automation, but today, specifications are available for large building automation, retail applications and health monitoring as well. Most of the protocol specifications are based on the IEEE 802.15.4 radio, but the quite recent specifications for Smart Energy are no longer tied to the physical and medium access control specifications of IEEE 802.15.4 (Bui 2011). ZigBee specifications also cover functionalities for an Internet Gateway, which can be used to convert ZigBee packets in an Internet-compliant way (Koivunen 2011; ZigBee Alliance 2010). In addition, ZigBee frames can be transferred on top of TCP using the gateway remote interface protocol (GRIP) specifications (ZigBee Alliance 2010), and on top of UDP using the compact application protocol (CAP) (Tolle 2008).

It is difficult to estimate the exact market share or number of installed ZigBee devices but, although the protocol has had its problems with, for example, IP-compatibility, it is clearly one of the front-runners in the IoT field. ZigBee is one of the few protocols capable of adapting to different market sectors. Maybe one of the reasons thereto is the constant effort of ZigBee Alliance to increase interoperability with the native Internet protocols allowing flexibility in the underlying technologies.

Z-Wave

Z-Wave is a short-range wireless technology which is often referred to as the major competitor for Zigbee. Z-Wave is claimed to be the follower of the fixed home automation protocol X10 used on top of power lines (Koivunen 2011). The development of Z-Wave technology was started by a small Danish company called Zensys (Knight 2006) founded in 1999. It was the first company to publish a viable wireless mesh networking technology (Jacobson 2008). Later on, Zensys was acquired by Sigma Designs, which is still one of the principal members of Z-Wave Alliance (Z-Wave Alliance 2012).

Just like ZigBee Alliance, Z-Wave Alliance has three levels of participation: principal, full and affiliate members. Principal and full members are able to take part in the development of the Z-Wave technology, whereas affiliate members only have access to complete specifications. The annual fee is USD 3500 for full members and USD 300 for affiliate members. Knight (2006) reported that, in 2006, the chip giants Intel and Cisco supported Z-Wave technology,

but currently neither of the companies is on the member list of Z-Wave Alliance. Only a few big names, NEC, NTT Docomo, Verizon and Zyxel, are full members of Z-Wave Alliance.

The Z-Wave protocol stack is vertically integrated and it only works on top of Z-Wave proprietary radio. Z-Wave protocol does not specify the interoperability with the Internet protocols, so the gateway implementation is fully up to the vendors (Koivunen 2011). Basically, the gateway needs to convert the Z-Wave application protocol into a convenient presentation format, such as a web page. Unlike Zigbee, Z-Wave only has applications for home environment.

Besides ZigBee, Z-Wave is clearly the other major technology used in home automation, but the comparison of their market shares is difficult. However, based on some online posts, ZigBee seems to be stronger in smart meters, but Z-Wave is claimed to have more smart home devices on the market (St. John 2011). Z-Wave has also been claimed to have bigger market share in the United States, while ZigBee is stronger in Europe, for example.

Insteon

Similar to Z-Wave, Insteon is a proprietary technology for home automation. The development has been driven by a company called SmartLabs Inc., which was founded in 1992. Insteon enables the interconnection of home devices, such as light switches and motion sensors. It works on top of power lines or using a proprietary radio technology (Cao et al. 2009). Insteon Alliance has currently around 90 members including, for example, D-Link, but no other major player in the market is supporting the technology (Insteon Alliance 2012).

Insteon supports Internet gateway specifications and several gateway devices are available on the market. Since Insteon is used on top of power lines, it has been designed to be compatible with X10, so the devices supporting X10 and Insteon are partly interoperable.

EnOcean

EnOcean is another wireless sensor networking technology, which clearly differs from its competitors in one aspect. EnOcean devices operate without batteries, so the sensor devices harvest their energy from the environment. EnOcean technology is carrying the name of its original designer company. EnOcean Alliance was established in 2008 to promote the development of the technology. Since its establishment, EnOcean Alliance has welcomed seven other promoters, including Texas Instruments, which make the final approvals about specifications. Participant members, which can also propose work items and approve draft specifications, include General Electric, Siemens, Renesas Electronics and Yamaha, and the group numbers over 100 members. Currently, EnOcean Alliance has 145 associate members, including Hitachi and Mitsubishi Materials. The membership fees in EnOcean Alliance are USD 35 000 for promoters, USD 6000 for participants and USD 250 for associates.

The EnOcean technology enables sensors to communicate with a gateway in a star-based manner with an actuator, a controller or a gateway, which are powered network components (Anders 2011). The EnOcen gateway specifications support several major building automation systems such as KNX, BACnet, LONWorks and ModBus (see "Other building automation protocols" below) as well as TCP/IP stack.

On its website, EnOcean Alliance claims that the technology is deployed in over 200 000 buildings around the world, which means that the number of EnOcean devices can easily count up to millions of devices worldwide. Presumably the number is still smaller than for ZigBee and Z-Wave, which have been longer in the market. However, the growth of EnOcean technology

seems to be relatively rapid; EnOcean Alliance is claimed to be one of the fastest growing alliances of its kind (Vanderpool and Gallagher 2011). In 2010, around 50 companies joined the Alliance, and in 2011, the number was almost 90 companies.

ONE-NET

ONE-NET is an open source initiative in the field of home automation. The development was started by the company called Threshold, which was founded in 2004 to develop smart homes which integrate all kinds of services in the home, or in office environment, from security and appliance automation to monitoring and energy management. The company looked for the alternatives in the market and concluded that no suitable technologies were available. It started to develop its own protocol which was named ONE-NET (ONE-NET 2012).

The promoters of ONE-NET technology total 14 and, in addition to Threshold Corporation, they are mainly chip and semiconductor manufacturers, such as Texas Instruments, Renesas and Silicon Labs. In spring 2012, ONE-NET welcomed a new member IQD, while the second last new member joined in 2010.

ONE-NET is a fully open source technology that has its design information as well as some software codes available online. The web pages do not currently show any specification for an IP gateway, so apparently it must be developed by the device vendors themselves.

Other building automation protocols

In this section, we describe a few higher layer technologies in the field of building automation, which do not rely on any specific physical layer technology. Originally, these protocols have been designed for wired communication, but some commercial implementations already cover radio links.

KNX

KNX (or Konnex) is probably the most established technology in the field of building automation, with devices deployed both in commercial and in residential buildings. KNX technology is based on three former technologies: Batibus, European Installation Bus (EIB), and European Home Systems (EHS) (Hersent et al. 2012). The developer of the KNX technology is KNX Association which currently has over 250 members, including ABB, Bosch Schneider and Siemens, and partnership agreements with over 30 000 installer companies and around 60 universities around the world (KNX Association 2012). The Association was established in 1999.

KNX Association standardizes KNX technology in collaboration with the European Committee for Electrotechnical Standardization (CENELEC) Technical Committee 205 (TC 205) for Home and Building Electronic Systems (Hersent et al. 2012). KNX has been standardized in Europe (EN 50 090, EN 13 321-1 and EN 13 321-2) and in the global level (ISO/IEC 14 543-3). KNX is also being standardized in China.

Several versions of KNX protocol exist, which are all backwards compatible. KNX protocols can use several physical layer implementations, such as twisted pair, PLC, and also specific radio transmission called KNX-RF. The KNX protocol itself specifies the layers from link up to application layer. The specifications of a TCP/IP gateway also exist (see EN 13 321-2), and gateway devices are available from multiple vendors.

LonWorks

The development of LonWorks (Local Operational Network) started by an American company called Echelon Corporation in the 1980s. LonWorks is claimed to be one of the most popular protocols for building and industrial automation with over 90 million installed devices (Hersent et al. 2012). LonWorks technology covers a series of networking protocols, which were standardized by ANSI in 1999, by European Committee of Standardization (CEN) in 2005 and also in China in 2006. The LonWorks standards (ISO/IEC 14 908-1, -2, -3, -4) were approved in 2008.

LonWorks platform has its own promoters in LonMark International, established in 1994 (LonMark International 2012). LonMark International highly advocates open systems. The association even warns about the "seemingly open" but in practice proprietary systems, and claims that they are the most open control platform in the field. Unlike many other technology support organizations, LonMark International has local affiliate organizations in 12 countries around the world. The organization has four levels of membership: sponsors, partners, associates and individuals, with annual membership fees of USD 20 000, 5000, 1000 and 200, respectively. The sponsors and partners mainly comprise manufacturers of LonWorks products, the associates distribute and integrate LonWorks products, and the individuals represent consultants, research institutes and end users. The lower-level members may participate in task groups, which develop the technology. LonMark International and its affiliate organizations have currently over 400 members around the world, including Philips, Siemens, ABB, and Kone.

The development of the LonWorks platform was motivated by the pursuit of moving away from a centralized control mode, where all the sensors send measurements to a controller which further sends the commands to the actuators. LonWorks enables direct communication between the devices. Similar to KNX, LonWorks is media independent and can operate on top of twisted pair, power line, radio, fiber and even infrared light. LonWorks standards include specifications from link layer up to application layer. In addition, specifications exist for IP tunneling.

BACnet

BACnet is yet another solution for building automation and its applications are many, including HVAC, lightning control, fire control and alarm, security and interfacing towards utility companies. Unlike many other protocols, the development of BACnet protocol started as a fully open and royalty-free standard protocol and it has several open source stack implementations available. The standardization started already in 1987 within the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). The standardization was led by university professors until 2004 (Hersent et al. 2012).

BACnet was first published as an ANSI standard and, later on, it was also ratified as an ISO standard (ISO 16 484-5) in 2003. Earlier, there were two associations supporting BACnet technology (BACnet Interest Group and BACnet Manufacturers Association) but, in 2006, these associations decided to join their efforts and established a new organization called BACnet International (BACnet International 2012).

BACnet protocol implements a "collapsed" OSI model, which means that transport and session layers are not specified. BACnet is also neutral to physical layer technology. The protocol has an IP tunnel implementation but some BACnet/IP devices have been

developed to directly communicate over IP networks. BACnet specifications also cover interoperability functions with KNX and ZigBee.

ModBus

Similar to BACnet, ModBus has been developed for industrial automation and metering and not for home specific installations. ModBus is an application layer protocol which has become a de facto standard because of its simple and license-free nature. It provides client/server communication between devices connected to several types of buses and networks (Hersent et al. 2012). ModBus was first published in 1979 by Modicon (part of Schneider Electric group).

The development of ModBus is led by ModBus Organization, which currently has 74 members (ModBus Organization 2012). ModBus has implementations for both serial bus and Ethernet communication. Newer specifications of the protocol, published in 1999, provide ModBus communication over TCP/IP networks. ModBus implementation has not been standardized in any higher level organization and real-life implementations have variations. Therefore, the compatibility between vendor devices cannot be guaranteed.

IEEE 802.11x standards (e.g. WiFi)

Based on the IEEE 802.11 standards, WiFi is a widely adopted technology in home, office and also public environments to provide wireless Internet access for various end-user devices. WiFi can also be seen as a potential technology for M2M communication. The deliverable of WP1 (D1.1.4) analyzes the feasibility of WiFi technology in the IoT context.

However, many application areas have different requirements for the wireless access technology. Therefore, the IEEE standards body has started to develop an amendment, IEEE 802.11p (Jiang and Delgrossi 2008) targeted to Wireless Access in Vehicular Environments (WAVE). The protocol can be used in both intra and inter-vehicle applications. The new protocol specifications are supposed to increase the efficiency of connection setup which is crucial in the automotive applications, since the time windows for communication are really small due to fast moving vehicles.

The development of dedicated short-range communications (DSRC) first started in 1999 within the ASTM International, formerly known as the American Society for Testing and Materials (ASTM). It moved into the IEEE standardization process in 2004, which guaranteed that the protocol would be applicable also in other parts of the globe, and it ended up to be part of IEEE 802.11 working group. IEEE 802.11p will use a different frequency than regular WiFi (5.9 GHz in Europe) but some WiFi cards can be tuned to use that frequency. In addition, some modifications are required in the link layer (more specifically in MAC) to make it compliant with IEEE 802.11p. The IEEE 1609.3 standard specifies the modifications for the MAC layer. In the IoT consortium, Mobisoft is testing a vehicular safety system based on IEEE 802.11p radio in WP6.

IEEE has also specified around a dozen other amendments to 802.11 specifications. For example, 802.11s specifications allow mesh networking between base stations supporting the standard. All these specifications are not discussed in this document but can be studied, for example, in (Bernardos et al. 2008).

Other vehicular protocols

Other protocols used in vehicular environments include controller area network (CAN), Local Interconnect Network (LIN), and FlexRay. All these protocols are wired and meant to be used over cables dedicated to communication applications or alternatively over the vehicle's power lines. CAN is the oldest of the three technologies and its origins date back to 1983. The Society of Automotive Engineers (SAE) has published two standards: one for trucks and other heavy vehicles and the other for passenger cars.

The development of LIN was motivated because the development of CAN became expensive with the increasing number of interconnected components in cars. The LIN Consortium was established by BMW, Volkswagen Audi Group, Volvo Cars, and Daimler Chrysler in 1990. The first full version of LIN protocols was published in 2002.

FlexRay provides higher reliability and data rates for automotive communication than CAN but, accordingly, it is also more expensive to implement. The technology was developed by FlexRay Consortium, which came out with the specifications; the consortium started its work in 2000 and ended in 2009.

DASH7

DASH7 was originally designed for military purposes, especially for the U.S. Department of Defence (DoD), and started as a proprietary technology of Savi Technologies (Burns 2011). The technology was ratified as an ISO 18000-7 standard in 2004 because several vendors wanted to serve the DoD with this technology. The technology took a big leap forward in 2009 when the DoD invested in a USD 429 million contract for DASH7 devices (Fornazier et al. 2012). Other application areas where DASH7 has already been deployed include monitoring of supply chain assets in logistics, tire pressure monitoring in automotive industry, as well as access control and smart energy in building automation. A prospected application area promoted by DASH7 Alliance is automated location-based service. Instead of a manual check-in at various venues, consumer devices with embedded DASH7 technology could do it automatically in the future.

The interest to use DASH7 for other applications as well has increased a lot during the past few years. Therefore, DASH7 Alliance was established in February 2009, which started to develop Mode 2 of the technology, and the Alliance intends to have the second version standardized by ISO. For the Mode 2 version, DASH7 Alliance also provides an open source stack for DASH7 technology, which enables different developers to build DASH7 devices and systems. Currently, DASH7 Alliance has around 30 members. In addition, there are 11 members in the advisory board including, for example, RFID Alliance and five members in the university relations program (DASH7 Alliance 2012).

The strength of DASH7 technology is the longer range (up to 1 km or beyond), as compared with, for example, WiFi, Bluetooth or Zigbee, and it also provides a longer battery life since the supported data rate is small. DASH7 is an active RFID technology, which makes the use of small batteries instead of absorbing the power from the reader, as is done by the passive tagging technologies, such as NFC (Schneider 2010). Advocating openness, DASH7 Alliance has also specified IPv6 interoperability.

RuBee

Based on the IEEE 1902.1 standards, RuBee is another active two-way wireless protocol. Compared with other technologies, RuBee works on a low frequency at 132 kHz (O'Connor

2006). The essential characteristic of the protocol is the capability to penetrate metals and also water. Basically, it is a solution for tagging in tough conditions. Practical deployments are known to be mission critical applications, such as weapon lockers.

The technology has been originally developed by a company called Visible Assets and it seems that there is a big momentum in the market for this technology. The developer company has recently gathered a small number of companies to deliver its RuBee based devices. However, the application area of the technology seems to remain more in the niche.

Bluetooth and Bluetooth Low Energy (LE)

The origins of Bluetooth date back to the year 1994 when Ericsson started to investigate the possibilities to connect mobile accessories without wires (Baker 2005). By 1998, Nokia, Toshiba, IBM, and Intel had joined Ericsson and formed Bluetooth Special Interest Group (Bluetooth SIG), which drew up the first specifications of Bluetooth technology. The first specifications of Bluetooth technology were also ratified as the IEEE 802.15.1 standard, which was published in 2002.

The development of Bluetooth Low Energy (also known as WiBree) started in 2001 when Nokia engineers identified use cases for which none of the current technologies were feasible. Nokia Research Centre started the development of the technology which would provide lower energy usage and accordingly also lower price. The technology was further developed under the EU FP6 project called MIMOSA and it was first released in 2006. The development of Bluetooth LE is now under the Bluetooth SIG, and the first commercially ready version of the protocol (Bluetooth v4.0) was released in summer 2010 and the first products were shipped during 2011.

Both Bluetooth and Bluetooth LE specifications implement higher layer specifications and their implementations vary in different operating systems. New applications can be added by using a specific API for Bluetooth and Bluetooth LE. According to our knowledge, no IP gateway specifications exist for Bluetooth or Bluetooth LE, so the implementation of a gateway is up to the vendors.

ANT/ANT+

ANT/ANT+ technology is perhaps the most serious competitor for Bluetooth LE. Similar to Bluetooth LE, the ANT technology is an ultra-low power protocol, and is currently implemented in body and health monitoring applications, for example, in heart rate meters. Its development was driven by the need to create a foot-pod-to-watch communication solution for the running shoe manufacturer Nike in 2000 (ANT+ Alliance 2012). Compared with Bluetooth LE, the ANT technology has the advantage of being the first on the market, with over 19 million devices deployed (McDonald 2011).

ANT/ANT+ is yet another de facto standard in the market. It was developed by the Canadian company called Dynastream Innovations, which was acquired by Garmin International in 2006. The vendors of ANT technology include Polar, Garmin, and Nike. Suunto is also selling products based on ANT, but it seems to have a parallel interest towards Bluetooth LE technology.

ANT technology specifies the radio interface, while ANT+ covers specifications also for more complex network topologies. As of 19 April 2012, ANT+ Alliance had around 340 members, which do not include all the adopters of the technology. ANT+ technology has already penetrated into the smartphone market. Apps are available for, at least, Android and iOS, and Sony Ericsson has launched several phones supporting ANT technology. According to our

knowledge, the ANT specifications do not support any interoperability for IP gateway or interoperability with other WSN technologies. The interoperability functionalities are up to the vendors themselves.

Protocol Comparison

Figure 6 below provides a stack model of the short-range protocols presented above. The mapping of these protocols is relatively difficult, since the documents introducing the proprietary protocols rarely reveal exactly which layer functionalities the protocol implements. We have mapped each protocol into the layer model on the basis of our best understanding.

Figure 6 also includes protocols being developed within the Internet Engineering Task Force (IETF), which is the organization responsible for standardizing Internet protocols. The IETF-based protocols are identified inside a red rectangle. All the protocols developed by the IETF are basically neutral for the underlying physical layer technology, but typically, the IETF protocols are referred to be used on top of IEEE 802.15.4 link layer.

Constrained Application Protocol (CoAP) is an application layer protocol, but it also implements some network layer functionalities (Koivunen 2011). CoAP is a lighter version of HTTP, and it is intended to be used similarly in sensor networks as HTTP is being used for web services on the Internet. Since both HTTP and CoAP are IP-based protocols, CoAP easily translates into HTTP; but nevertheless, a gateway is needed to make the translation (Shelby et al. 2012). The major difference between the CoAP and many other application layer protocols in the field is that it only specifies the syntax of different functionalities. A separate markup language is needed in order to implement specific requests (e.g. for temperature measurements) from a CoAP capable device (Koivunen 2011). Just like XML is used on top of HTTP, CoAP requires a language that encodes documents in a useful format.

Figure 6. Short-range wireless protocols

6LowPAN (acronym for "IPv6 over Low power Wireless Personal Area Network") has been specified to embed the IPv6 protocol into sensor networks. IPv6 as such is too heavy to be used in low power environments. 6LowPAN provides a bunch of specifications to define the use of IPv6 in sensor networks (Kushalnagar et al. 2007). A specific routing protocol called Routing Protocol for Low-power and Lossy Networks (RPL) has been defined for sensor networks which may act in an ad-hoc manner (Thubert 2012).

As of yet, IoT applications based on pure IETF specified stack do not seem to be available in a wider scale but, at least, a few start-ups are currently known to be working solely on the IETF protocols. Those companies include, for example, SkyFoundry (SkyFoundry 2012), which is providing data analytical solutions for smart buildings, and Sensinode (Sensinode 2012), which is working in the area of connected home, intelligent municipal lightning systems, and smart grids. These two companies have been active in developing, for example, the CoAP protocol within the IETF.

To provide a more tangible idea about the technical characteristics of each technology, we compared the wireless protocols that have physical layer implementation. Table 11 compares the technologies by frequency and communication range of a single link. The table also shows which network topologies are supported by a specific protocol, whether IP gateway functionalities are supported, and what is the level of interoperability with other protocols in the layers below and/or above.

Table 11. Comparison of wireless short-range protocols

	Network topology	Range	Frequency	Internet GW specs	Protocol inter-operability
Zigbee (IEEE 802.15.4)	Tree, star, mesh	< 100 m	868 MHz 915 MHz	+	GRIP protocol
Z-Wave	Mesh	< 30 m	900 MHz	-	None
Insteon	Mesh	~20-30 m	902 – 924 MHz	+	X10
ONE-NET	Star, multi-hop	50 m – 500 m	868 MHz 915 MHz	+	Open source
KNX	Tree	~50 m	868 MHz	+	Several protocols beneath
WiFi (IEEE 802.11)	Star	30 m – 200 m	2.4 GHz	N/A	Several protocols on top
NFC	P2P	Few cm	13.56 MHz	N/A	N/A
DASH7	Multi-hop (two), star	10 m – 10 km	433 MHz	+	Open source
RuBee (IEEE 1902.1)	P2P	1 m -30 m	132 kHz	N/A	Several protocols on top
EnOcean	Star, mesh	30 m -300 m	868 MHz 315 MHz	+	None
Bluetooth (LE)	Star	5 m – 100 m 50 m (LE)	2.4 GHz	N/A	Several protocols on top
ANT(+)	Star, tree, mesh	~50 m	2.4 GHz	-	None

1.2.2 Long-range protocols

As already mentioned earlier, WP1 is working on a white paper which includes comparison of several wide-range technologies. Therefore, we do not go through the wide-range alternatives in detail. Many long-range M2M applications, which are seen today, are based on the plain old Internet technologies (see Figure 7), so in some cases new protocols are not even needed. However, white space technologies are gaining momentum in the IoT field. Some start-up companies, such as NEUL (NEUL 2012), are building a long-range wireless network specifically optimized for M2M communication. In addition, IEEE initiated standardization activities related to white space usage, see (Cordeiro et al. 2005).

Application layer	HTTP		
Transport layer	UDP	TCP	
Network layer	IPv6	IPv4	
Physical layer	2G / 3G	LTE	White space technologies

Figure 7. Wide-range wireless protocols

As compared with short-range technologies, the wide-range technologies applied in IoT have significant drawbacks. In particular, as evidenced by Table 12, the wide area technologies suffer from their power inefficiency and relatively high cost: the wide-range alternatives consume an order of magnitude more of energy and cost twice as much as their short-range counterparts.

Table 12. Short-range vs. wide-range technologies (Morioka 2011)

Characteristic	PAN/LAN	WAN
Main standards	ZigBee, WiFi, Bluetooth, Z-Wave. KNX-RF	GPRS/GSM, UMTS, LTE, WiMAX, CDMA, EV-DO
Cost	< $5	≥ $10
Power	~0 dBm	~24 dBm
Spectrum	Unlicensed	Licensed
Topologies	Star and mesh	Star

As shown in Figure 8, a mixture of short and wide-range technologies is currently being used for connecting the things in the IoT. Cellular, satellite, Ethernet, and WiFi communications are all commonly used, whereas the technologies optimized for constrained devices – exemplified by ZigBee and Bluetooth – are still utilized relatively rarely.
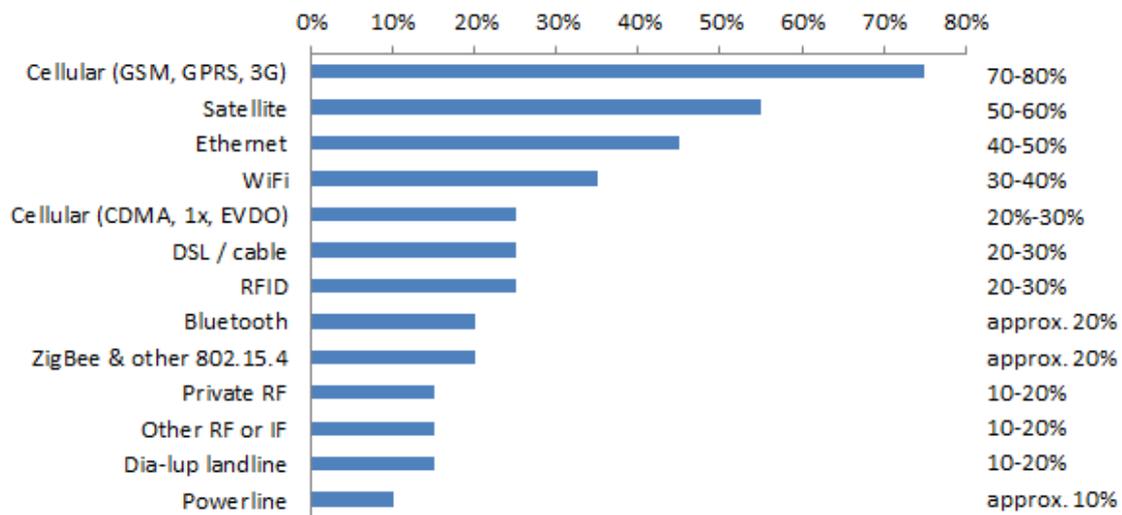
Figure 8. Usage of cellular and satellite M2M technologies (Duke-Woolley 2012)

1.3 Vertical industry evolution

According to the industry lifecycle theory originally presented by Gort and Klepper (1982), product-oriented industries evolve through five phases, which differ by the net entry rate of the firms in the relevant industry. Specifically, the evolution in the industries proceeds through the following phases: 1) new product introduction, 2) rapid growth, 3) equal entry and exit rates, 4) negative net entry referred to as a shakeout, and 5) maturity phase with roughly equal entry and exit rates. The industry evolution is affected by external innovations and the accumulated experiences and profits of incumbent firms. Later on, Agarwal and Audretsch (1999) compressed the five-stage industry lifecycle model into two stages, namely the formation stage and the maturity stage, which are characterized by positive and negative net entries, respectively.

The structure of an industry often gradually evolves from a vertically integrated to a vertically disintegrated or specialized structure. The process of vertical disintegration/specialization is defined as "the restructuring of industry-wide value chains, such that different stages of the development, production, and marketing processes are controlled by different firms, rather than being vertically integrated within the boundaries of individual firms" (Macher and Mowery 2004). The model of vertical software industry evolution by Tyrväinen et al. (2008) suggests that the vertical software industries are iterating through five phases. In the first, Innovation phase, the software development takes place in-house within the vertical industry firms that strive to gain a competitive advantage by automating their core business processes. In the second phase of Productization and Standardization, the firms within the industry improve their in-house software by adopting the best practices of their competitors towards industry-wide standardized offering; the software development in this phase is either preserved in-house (the vertical market leader) or alternatively outsourced as a business unit or a spin-off joint venture (competitors joining their forces against the leader through the standardization of key interfaces and/or protocols). The third, Adoption and Transition phase, is characterized by the growing user base and market share of the emerging standard offerings; outsourcing the software development is increasingly common in this phase. In the fourth, Service and Variation phase, one of the competing offerings becomes the dominant design that serves as a center of mass, attracting the majority of the subsequent software development activities.

Finally, in the Renewal phase, new software-related business opportunities are treated as bringing competitive advantage by some firms, which then initiate a new evolution cycle.

At the present, as described in the previous sections, the IoT technologies are utilized in many vertical application domains, varying from automotive and machinery to home automation and consumer electronics. Earlier, these technologies were implemented as a part of industrial in-house solutions based on machine-to-machine communications and/or embedded systems. More recently, specific products – also in the consumer electronics domain – have started to appear in the market, with wellbeing devices (e.g., Withings) and smart home solutions (e.g., GreenWave Reality) being among the most prominent examples.

The current solutions are dominated by a variety of proprietary and standard platforms, protocols and interfaces, making the components of the solutions offered by different vendors barely compatible, while keeping the prices of the components high. For instance, Z-Wave – a short-range wireless technology for home automation promoted by Z-Wave Alliance – represents a vertically integrated protocol stack that only works on top of Z-Wave proprietary radio; it does not specify the interoperability with the Internet protocols, and thus a dedicated gateway is needed to convert the Z-Wave application protocols into a convenient presentation format (Koivunen 2011). In a similar manner, the KNX protocols for building automation, developed by the KNX Association, specify the layers from link up to application layer, with a dedicated gateway device needed to perform the conversion to TCP/IP. A notably different approach is taken by the ZigBee Alliance, which promotes the ZigBee protocol stack running on top of IEEE 802.15.4 radio. The Alliance complements the network (originally non-IP) and application level protocols by defining the so-called public application profiles that enable cross-vendor interoperability within specific application domains, such as home automation, smart energy, healthcare etc. The universality and flexibility of ZigBee comes at the cost of greater complexity, thus making it less attractive for constrained smart objects (besides some other problems, such as crowded frequency band and compatibility issues[23]). In contrast to the above standards, which are either proprietary or prohibitively complex, the IETF protocol suite, including CoAP, RPL and 6LowPAN, is a simple IP-based alternative[24].

Thus, given the appearance of products on the market but lack of a dominant design and abundance of proprietary protocols and platforms, the IoT vertical application domains could be seen as belonging to no later than the Productization and Standardization phase of vertical software industry evolution (Tyrväinen et al. 2008). In particular, although the upcoming IETF protocols, including CoAP, RPL and 6LowPAN, represent a promising alternative to proprietary or prohibitively complex web protocols, they are just leaving the research labs and making their way into the industrial products and solutions, while the protocol standardization has just been completed or is still being finalized. For instance, the proponents of CoAP, such as Ericsson, INRIA, Lulea, NXP, Sensinode, SICS, STMicroelectronics, Watteco and Wisenet, are currently testing their CoAP implementations and their interoperability; however, only few reported examples of the actual deployment of the protocol in commercial products could be found (e.g., NanoService by Sensinode). Therefore, the competition is still upcoming between the traditional HTTP-based and proprietary solutions, on one hand, and the new IETF-based solutions, on the other hand, for the position of the new dominant design in future IoT applications.

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[23] See http://frostdale.wordpress.com/2011/01/06/zigbee-vs-z-wave-part-1/, also http://www.zwavereviews.com/index.php?artid=3&catid=1
[24] See http://www.pikeresearch.com/blog/the-zigbee-%E2%80%9Cip-ification%E2%80%9D-wars

Certain factors may inhibit the evolution process. Some of these factors are as follows: a small market size, a high degree of market regulation, a high degree of required customer-specific tailoring, the need to coordinate innovation efforts spanning over several vertical layers, the internal complexity of the business processes being automated by the software and the need to maintain compatibility with older systems (Tushman and Murmann 2003; Tyrväinen and Mazhelis 2009; Mazhelis et al. 2013). Furthermore, according to the technology acceptance models, the widespread adoption depends on the expected performance and the perceived ease of use (Venkatesh et al. 2003; Venkatesh and Bala 2008). For example, if the new protocols provide only minor benefits as compared with the proprietary or HTTP-based solutions, if they require significant investments that are unlikely to pay off, or if they are complex to implement, their adoption and consequently, the emergence of a new dominant design is likely to be hindered, similarly to the failure of WAP protocol in the past (Sigurdson 2001).

Chapter 2.   IoT ecosystem(s): emergence and the role of platforms, standards and open interfaces

By Oleksiy Mazhelis and Henna Warma

In this chapter, we consider the business ecosystems present in the IoT domain. First, the concept of a business ecosystem is introduced, followed by an overview of related works and the description of the IoT ecosystem players and their roles.

2.1 Business ecosystems, structure and players

The concept of an ecosystem and ecosystem modeling were brought over by James F. Moore from biological studies, in which a *natural life ecosystem* is defined as a biological community of interacting organisms plus their physical environment with which they also interact. According to Moore (1996), the ecosystem actors "coevolve their capabilities and roles".

Moore defined *a business ecosystem* as "the network of buyers, suppliers and makers of related products or services" plus the socio-economic environment, including the institutional and regulatory framework. Interacting organizations and individuals represent the organisms of the business world and form the foundation of the economic community delivering goods and services to customers — as well as the members of the business ecosystem (Moore 1996).

Besides the ecosystem core, which consists of the firms delivering the goods/services along with their customers, market intermediaries and suppliers, the business ecosystem also includes the owners and other stakeholders, as well as the regulatory bodies and competing organizations, as shown in Figure 9.
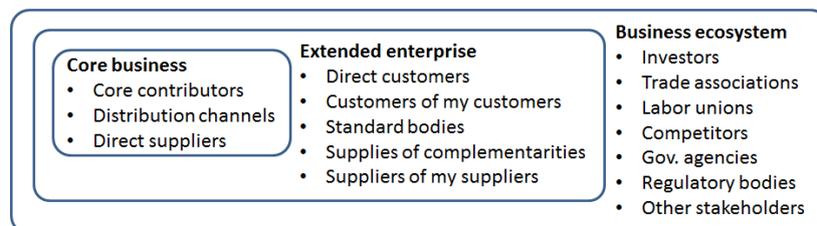

Figure 9. Actors in a business ecosystem (Moore 1996)

Similarly to the organisms in the biological ecosystems, the firms in the business ecosystem coevolve their capabilities around specific innovation(s) by both competing and cooperating with each other. The pace of evolutionary and ecological changes, however, is different. In the biological systems, evolutionary changes span several generations while multiple ecological changes are likely to occur within a lifetime of an organism. In a business ecosystem, both types of changes are co-occurring, owing to the firms' ability to guide their own evolution, also proactively.

Biological ecosystem is a useful metaphor for understanding a business network, since both the species in a bio ecosystem and the firms in a business ecosystem have to interact and coevolve: the survival of each one is related to the survival of others, thus supporting a balance of both cooperation and competition (Corallo and Protopapa 2011).

According to Moore (1996), the firms' capabilities in a business ecosystem coevolve around innovations (as compared with species' evolutionary paths). Talvitie (2011), following Iansiti and Levien (2004), argues similarly that the business ecosystems are formed around a specific *core*, i.e., a set of assets shared and commonly utilized by the firms constituting the ecosystem. The core can be in the form of platforms, technologies, processes, standards or other assets common to and used by the members of the ecosystem in their businesses.

Structure and roles

Topologically, the ecosystems can generally have either a hub-centered star structure or a flat mesh-like structure. The star structure (often hierarchical) can be exemplified with the so-called *keystone model* matching the typical structures in the USA. This model, as described by Moore (1996) and elaborated by Iansiti and Levien (2004), assumes that the ecosystem is dominated by a major hub firm interacting with a large number of small suppliers. On the other extreme, the *flat model* of the business ecosystem, which is more typical of Europe, is composed of mainly small and medium-sized firms, yet accommodating also large ones (Corallo 2007).

Iansiti and Levien (2004) focus on modeling the business ecosystems as networks of firms. They argue that, in various network structures, including the networks of firms, *hubs* can be identified as the nodes having significantly more interconnections with other nodes, as compared with the other nodes. The presence of the hubs makes the network robust to the removal of individual nodes, provided that the hubs are intact. On the other hand, removal of a hub often results in a collapse of the whole network.

In line with the biological metaphor, Iansiti and Levien (2004) suggest that the *roles* in the biological ecosystem correspond to the *strategies* of the firms in the business ecosystem. The most critical roles in the business ecosystem are the roles of the so-called keystone, dominator, and niche player.

A *keystone* is a hub player in the ecosystem that provides benefits for the whole ecosystem, thereby increasing the ecosystem's chances of survival. In particular, by limiting and removing the number of players that would negatively affect the ecosystem, and by providing the remaining players with a foundation (software platforms, development tools etc.) to survive and succeed, the keystone player increases the stability, diversity, and productivity of the ecosystem. An example of a keystone-driven ecosystem is the so-called Intel-IBM-Microsoft ecosystem.

As opposite to the keystones, the *dominators* eliminate and absorb the functions of other players in their ecosystem (i.e., effectively occupy multiple nodes in the ecosystem network), and therefore decrease the ecosystem diversity. They are also significantly greater in size than the keystone players. The dominator-driven ecosystems are less stable, as there is insufficient diversity to tolerate external disruptions. Two subtypes of dominators are distinguished. The *classic dominators*, exemplified by Apple, integrate vertically or horizontally a large portion of their business network, and therefore are responsible for value creation and capture in the ecosystem. The *hub landlords,* exemplified by Enron, on the other hand, represent value dominators that bring little value to the network while extracting the value from the network to the greatest possible extent. Both of these subtypes give little opportunities to the other players in the ecosystem.

A *niche* player occupies a small portion of the network and focuses on developing a specialized/differentiated set of capabilities. While small individually, the niche players constitute the majority of the (keystone-driven) ecosystem mass. Due to their specialization, the presence

of niche players reduces the duplication of efforts and increases the health of the ecosystem. Often, the niche player may participate in multiple ecosystems, increasing their leveraging power at the expense of the need to maintain multiple platforms.

2.2 IoT ecosystem players and their roles

Deriving from the definitions of Moore Moore (1996), Iansiti and Levien (2004) and Talvitie (2011), as presented above, an *IoT ecosystem* can be defined as

> *a business ecosystem which comprises of the community of interacting companies and individuals along with their socio-economic environment, where the companies are competing and cooperating by utilizing commonly shared core assets related to the interconnection of the physical world of things and the virtual world of the Internet. The core assets may be in the form of hardware and software products, platforms or standards that focus on the connected devices, on their connectivity, on the application services built on top of this connectivity, or on the supporting services needed for the provisioning, assurance and billing of the application services.*

Within the last decade, notable research efforts have been devoted to studying the business entities and their roles in the domain of telecommunications (Kaleelazhicathu 2004; Stanoevska-Slabeva 2010) and in the IoT domain (Eurich et al. 2011). Some of these roles are also described in industrial reports on M2M communications (ABI 2010, OECD 2012) and architectural frameworks of relevant standardization organizations (EPCglobal 2004, ETSI 2012).

Figure 10 shows the typical roles in telecommunications business and their relationships, as identified by the ECOSYS project (Kaleelazhicathu, 2004). Telecommunications is likely to play a significant role in the IoT domain, and hence the roles in the figure are relevant for the IoT work as well. However, as the roles focus on the telecommunications domain, the complementary roles of application service providers, application platform providers and other such players are not taken into account in this model. Thus, the identified roles actually represent a subset of the roles (and relationships) present in the IoT domain.

In addition to the ECOSYS roles shown above, a study published within the C-CAST project has identified the role of a broker that aggregates and mediates the access to the contextual information about the user (Stanoevska-Slabeva 2010). The importance of the broker role in the IoT domain is considered by the SENSEI project, which differentiates the roles of a wireless sensor and actuator network (WSAN) operator, WSAN service provider, and Sensor/Actuator Service Broker (Eurich et al. 2011). The roles and relationships considered in these two studies are portrayed in Figure 11.

ABI Research (Lucero 2010) describes a mobile M2M value chain, as shown in Figure 12. As compared with the above-mentioned studies, this report details the roles visible in the product chain (chip, module, and OEM/ODM) that help the ASPs in designing and pre-certifying with MNO the radio-subcomponents of M2M products.
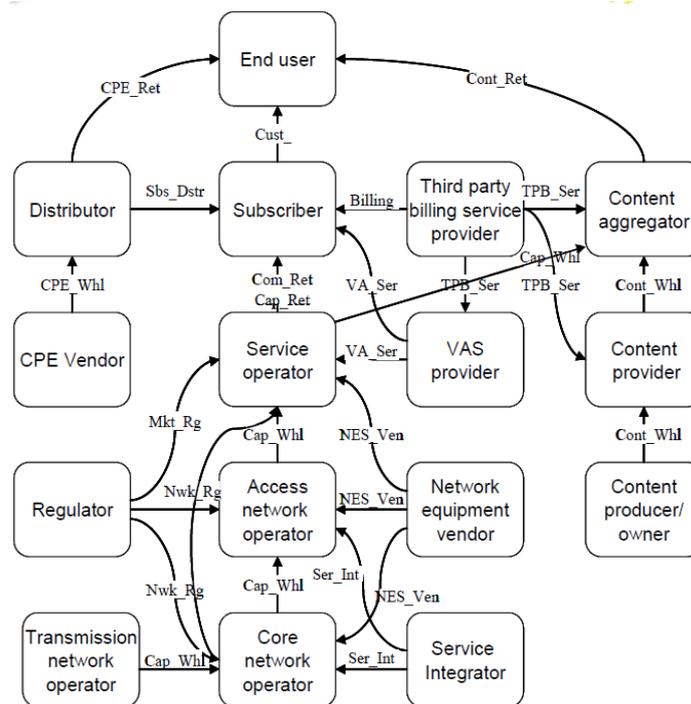
Figure 10. Roles of business entities and their relationships in telecommunications domain (Kaleelazhicathu 2004)

Finally, the above studies on M2M and WSAN-related business roles assume that the available core network and transmission network infrastructure, including routers, domain-name servers etc., are sufficient for the IoT applications. While this may be the case for the majority of the M2M and WSAN-based applications, the applications relying on RFID tags are likely to require further infrastructure components, such as discovery services and object name services (ONS) (Hartley 2004; Shih et al. 2006). The presence of these additional components may require the introduction of new business roles, for instance, the role of the ONS provider.

Figure 13 aggregates the roles identified in various IoT-related studies into a generic map of the IoT ecosystem roles; the definitions for these roles are given in Table 13. The roles are mainly organized along the service delivery dimension, where several groups of related roles are identified, including the device, connectivity, and service related groups. The figure also shows the dimension of product/service lifecycle, consisting of the development, distribution, provisioning, assurance, and billing roles. Other essential ecosystem roles shown in the figure include the legislative, regulatory, standardization, and other bodies that directly or indirectly affect the IoT domain, as well as the roles responsible for domain specific auxiliary (e.g., infrastructure) technologies.

Figure 13 also includes other auxiliary roles, exemplified with the holders of intellectual property rights (IP), the vendors offering domain specific databases and middleware, as well as the providers of application-specific infrastructure.

Depending on the application domains, some of the roles may be redundant. For instance, in the case of a private WSAN solution, there is no need for a SIM provider. Such optional roles are shown in the figure using dashed boxes.
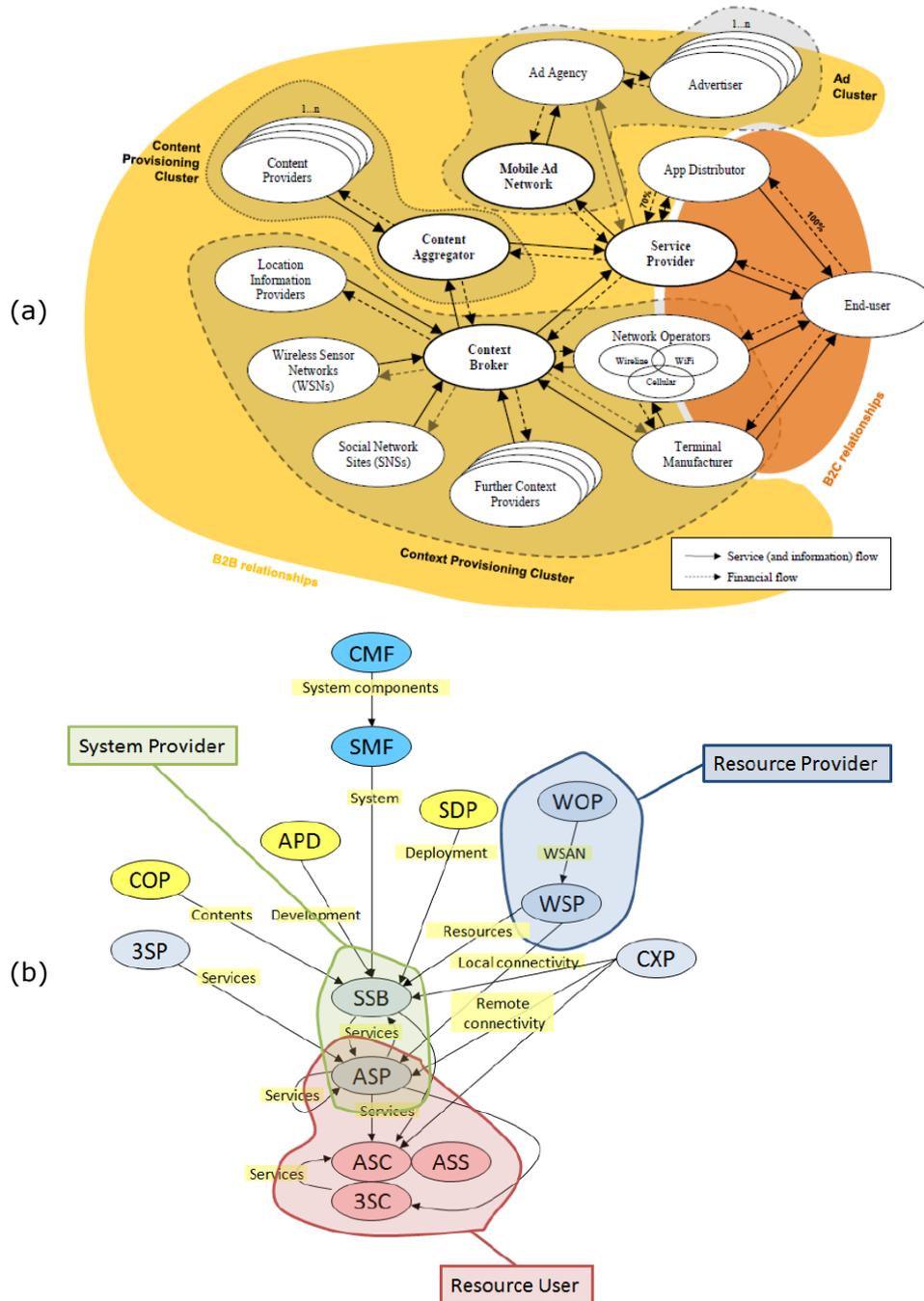
Figure 11. The roles and relationships identified by (a) C-CAST project (Stanoevska-Slabeva 2010; and (b) the SENSEI project (Eurich et al. 2011), where the role of a broker is introduced.
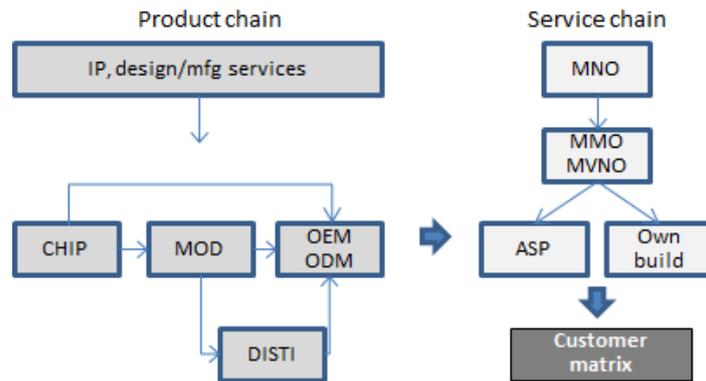
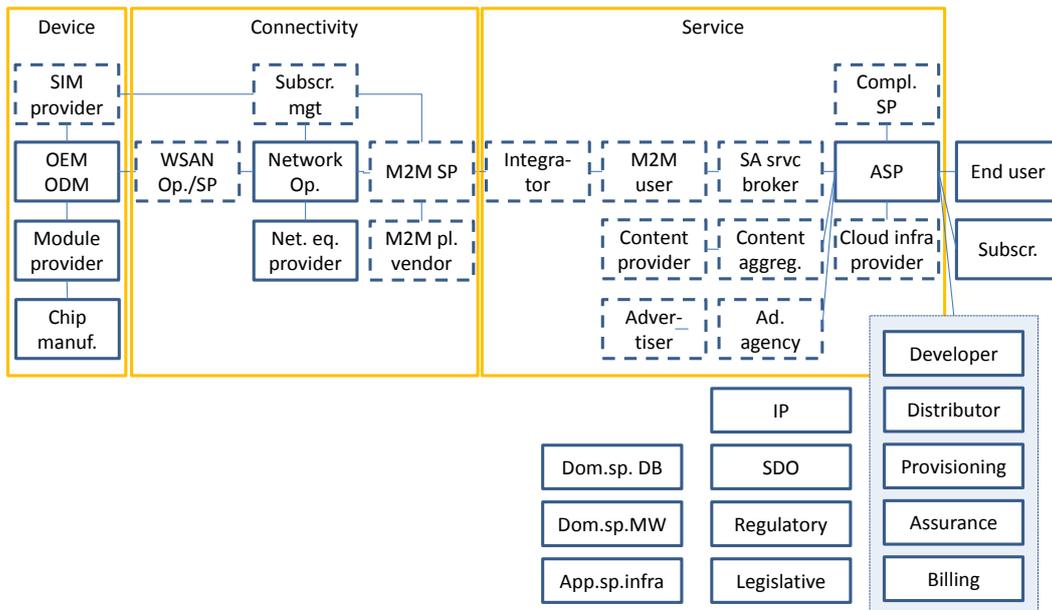**Figure 12. Product vs. service chains in the mobile M2M value chain (Lucero 2010)**

Figure 13. Roles in the IoT ecosystem

Table 13. Definitions for the roles in the IoT ecosystem

Role	Description
Chip manufacturer	Designs and manufactures integrated circuits for module and device manufacturers.
Module provider	Manufactures components such as sensors of modems and supplies them to OEM/ODM.
OEM/ODM	Integrates components to produce the device or other piece of equipment.
SIM provider	Manufactures SIM cards for network operators
WSAN operator and service provider	Operates and delivers services/information from WSANs under its responsibility

Role	Description
Network operator	Provides connectivity between WSAN and the IoT applications; it may encompass the access (mobile or landline) network, the core network, and the transmission network.
Network equipment provider	Manufactures network elements and provides related services and offers them to network operators
Subscription management	A third party that manages SIMs and contracts on behalf of M2M user; is responsible for the roaming and switching of networks (similar to MVNO (OECD 2012, p.31)).
M2M service provider	Manages the M2M service platform.
M2M platform vendor	Produces the M2M service platform which handles device-specific tasks, including fault detection, management of SIM cards etc.
Integrator	Ensures seamless inter-operation between the devices and the M2M platform.
M2M user	Is an organization that is formally in charge of the sensor and actuator devices/network.
Sensor and actuation service broker	Acts as a broker between the providers and consumers of the sensor and actuator services.
Application service provider (ASP)	Builds the application/service from the components (own or made by other service providers) and delivers it to the user.
Complementary service provider	Provides the services complementary to those of ASP.
Cloud infra provider	Provides cloud computing infrastructure services, on top of which the ASP can deploy and run the applications.
(Application) developer	Designs and develops IoT applications and services.
Distributor	Retails physical or digital goods and services.
Provisioning service provider	Deploys the application/service.
Assurance	Carries out maintenance to ensure the availability of the services and guarantee that these services perform in line with SLA or QoS performance levels
Billing service provider	Provides billing services to a service operator, serving as a financial intermediary between the operator and customers.
Ad agency	Provides ads and manages ad campaigns for advertisers, acting as intermediary between the advertiser and a service provider.
Advertiser	Orders advertisements (individual or campaigns).
Content aggregator	Distributes content from different content providers to different SPs, acting as an intermediary between them.
Content provider	Provides user-generated or professionally created content.
End user	Uses the application/service provided by the ASP.
Subscriber	Negotiates and commits to the agreement with the ASP on the service and its qualities.
Standard development organization	Develops standards in the form of an official organization, industrial alliance or a special interest group.
Regulatory body	Controls the processes, as mandated by a legislative body.
Legislative body	Makes, amends or repeals laws.

Ecosystem core

As discussed above, an ecosystem emerges around a core, which represents shared assets commonly used by the ecosystem members. Since the essence of IoT is the interconnection of the physical world of things with the virtual world of the Internet, the software and hardware platforms as well as the standards commonly used for enabling such interconnections may serve as a core of an IoT ecosystem. More specifically, the core may comprise the following:

- The connected devices and gateways, including both hardware platforms (Arduino prototyping platform[25], T-Mote Sky, Zolertia Z1, and other platforms based on Texas Instruments MSP430) and software platforms (TinyOS, Contiki OS), as well as the related standards (e.g., gateway specifications by Home Gateway Initiative[26]);
- The connectivity between the devices and the Internet, which may be implemented e.g., through a mobile wireless modem or a Wi-Fi router, or through a WPAN gateway device; namely, hardware platforms (e.g., single-chip modems by RMC[27]), the standards and protocols governing the communication (e.g., IETF 6LoWPAN, ROLL, and CoAP protocols promoted by IPSO Alliance, WPAN standards by ZigBee Alliance), or the software platforms to support the connectivity (e.g., Californium Java CoAP framework (Kovatsch et al. 2012), Erbium CoAP framework for Contiki (Kovatsch et al. 2011));
- The application services built on top of this connectivity with the help of common software platforms (e.g., Pachube[28]) and standards governing the service composition and data format compatibility (EPC, JSON, SOA);
- The supporting services that are needed for the provisioning, assurance, and billing of the application services (e.g., NSN M2M software suite (Harjula 2011), Ericsson Device Connection Platform (Blockstrand et al. 2011)), as well as M2M optimized network elements (e.g., the GGSN enabling network initiated PDP context) and related standards (e.g., the standards developed by ETSI M2M technical committee[29]).

These common assets with a potential to serve as a core for an IoT ecosystem are listed in Table 14, where they are categorized as hardware or software platforms or standards. This categorization is not fully exclusive, for example, the standards for the application services are likely to concern the connected devices as well. As can be seen from the table, various candidates for the ecosystem core can be identified. Arguably, software platforms attract the greatest attention, with dozens of platforms competing currently in the market; some of them are listed below.

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[25] Arduino open-source electronics prototyping platform, http://www.arduino.cc/.
[26] Home Gateway Initiative publications,
http://www.homegatewayinitiative.org/documents/publications.asp.
[27] Wireless Modem Chipsets, Renesas Mobile Corporation,
http://renesasmobile.com/products/lte-modem.html.
[28] Pachube (now Cosm) real-time open data web service for the IoT, https://pachube.com/
[29] ETSI Technical Committee for Machine to Machine Communications,
http://www.etsi.org/Website/Technologies/M2M.aspx

Table 14. Examples of IoT ecosystem cores

Core	Hardware platform	Software platform	Standards
Connected device	Arduino, T-Mote Sky	TinyOS, Processing, Contiki OS	HGI
Connectivity	Wi-Fi or ZigBee systems-on-chip	Californium, Erbium	IPSO Alliance, ZigBee Alliance
Application services	Cloud infrastructure	Pachube	SOA, JSON, EPC
Supporting services	M2M optimized GGSN	NSN M2M suite, EDCP	ETSI M2M TC

Connected device software platforms:

- TinyOS
- Contiki OS
- MantisOS
- Nano-RK
- Android

Connectivity software platforms:

- Arrayent, connecting middleware including a gateway (http://www.arrayent.com)
- Californium, Java CoAP framework
- Erbium, CoAP framework for Contiki
- XMesh networking stack

Application (cloud) software platforms:

- IoBridge Thingspeak (https://www.thingspeak.com/)
- Nimbits (http://www.nimbits.com/)
- Evrythng (http://evrythng.net/)
- Open.Sen.se (http://open.sen.se/)
- NanoService (http://www.sensinode.com/)
- Pachube/Cosm (https://cosm.com/)
- Exosite One (http://exosite.com/)
- HP CeNSE (http://www.hpl.hp.com/research/intelligent_infrastructure)
- Isidorey (http://www.isidorey.com/)
- Paraimpu (http://paraimpu.crs4.it/)
- AMEE UK (http://www.amee.com/)
- SensorCloud (http://sensorcloud.com/)
- ThingWorx (http://www.thingworx.com/)
- Yaler (https://yaler.net/)
- Buglabs (http://www.buglabs.net/bugswarm)
- ProxPlatform (http://www.neuaer.com/developers)
- iDigi (http://www.idigi.com/)
- GroveStreams (https://grovestreams.com/)
- Manybots (https://www.manybots.com/)
- Global Sensor Networks, application oriented middleware for sensor networks

Supporting services software platforms (based on http://blog.m2mapps.com):

- ABO Data S.r.I.
- Accenture plc
- Aeris Communications Inc
- Airbiquity
- Ampila Solutions
- Arkessa
- Axeda
- CalAmp
- Connected Environments Ltd
- Device Insight
- Deutsche Telecom
- Digi International
- Ericsson
- Eurotech
- Everything Everywhere
- ILS Technology LLC
- Inilex
- Jasper Wireless
- Kore Telematics, Kore Systems
- Macheen
- Maingate
- Mdex
- Mesh Systems
- M2M Data Corp
- NEC Corp
- Nokia Siemens Networks
- Novatel (Enfora)
- nPhase
- Numerex
- Odyssey Software Inc.
- Orange-France Telecom
- Raco Wireless
- Reply
- SeeControl, Inc.
- SensorLogic
- Sierra Wireless
- Tekelec
- Telenor Objects AS (Telenor Group)
- Tridium
- Viagents
- Viewbiquity, LLC
- Vodafone
- Wireless Logic
- Wyless Group
- Xact Technology, LLC

The proliferation of the platform offerings can be partly attributed to the fact that the value is likely to be distributed unevenly among the players in different roles. In particular, it is claimed that the greatest share of the value will eventually be taken by the service enablers providing (M2M) platforms and/or applications, which therefore represent the most attractive roles (Schlautmann et al. 2011). The network operators, as well as system integrators, are deemed

to appropriate a smaller share of the total value, and are therefore expected to aim at expanding towards other roles as well. Finally, the providers of the devices and their components represent only 5-10% of the overall share, due to a strong competition in this area. The forecast by Harbor Research suggests roughly the same split of revenues among the roles (Harbor Research 2011).

Chapter 3.   Business models of the IoT firms

By Seppo Leminen, Petri Ahokangas, Pasi Pussinen, Mervi Rajahonka, Riikka Siuruainen, Hanna Okkonen, Alexey Shveykovskiy, and Jenni Myllykoski

3.1 Introduction

By Petri Ahokangas

The purpose of Chapter 3 is to discuss how the technological advancements and convergence within the IoT related technologies facilitate and potentially shape the emergence and transformation of IoT businesses and dynamic IoT ecosystems. The objective is to gain insight into the processes that play a role in the transformation of the existing IoT businesses and ecosystems, as well as in the emergence and creation of new IoT businesses and business ecosystems. The key to these processes lies in understanding the processes of value creation and capture. The core elements include the IoT future scenarios, which are created and studied through two complementary approaches, Scenarios and Delphi, the IoT business models, and the ICT ecosystems.

Within IoT, the technical and business perspectives merge at several levels, as shown in Figure 14. At the most profound level, the trends affecting IoT businesses concern, from the business perspective, digitalization of services, and from the technical perspective, cloudification of services. At the broader levels, the analysis and description of the business and physical domains, as well as the discussion concerning the ecosystems and solution lifecycles, provide a backdrop for discussing business. In some sense, the figure depicts a first attempt toward an "IoT Map" that would be of help in defining the context, content and evolution of IoT.
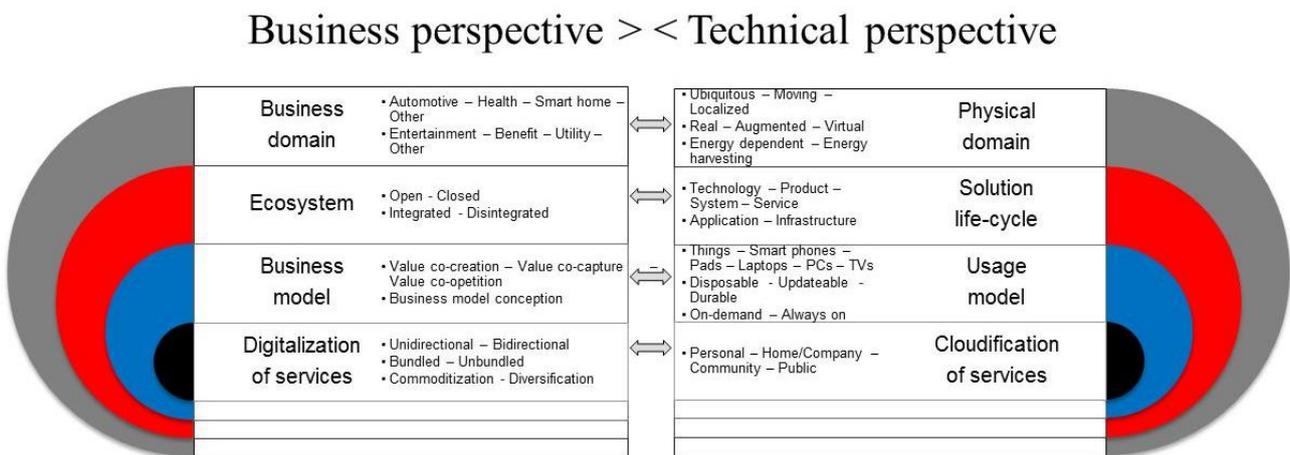

Figure 14. Business and technical perspectives on IoT

Methodologically, this Chapter is based on three approaches: 1) Case studies concerning IoT businesses, 2) Scenarios to provide an outlook and potential context for IoT businesses, and 3) Delphi study results to open up expert opinions on the IoT business models.

In the following, we first review the existing ecosystems and scenarios, as well as business models. Next, we describe the results of the Scenario and Delphi based research. Finally, we elaborate on our key findings and conclusions regarding future business opportunities of IoT ecosystem and business models research.

3.2 Theoretical background

By Seppo Leminen, Mervi Rajahonka, Riikka Siuruainen, and Jenni Myllykoski

3.2.1   Ecosystems and scenarios

By Jenni Myllykoski

Business ecosystems

Ecosystem has become a widely used metaphor for describing the environment and network of actors in which companies are operating. The reason for borrowing the concept from biology into the business discussion has been to illustrate how companies share some fundamental properties with natural ecosystems, i.e. interconnectedness, complexity, adaptation, and "coevolution" (Peltoniemi 2006). Just like biological organisms, companies are a part of an environment that is defined by the actions of other evolving organisms (Pagie 1999). In that environment, the success of individual firms is determined by the health of the ecosystem it is a part of. This eventually means that "each member of a business ecosystem ultimately shares the fate of the network as a whole, regardless of that member's apparent strength" (Iansiti and Levien 2004b).

What differentiates business ecosystems from the biological ones is the companies' ability for conscious decision-making and innovativeness. However, in spite of this, individual organizations have only limited ability to shape the ecosystem. Ecosystems are complex and emergent, which means that the "links between individual agent actions and the long-term systemic outcome are unpredictable" (Smith and Stacey 1997). A single actor cannot, on its own, determine or control the development of the ecosystem. Instead, the system is self-organizing and the decision-making is decentralized. The ecosystem members evolve together, which is called *"coevolution"*. Peltoniemi (2006) defines this "coevolution" as "two-way interaction where both entities have an effect on each other's success potential, which may induce change in some direction".

Moore (1998) describes business ecosystems as synergistic "communities of customers, suppliers, lead producers, and other stakeholders - interacting with one another to produce goods and services". In an effectively functioning ecosystem, all critical domains or roles involved in the product or service delivery have to be healthy, as they affect the performance of the whole ecosystem (Hearn and Pace 2006, Iansiti and Levien 2004). The literature presents some attempts to identify the key ecosystem roles. For example, as overviewed in Chapter 2, Iansiti and Levien (2004a) discuss three typical roles in an ecosystem: keystones, niche players and dominators. Keystones are companies that act as important enablers or hubs in the ecosystem. While they have a great impact on the health of the entire ecosystem, the keystones constitute only a small fraction of the total mass of companies within the ecosystem. Niche players, in turn, have very little impact on the ecosystem on their own, but collectively, they form the larger mass of the business ecosystem. Dominators serve, to some extent, as contrasts for the keystones, and are easy to detect, for example, because of their size. Unlike keystones, they have a tendency to take over the functions of other companies, thus

eliminating them from the ecosystem. In such dominated ecosystems, the danger is their limited ability to adjust to sudden changes in the environment (Iansiti and Levien 2004a).

These above mentioned key roles could help us better understand the division of power and the basic dynamics of an ecosystem. However, how to define the boundaries of an ecosystem and how to understand the connections between different ecosystem actors remain as challenging questions. Typically, the ecosystem boundaries do not equal the traditional industry boundaries, but may instead span across several industries. The ecosystem is held together by the cooperative and competitive interactions between different companies. When trying to capture these connections between the different firms within the ecosystem, the *business model* can be a useful concept. This kind of approach suggests that companies are connected with each other *through their business models*, and consequently, a business ecosystem can be defined as *a co-opetitive, synergistically value creating and capturing aggregate of interdependent business models* (Ahokangas and Myllykoski 2011). This approach suggests that the business ecosystem boundaries are thus defined through the dependence of the business models on each other. By looking at the business models within an ecosystem, we can gain a deeper understanding of different actors' roles that goes beyond their classification into the three above mentioned key role types. The business model driven definition of the ecosystem differs significantly from the technical ecosystem approach, in which the boundaries are defined on the basis of technology usage and development. Following this notion, a conceptual clarity between business ecosystem and technical ecosystem is needed.

Understanding change through scenarios

Companies are continuously sharing one universal challenge: How to prepare for the future that is unknown? This paradoxical challenge is very contemporary, as the speed of change is increasing and the business environment is becoming more and more networked, turbulent and uncertain. At the same time, rapid adaptation to the changing environment is needed both for companies (Kagerman et al. 2010) and for the business ecosystems. Predicting the future is naturally impossible, but however distant and uncertain it may be, the future should be included in the strategy-making process. To a certain extent, the companies can influence their own future, for example, through innovations and the development of new technologies (Kagerman et al. 2010). It is important to understand what is likely to change in the future, and what the implications of the changes to the future business will be. Therefore, playing with different future scenarios can be a fruitful approach.

The basic idea of the scenario approach is that it considers multiple alternative futures (Van Der Hejden 2007). It enables us to identify critical elements of change and to play with different alternatives for the future changes. The scenario process is useful both at industry level and at single firm level. At the industry level, it is possible, for example, to increase understanding of the implications of technological development, world economy, or the dynamics of the industry ecosystem. At the firm level, creating scenarios enables us to identify both risks and opportunities related to the firm's future, so that the strategy and business model can be built on a more solid foundation. When making scenarios, the purpose is to identify those change elements that have a great impact on the industry or an individual company's future, but whose consequences are hard to predict. Usually, scenarios are prepared as a matrix where the different outcomes are significantly spread out and different from each other (Van Der Hejden 2007, 247).

In strategy making, scenario techniques have already been widely utilized. Van Der Hejden (2007) argues that, for management the "scenarios are the best available language for the strategic conversation, as it allows both differentiation in views, but also brings people

together towards a shared understanding of the situation, making decision making possible when the time has arrived to take action". Scenarios are useful when facing uncertainty about future, because intuition is as important as strategic reasoning in such a situation (Van Der Hejden 2007). Therefore, the challenge of scenario-based planning is how to engage the key people fully and creatively, especially when trying to encourage radically different thinking and take a wide perspective to the future business (Mason and Herman 2003).

3.2.2   Business model

By Seppo Leminen, Mervi Rajahonka and Riikka Siuruainen

Business model research has expanded since the 1990s among the science community. Many characterizations, perspectives, and models have been suggested in the literature as a result academic studies. However, it has been difficult to agree on the definition of the concept 'business model' (Magretta 2002, Leminen et al. 2006, Osterwalder et al. 2005, Amit and Zott 2010, Casadesus-Masanell and Ricart 2010). The business model of a company depicts how it operates in the market and how it creates value (Westerlund et al. 2011). Osterwalder et al. (2005) discuss the development of the concept and suggest that business model studies are evolving towards applied models in practice. The first phase was before the Internet bubble burst in the beginning of the 21st century, when business models were defined and classified /for e-business (Timmers 1998). After that, the focus moved on to defining various components, or building blocks, of business models (Amit and Zott 2001). Diverse reference models and ontologies for modeling and testing business models were provided in the following phases (Osterwalder and Pigneur 2002). Management applications and conceptual tools were achieved as outcomes when applying business models in practice (Osterwalder et al. 2005, Sosna et al. 2010).

Zott and Amit (2008) emphasize that there should be a fit between the market strategy and the business model of a firm. In their studies, they make a distinction between novelty-centered and efficiency-centered business strategies. This also links business models with ecosystems. Zott and Amit (2010) define business model as a system where activities link together through the focal company and the surrounding network.

Westerlund et al. (2011) studied business model management and proposed that researchers can identify various business models and their differences in the ecosystem context when connecting business models with the relationships of the firm in question. When aiming to robust and lucrative models in the emerging markets and domains, such as IoT, business model management is utmost important (Westerlund et al. 2011).

3.2.3   IoT business models

By Seppo Leminen, Mervi Rajahonka and Riikka Siuruainen

New business opportunities will be opened with IoT, because applications and business models are facilitated by the IoT smart objects (Bohn et al. 2005). Successful business models always require sufficient data. The data collected automatically from the information exchange of the devices helps to solve problems, and embedded new services and revenue models can be developed. Most of the IoT research has focused on technology and technology layers, although the importance of developing IoT business models has been widely identified(ITU 2005, Fleisch 2010, Internet of Things 2011, OECD 2012). Only few authors have pursued to increase the understanding of the emerging IoT business models and ecosystems, using the following approaches (Leminen et al 2012a):

- Structural approaches, for example, the discussion and analysis of value chains in ubiquitous computing environments (Lee et al. 2005), IoT value chains (Banniza et al. 2010) and drivers (Fleisch 2010), and digital business ecosystems (Banniza et al. 2010).

- Methodologyapproaches, for example, the study of methods for developing business models in ubiquitous computing environments (Banniza et al. 2010), and multipath deployment scenarios (Levä et al. 2010).

- Design approaches, for example, the specification of networked business models for emerging technology-based services in ubiquitous computing (Palo and Tähtinen 2011), and application of the business model canvas framework to IoT (Bucherer et al. 2011).

The networked infrastructure of IoT enables both incremental and radical business changes, but so far the potential has not been fully leveraged (Bucherer et al. 2011). There are almost endless ways to utilize information and IoT structures, due to the resource pooling in networks containing numerous nodes and links between the nodes. According to Bucherer et al. (2010), when designing and developing IoT business models, the key issues are the information exchange between the nodes in the IoT network and the win-win information exchange for all the stakeholders. In order to unleash the business potential of IoT, a value-focused approach must be taken instead of the cost-centric approach. To accomplish this, Bucherer and Uckelmann (2011) suggest a triangle of information exchange that consists of the business and the thing, and the consumer between them.

According to Mejtoft (2011), there are three layers of value creation in IoT: manufacturing, supporting and value co-creation. Firstly, manufacturers or retailers benefit from the possibility of tracking items. The supporting layer creates value as the collected data can be used in the value creation processes of both the industry and the customers. Thirdly, IoT is a co-creative partner, meaning that the network of things can think for itself.

IoT combines diverse technologies and systems together, and bundles technologies and functionalities. For this reason, the IoT business model design requires a lot of information, but this does not always succeed due to the failing integration of information exchange (Fleisch 2004). Real-world visibility and business process decomposition are the two paradigms behind the business value potential of IoT (Haller et al. 2009). Business process decomposition (or modularization) means that processes can be decomposed into process steps that can be executed in a distributed manner, even at the edges of the network. The modularization of processes leads to a shift of power and decision-making towards the rim of the network, but also increases scalability and performance of the system (Haller et al. 2009). Leminen et al. (2012a) suggest that, in the extreme case of IoT, all devices would offer their functionality as a web service, and device integration would mean the same as service integration, and service modularity principles could be applied.

Next, we adapt a framework originally presented by Leminen et al. (2012a) for identifying and analyzing IoT business models. The framework is based on the business model design approach.

3.2.4   Framework for IoT business models

By Seppo Leminen, Mervi Rajahonka and Riikka Siuruainen

Leminen et al. (2012a) use the business model canvas thinking presented by Osterwalder and Pigneur (2009) to build a conceptual framework for identifying and analyzing IoT business

models. This approach includes the basic elements of the value proposition, financial, infrastructure, and customer perspectives. These elements are often mentioned in the academic literature as the key components of business models (Westerlund et al. 2011). The concept of infrastructure can here be replaced with a slightly broader concept of ecosystem (Leminen, et al., 2012a). The other axis contains the perspective of customers. One dimension of the framework identifies the type of the ecosystem (closed private or open networked) and the other the type of customers (business or consumers). With these dimensions, four different types of IoT business models can be defined. This classification captures many of the basic differences between the business models. Numbers from I to IV can be used for describing the diverse IoT business models.

The 2*2 matrix framework helps to visualize and analyze the variety of current and potential IoT business models and their evolution. Value propositions can be comprehended as the cases that are placed onto the framework. According to Leminen et al. (2012a), the financial aspects of the canvas approach are not explicitly included in this visualization, but they can be included in the case descriptions.

According to Uckelmann et al. (2011), open, scalable, secure, and standardized infrastructures are needed for IoT, although they do not always necessarily exist today. Leminen et al. (2012a) state that there is an ongoing shift from closed private ecosystems (the lower-end models I and III) towards open networked ecosystems and business models (the upper-end models II and IV). They also maintain that the IoT solution markets today are dominated by business-to-business (B2B) solutions (the left-end models I and II), but there is also a trend towards business-to-consumer (B2C) solutions (the right-end models III and IV).

Good case examples can be chosen from the automotive industry and logistics, because there are many IoT–based solutions in that area. In the following, we use RFID, car sharing, intelligent manufacturing and traffic safety services as illustrations of IoT business models in our framework (see Figure 16).
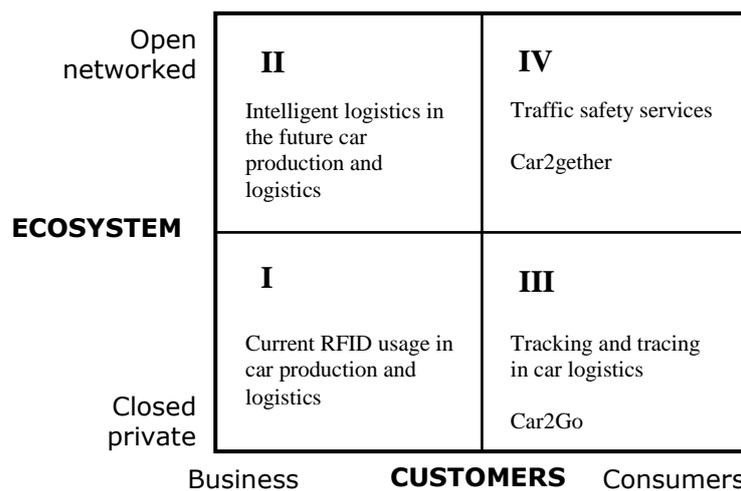

	Business	Consumers
Open networked	**II** Intelligent logistics in the future car production and logistics	**IV** Traffic safety services Car2gether
Closed private	**I** Current RFID usage in car production and logistics	**III** Tracking and tracing in car logistics Car2Go

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Figure 15.   IoT business model examples in the automotive industry (adapted from Leminen et al. 2012a).

Closed private infrastructures (model I), such as RFID or machine-to-machine (M2M) solutions that are commonly used in the automotive production or logistics today, are more like Intranet or Extranet of Things solutions than Internet of Things solutions. Today, almost 80 percent of car parts are produced by external suppliers. Cost reduction and other efficiency benefits are pursued with technological solutions, such as RFID.

In our framework, the future intelligent logistics provides an example of an open networked ecosystem (model II). Logistics service providers, such as the Germany-based Geis Group, have for quite a long time provided intelligent logistics services to the automotive industry and its suppliers. IoT technology will increase in the future as the companies are pursuing to offer services economically and environmentally-friendly, but also on time and according to the customer-specific quality parameters (Geis Group 2010).

The closed systems should be shaped into open Internet architectures (Uckelmann, et al. 2011, Leminen et al. 2012a). For example, Daimler AG launched a 'Car2Go' concept in Germany in 2008. This is a new mobility concept based on the PaaS (product as a service) principles, where consumers can easily share cars. A member of the club can rent city cars anytime. The price of usage is minute-based, including taxes, insurance, distance cost and fuel. An electronic chip in the registered user's driving license allows the customer to unlock a car, and the car can be returned in any public parking space (Smart 2012). In 2012, the concept covered 13 cities in Europe and USA (Daimler AG 2012). In this service concept, consumers use a closed ecosystem that relies on company-provided services (model III).

Daimler AG has also tested a ride-share community 'Car2gether' in two German regions since 2010. In this concept, the customer who rents a Car2Go vehicle can offer a free seat for other members via the Car2gether system. In the Aachen region, the Car2gether system is also linked to the local public transport system, so that also public transport options are suggested when a customer searches for transportation alternatives. This makes the service ecosystem even more open and networked (model IV). Consumers can find available vehicles or seats via Internet in both Car2Go and Car2together concepts. (Daimler AG 2012)

As an example of a traffic safety system (model IV), the 'Volvo on Call' system consists of a mobile phone containing a built-in GPS satellite unit. The phone automatically calls emergency services, if an airbag is deployed in an accident. Also an audio channel will open. If the driver is unable to speak, the Volvo representative will contact emergency services and inform about the location of the car. The driver can also other times, whenever necessary, contact the emergency services by pressing the SOS button. If the car breaks down, the driver can use the Volvo on Call button to contact a Volvo Center. The system can also track stolen cars and report their location to the police (Volvo Car UK Newsroom 2012). Emergency service systems relying on vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication (Martínez et al. 2010), cannot work properly without open networked ecosystems where multiple actors (car manufacturers and public sector actors, i.e., police, hospitals, other authorities etc.) work together. (Leminen et al. 2012a)

3.3 Review and description of IoT scenarios

By Petri Ahokangas, Hanna Okkonen, Pasi Pussinen and Alexey Shveykovskiy

3.3.1   Scenarios for IoT

By Pasi Pussinen & Hanna Okkonen

IoT offers seemingly unlimited possibilities to create valuable networks of "things". Only a fraction of these possibilities are available or recognizable today. Potential scenarios or domains for IoT have been previously investigated in both academic and market studies. In this section, we review the existing literature on IoT scenario studies and outline some of the current trends in IoT.

In the EU FP7 project "Internet of Things Initiative", a survey was done to identify scenarios for IoT. A total of 14 categories were agreed upon, containing from two to eight application scenarios each (Presser 2011):

- Transport (7 application scenarios)
- Smart Home (3)
- Smart City (5)
- Smart Factory (3)
- Supply Chain (3)
- Emergency (5)
- Health Care (7)
- Lifestyle (6)
- Retail (3)
- Agriculture (2)
- Culture and Tourism (4)
- User Interaction (3)
- Environment (4)
- Energy (2).

In Atzori et al. (2010), potential IoT scenarios were outlined as the most likely ones to improve our lives in the following fields:

- Transportation and logistics (5 applications)
- Healthcare domain (4)
- Smart environment (3)
- Personal and social domain (4)
- Futuristic (3).

Table 15 shows different potential application domains for IoT as presented in Sundmaeker et al. (2010).

Table 15. IoT application domains, description and examples (Sundmaeker et al. 2010).

Domain	Description	Indicative examples
Industry	Activities involving financial or commercial transactions between companies, organizations and other entities	Manufacturing, logistics, service sector, banking, financial, governmental authorities, intermediaries
Environment	Activities regarding the protection, monitoring, and development of all natural resources	Agriculture and breeding, recycling, environmental management services, energy management
Society	Activities/ initiatives regarding the development and inclusion of societies, cities, and people	Governmental services towards citizens and other society structures (e-participation), e-inclusion (e.g. aging, disabled people)

The ICT Knowledge Transfer Network (ICT KTN) was formed to outline IoT scenarios in the UK (Revell 2011). In one of their workshops, it was concluded that transport, smart energy and

healthcare would provide the vertical sectors and the electronics, creative industries, ICT and modern built environment sectors would provide the cross-cutting enabling horizontals for IoT. This is presented in Figure 16.
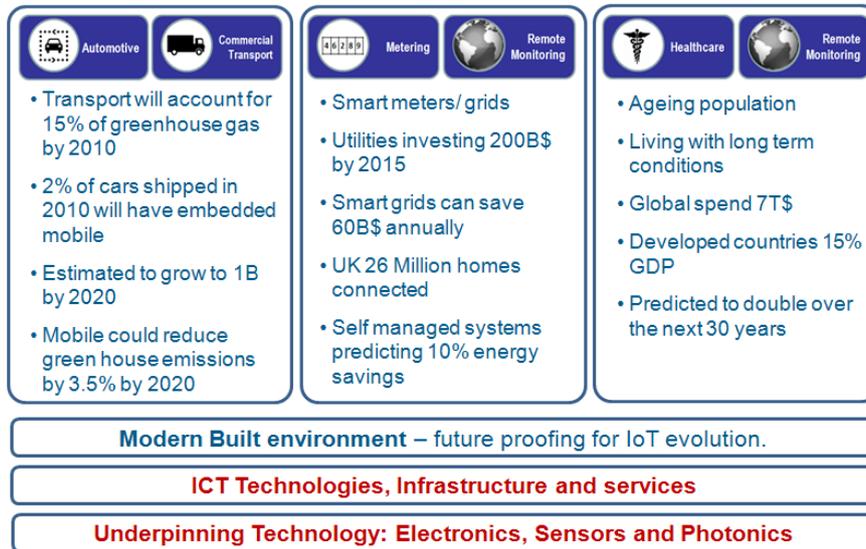

Figure 16. Major sector opportunities for IoT together with industry statistics from the GSMA (Revell 2011)

Italian consultancy company Casaleggio Associati presents IoT-related technologies in a grid which uses energy consumption and connectivity as the axes (Figure 17). In the grid, we can see similar domains that have been presented in the text above (i.e. home/smart environment, automotive/transport, cities).

Figure 17. Possible IoT applications in terms of connectivity vs. energy consumption, adapted from Casaleggio Associati (2011)

As a summary, it can be stated that transportation/automotive, home environment, and health and wellbeing seem to be most potential scenarios for the utilization of IoT. Next we will address the IoT-related possibilities in these scenarios.

Trends

Unless explicitly mentioned otherwise, the text in this subsection is based on Jurvansuu (2011).

Trends for the smart home scenario

There are already some standards for device interoperability, such as Plug-and-Play, UPnP and DLNA. They are, however, limited to the physical or media related interoperability. A lot of devices in the home environment are already connected to the Internet, for example, TV sets, blu-ray players and set-top boxes. They utilize the Internet connection for firmware updates, but also for additional services such as the Samsung appstore for Samsung TVs.

In the near future, more home appliances will be connected to the Internet; new software can be bought to further improve the existing appliance (similar to software for optimizing energy consumption) and the Internet connection can be used to order maintenance services or to inform about malfunctions or other product lifecycle events. The use of cheap and easy-to-use wireless sensors for a number of purposes at home will increase, for example, sensors for monitoring temperature and soil pH in the garden.

In the future, embedded chips will be the main source of electronics. Home appliances, furniture etc. will include factory installed chips or circuits. The long lifecycle of home and office environment will boost the development of long-life electronics and software. Devices in the home environment will form an ecosystem, and they will have a common language to securely exchange information and share resources (memory, CPU, Internet connectivity) with other devices in the ecosystem. Adding new devices to the ecosystem will be easy, as they can talk to each other. Smart spaces in the home can be considered as small spaces, like the living room where the family gathers to watch a movie. Other spaces (rooms) can be in power save mode.

Tags, sensors, circuits and bio-tags are embedded in goods, providing information to consumers and ensuring the quality for the entire lifecycle of the goods.

Future challenges include potential lack of business cases for extensive use of electronics, lack of desired value for the smart home scenario among the end users/customers, and price sensitivity of the scenario. A great challenge is posed by security issues related to interoperability of the devices. Health concerns related to the long-term exposure to increased amount of radio emissions call for further research and potential regulative actions.

Trends for the automotive scenario

Currently, cars include elements for detecting things in the environment, such as other cars, pedestrians and obstacles. Cars have automatic systems for reducing the speed if the car ahead slows down or if a pedestrian walks in front of the car. Drivers are monitored for alertness (eye movement) and driving habits (fuel consumption). GPS systems and smart devices provide the driver with real time traffic information. There is also standardization effort towards co-operative Intelligent Transport Systems (ITS) in Europe for communication on vehicle-to-vehicle, vehicle-to-infrastructure and infrastructure-to-infrastructure basis.

In the near future, cars will be connected to the Internet and access to Internet will be provided for the passenger as well. Cars will become a part of the personal network and assimilate partly to the smart home scenario. Smart devices can be shared with the car through standardization efforts like CE4A. Automatic monitoring services will monitor safety distances to more detail. Energy efficiency will improve with the hybrid cars gaining larger market shares and the full electric cars becoming more and more popular in urban areas where the distances are shorter. Cars will become capable of communicating with the infrastructure and other cars, for example, receiving information about green traffic lights to optimize fuel/electricity consumption for the trip.

In the future, connected cars will receive services, for example, to carry out mandatory inspections themselves. Cars can communicate with each other to minimize human injuries in the case of inevitable collision of cars. Intelligent roads can optimize traffic with cars much like telecommunication routers do. Software updates will be available directly to the car with new features and improvements. Traffic lights may become useless if cars can communicate with each other to optimize traffic and obey traffic rules. Gradually, the human control of the actual driving will diminish.

Challenges include the risk of the driver being distracted by other services in the car. This can result in new regulatory actions (like the hands-free today). Regulation and standardization are important steps toward the future IoT, and related efforts regarding connected cars have already started.

Trends for the healthcare and wellness scenario

In the future, hospitals will primarily be for emergencies, surgeries and other operations. Medical treatment will be carried out at home. Instruments and robotics at home will be used for monitoring, measurements, vaccinations and medications.

Physical abilities, including vision and hearing, can be encanced with digital and biomechanical aids. People will "wear" personal devices, with miniature electronics embedded in clothing, contact lenses or eyeglasses, for example.

Context awareness will turn into intention awareness; personal devices become supportive of user actions in a proactive fashion. It will not just be about learning daily routines but about understanding the user's situation now and before. Detected changes in walking style or arm or leg movement will provide information on the person's current physical condition and thereby have an impact on, for example, physiotherapy services and insurance claims.

3.3.2   IoT prospects for the future and examples

By Alexey Shveykovskiy

Among the many business domains within the IoT environment, we will focus on the smart home, health and safety, and automotive IoT business domains as a starting point of our overall IoT action research, and continue developing on the Oulu Business School research team's approach and positive experience. Other important IoT business domains such as energy, logistics, retail, office, industry, etc. should always be kept in mind, as they could gradually appear under the research scope as the IoT project progresses.

At the same time, the key IoT players and researchers may consider some hypothetical, yet based on reasonable assumptions, scenarios about future IoT environments from the end user's and customer's points of view. Even though fictitious, they may serve a practical

purpose because they reveal certain business opportunities and stimulate creative thinking about IoT applications, services and smart solutions in the chosen smart home, health and safety, and automotive environments. In our previous research, we defined five types of key players in the ICT context, i.e., equipment vendors, infrastructure vendors, regulators, communication service providers, content and service providers. Evidently, it becomes quite important that several of them should consider undertaking the role of market makers to secure the rapid and continues development of the IoT (Schlautmann et al. 2011).

The following hypothetical scenarios are inspired by two interactive workshops focused on the future IoT Home and Healthcare environments, conducted by the Oulu Business School research team during the course of the IoT Project in 2012. The interactive workshops fostered participation, contribution and collective thinking; therefore, several ideas were generated and became preliminary results of the interactive workshops, described in more detail in section 3.5. The following hypothetical scenarios should be treated as an intelligent guess and an attempt to picture the IoT prospects for the future, influenced by the interactive workshops and filled in with several examples of emerging IoT cases, applications and smart solutions.

The three IoT business domains—smart home, health and safety, and automotive—can be viewed as an emerging embodiment of Maslow's theory of hierarchy of needs in the era of digital revolution and the ubiquitous world. Because business solutions in these domains address and solve for basic human needs, wants and desires, described by Maslow more than half a century ago, yet, still remaining at the core of the modern human and business science.

The home environment, together with health and safety, are the very basis of the human needs pyramid, or Maslow's hierarchy of needs (Maslow, 1943 and 1954). The automotive business domain became the logical continuation, as well as an integer part of the first two business domains during the course of the 20th century and keeps growing in the 21st century. Therefore, the core of the IoT market potential lies in those business domains. The IoT phenomenon has a great potential to become the new Internet and communication revolution, remarkably changing and improving the existing standard of living, and ultimately the quality of life, because it creates and delivers value to human beings by providing new solutions for home, health and safety, property, transportation, resources, family and friends, self-esteem and confidence, communities and society as a whole.

Smart home

Leaving aside many complicated futuristic scenarios of the smart home environment, we will focus on the obvious, but not yet widespread smart solution for the home environment. There is a great demand for the 24x7 video monitoring and control of the property, home appliances, young and elderly family members, pets and plants in apartments, homes and summer houses for the modern population that spends most of its day time away from its property and loved ones.

Basic scenario

This most simplistic and user-friendly scenario requires minimum technology for a common user: several wirelessly connected webcams/IP cameras, with an independent and/or rechargeable power source, as well as the Internet OS and cloud-type storing capabilities for viewing live and/or browsing the recordings. The key players in this scenario could be: 1) the equipment vendor (EV), providing webcams with wireless connectivity to the Internet via Wi-Fi, GPRS, etc.; 2) the content and service provider (ConSP), like Google, Microsoft/Skype, others, that offer online access, storage and history browsing; 3) the communication service providers (CSP) and the infrastructure vendor (InfV), providing the Internet connection as usual. The

end user, in this scenario, pays for a webcam to the equipment vendor, possibly enjoys free live webcam solutions provided by the ConSP, e.g. Skype, and pays for the video content storing and browsing services. This basic scenario provides an opportunity for relatively easy and fast value creation to the end users, builds IoT awareness and necessary customer loyalty to the pioneering IoT companies, and, ultimately, lays down the foundation for the value capture. Of course, depending on the complexity and advancement of the smart solution, the device and service/need/business model and ecosystem bundle, the revenue streams, and the process of value capture could vary.

The same scenario could get more complicated with the addition of face recognition software, motion sensors and extra functionalities such as alerting the police and/or security company and instantly sending the intruder's picture, if this picture does not belong to the category of family and friends having access to the premises. The more complicated the scenario, the more additional equipment is needed, e.g., a server or PC running 24x7, triggering other issues like fire safety and energy consumption.

Advanced scenario

There are several existing and potential IoT solutions, ranging from climate control, electricity and utilities control to remote monitoring and care of pets and plants, which could be provided individually by different players. However, we could make a reasonable assumption that an end user would most willingly pay for a comprehensive system of the IoT smart solutions that solves his/her basic home environment and life needs, rather than paying for different solutions, and especially for their installation, to different players. Thus, as a simple rules strategy (Eisenhardt and Sull 2001), key players like CSPs could choose having several options of the IoT smart solutions system as a development, IoT awareness building, sales and marketing tool. For an advanced scenario, we can envision the IoT home environment system with smart solutions for safety, comfort, family, household, social networking and entertainment.

Home safety and energy saving

Besides the video surveillance and security solutions connected to the proper authorities, in the home and safety business domain, there is also serious need for fire, smoke, gas, water and boiler sensors and smart devices. When connected to the overall system, they will inform the owner and the proper authorities in case of an emergency, and/or about the utilities consumption, for example, electric lights and appliances, with ability to control them remotely. The complex IoT systems already have the technology and could soon provide solutions to increase survival chances in unfortunate home accidents, e.g., drowning, slipping and injuring in home bath of shower, fainting in sauna, or falling asleep when smoking in the bed, etc. There are also less emergency sensible but important applications, like monitoring the babysitter, checking if and what the postman delivered in front of the door, tuning the floor cleaning robot's work, or informing the owner that there is ice on the steps of his home, or a garden hose is leaking.

Comfort and energy savings

In this respect, the IoT complex systems have a great potential not just to maintain the home environment in the comfort or energy saving modes via climate control, HVAC, electric windows and blinds, etc., but also to inform the owner and maintenance, if any of the elements is not functioning properly.

Household well-being

Monitoring, feeding and caring for home pets and plants could be solved by IoT , so that an owner could peacefully leave the aquarium fish and outside/inside plants for up to several weeks or domestic animals for up to several days. IoT can also be utilized to walk the pets in the yard and allure them back home, or to cut the grass by operating the lawnmower remotely. It is quite possible that IoT gardening and pet care could become independent industries in the feasible future, with IoT solutions sold in the Petco, Home Depot, OBI, Bauhaus and other pet and hardware stores.

Social networking and entertainment

The above scenarios and solutions clearly bring benefits to the individual and family security, safety and wellbeing. Furthermore, the IoT solutions can take social networking and entertainment to a new level. Families and friends could form groups for monitoring, maintaining, controlling, and possibly sharing different smart objects, like monitoring favorite vacation places, maintaining and controlling a property, garden, etc. Another potential application for groups of friends and families would be creating and sharing the social group content such as photos and videos, news, favorite movies, books, articles, TV shows and music (user-generated content services). Thus, IoT becomes an integral part in generating and provisioning an easy and constant video, audio and text content, access and control to and by correspondents, via four major ICT screens: PC, smartphone, tablet, smart TV, and the soon emerging car navigation-entertainment-communication screen.

Healthcare and wellness

Health and safety issues are quite indispensable to each other in the healthcare domain, and as described above, they are closely related to the home environment. There are several examples of IoT health solutions and ongoing research available around the world, focusing on monitoring vital/life signs and assisting sick and elderly people living alone and/or remotely. A complex IoT health solution could provide vital signs and other important information about a patient to a physician and alert emergency services based on the patient's condition, moving activity and patterns. It could be reasonably assumed that, in the feasible future, there will be medical devices capable of providing certain injections and cardio stimulation remotely by a physician in an emergency, if direct human medical assistance is not possible.

Table 16. Examples of IoT solutions for several business domains

Company/ Project	Smart Solutions (Services and Products) Description	Additional Domains (Industries & Sectors)	Source
Home & Office			
Verizon, U.S.	Home Monitoring and Control: o Home Monitoring Kit ($9.99 per month, $89.99 equipment and installation): gateway; indoor/outdoor camera; light module. o Add-Ons: door locks; door & window sensors; home appliances modules (energy consumption and remote control); energy reader; smart thermostats & control panels		http://www22.verizon.com/home/homemonitoringandcontrol/

Company/ Project	Smart Solutions (Services and Products) Description	Additional Domains (Industries & Sectors)	Source
VGo, U.S. (Verizon Innovation Centers)	VGo: o Healthcare: home patient monitoring; urine and asthma sampling (is coming) o Education o Business: remote executive, engineer; training o $ 6,000 USD, plus Verizon 4G LTE subscription	Healthcare, education, office & production	http://www.vgocom.com/ http://innovation.verizon.com/content/vic/en/experience.html
iVEE, U.S.	Sleek (New product and concept introduced at CES-2013): o Voice control bedside assistant for all WiFi-connected devices (thermostat, I-Robot Rumba, etc.) o For Nest thermostat and Belkin smart plug "a programmer build a work-around" – were initially rebuffed		http://bits.blogs.nytimes.com/2013/01/11/c-e-s-2013-the-voice-controlled-home-with-a-catch/?smid=tw-nytimesbits&seid=auto
Belkin, U.S.	Connected Home (WiFi-Internet-Smart Phone Solutions): o NetCam Wi-Fi Camera with Night Vision: $99.99; o WeMo Switch, $49.99; WeMo Baby Monitor $89.99; WeMo Motion Sensor $59.99. o (Linksys will participate in WeMo, light switch at CES-2013, integrated video cameras)		http://www.belkin.com/us/c/WSCH
Elisa, Finland	Elisa Vahti: o Room/home monitoring (from €14.90 per month): wireless webcam.		http://www.elisa.com/en/vahti/ http://www.youtube.com/watch?v=UkQihvDSc0w
Yoga Intelligent Building, Tallinn, Estonia (SME. Partners: Ericsson, TeliaSonera, Etisalat, Mobility and VTT)	Smart Home System: o Entry telecom package - €150 plus €10/month subscription; full package - €10,000 for commercial property, €3,000 for a villa and €1,500 for an apartment. o Climate (including CO2 fresh air in ppm), lighting, access, multimedia (including smart TV and video calls) and smart appliances control o Security System, remote metering (gas, electricity, water), smart grid connectivity o User interfaces for smartphone (iPhone), smart TV, plus Yoga Touchpad and Yoga Switch devices o Comfort modes/ambience o Connected services (possibility to add a vast number of different services and features)	Commercial property, utilities and smart grid	http://www.yogasystems.com/ http://events.cleantech.com/amsterdam/sites/default/files/CTForumAmsterdam_Yoga_Systems_Executive_Summary.pdf
SmartThings, U.S. (SME)	SmartThings: Control your world (Hardware, software and user interface): o SmartThings Mobile App o SmartThings Hub o SmartSense Multi – door/window open-close, temperature and vibration sensor, accelerometer/tilt positioning, etc. (claiming thousands of applications) o SmartPower Outlet; SmartSense Presence; SmartSense Motion; SmartSense Moisture; Smart Alert Siren; Open/Closed Sensor		http://www.smartthings.com/ http://www.smartthings.com/#meet-the-smartthings

Company/ Project	Smart Solutions (Services and Products) Description	Additional Domains (Industries & Sectors)	Source
	o Waiting line to get the products		
LIFX, U.S. (Project, startup)	The Light Bulb Reinvented: o WiFi enabled, multicolor, energy efficient LED light bulb, controls over iPhone or Android o Service life – 25 years; range of experiences – controlling every light, including color, from your smart home; sleep/wake up; Mood Lighting that matches music beat; compatible with existing switches.		http://www.kickstarter.com/projects/limemouse/lifx-the-light-bulb-reinvented
Healthcare			
Pamap, Germany, Greece, France (Project)	Physical Activitiy Monitoring for Aging People: o Body sensors network: motion, vital signs, unobtrusive o Mobile unit: collects, visualizes and records activity data o Information system – personalized health record: share (family, friends, clinicians), review, analyze data o Note: the system is dependent on the next generation of the wireless sensors		http://www.pamap.org/index.html
Healthcare Industry, Spain	o Main idea of this case is to combine capacity of the memory of the RFID tags, NFC-phones (near field communication) and twitter o RFID as a tiny database of a person's life log o RFID wristbands worn by residents and care staff's NFC mobiles can improve care data management and keep relatives up-to-date with elderly people's evolution, through a Web 2.0 social service o Set of predefined and standardised available logging suggestions (e.g. ate breakfast, took pill), which could further be explicitly annotated with some attributes (e.g. what pill she took exactly)		Lopez-de-Ipina D., Diaz-de-Sarralde I., Garcia-Zubia J.: An Ambient Assisted Living Platform Integrating RFID Data-on-Tag Care Annotations and Twitter, Journal of Universal Computer Science, vol. 16, no. 12 (2010), 1521-1538.
Healthcare, U.S.	o Caregivers receiving data via the Internet from RFID readers can monitor seniors' daily activities by recording which tagged items they have picked up, and when. By comparing real-time data with a record of an individual's normal daily routine, caregivers can easily spot any significant changes. o The Caregiver's Assistant even automatically fills out a daily activities form, which is normally completed by caregivers for the elderly when they make home visits.		http://www.leadingage.org/CAST.aspx CAST The LeadingAge Center for Aging Services Technologies (CAST).
Other			
HP, U.S.	M2M Software Solutions: o Remote monitoring & diagnostics of smart meters, o Firmwave updates for wireless communications equipment providers o Wireless gateway updating for an enterprise	Utilities and energy companies	M2M Magazine HP White Paper

Company/ Project	Smart Solutions (Services and Products) Description	Additional Domains (Industries & Sectors)	Source
	service provider		
IRobot, U.S.	Ava, Human-Robot Interaction: o Self-navigating mobile robotic platform with semi-autonomous operations o Platform for market innovations o Integrates technological advances in wireless connectivity, computational horsepower, artificial intelligence, sensors and power efficiency	Home & office, manufactur-ing, retail, education, etc.	http://www.irobot.com/en/us/cool_stuff/Research/Human-Robot_Interaction.aspx
Koubachi, Switzerland (Startup)	Koubachi WiFi Plant Sensor: o Send humidity and other data to a smartphone	Gardening, Agriculture	http://techcrunch.com/2012/03/03/koubachi-wi-fi-plant-sensor-takes-the-guesswork-out-of-container-gardening/
Enevo Oy, Finland	Smart Waste Management: o 30 percent waste collection costs saving by remote monitoring of waste and recycling containers fill level using wireless sensors o Optimization of the use of waste vehicles	Waste Management	http://www.goodnewsfinland.com/archive/themes/recycling/28fd81b4/
Encompass Solutions Oy, Finland (Startup)	Car Fleet Management System: o For a large Finnish company (idle motors monitoring and control) Ambience: o Ambient light and conference room presentation style and atmosphere settings based on Google image search text of a business card.	Car fleet management, automotive, office & conferences	Jason Brower, encompass@gmail.com
Albion Café and Poke (digital creative agency), London, U.K.	BakerTweet: o The bakery-friendly box sends a tweet to its cliental with text and picture what is ready, "right from the oven" Plus other Tweet functions	Bakeries, coffee shops, restaurants	http://www.bakertweet.com/ http://www.pokelondon.com/
Automotive			
Google, U.S. (Infotainment and Telematics Ecosystems)	Google Maps and Places in automotive telematics systems: o Hyundai's Blue Link: smart phone can unlock doors, other remote access features; voice recognition; uploading of points of interests from the owner's PC; eco-coach, voice text messaging; antitheft slowdown, immobilization and recovery; roadside assistance; communication – share your location via Facebook, map locations of your friends, voice-to-text messages, open lines of communication from driver's seat >> "Navigate, connect and discover with the push of a button" o Kia's 2nd generation UVO eServices		https://www.hyundaiusa.com/technology/bluelink/ http://www.kiamedia.com/us/en/media/pressreleases/5169/kia-motors-america-launches-uvo-eservices-in-new-2014-sorento-at-los-angeles-international-auto-showx

Company/ Project	Smart Solutions (Services and Products) Description	Additional Domains (Industries & Sectors)	Source
Garmin International, U.S.	K2 Platform: o Next-generation automotive infotainment solution, unveiled at CES-2013		http://www.machinetomachinemagazine.com/2013/01/07/garmin-k2-turns-car-dashboard-into-digital-cockpit/
Verizon	o Fleet management Solution		http://www.machinetomachinemagazine.com/2013/03/18/verizon-launches-fleet-management-solution/
Fujitsu-Telenor	Remote Engine Start Telematics: o Aftermarket product, connected services solution		http://www.machinetomachinemagazine.com/2013/03/13/fujitsu-ten-connects-with-telenor-connexion/
Huawei, China	o 3G and LTE modules for vehicles; GPS and eCall o 3G WiFi box for vehicles - enables insurance providers and fleet management companies to retrieve information such as location, vehicle conditions and driver habits		http://www.machinetomachinemagazine.com/2013/03/04/huawei-launches-first-vehicle-telematics-range/
Potential IoT			
TomTom, Netherland	Business and Government Solutions o Vehicle fleet management; traffic, location based services, company and business listing on TomTom's maps o Telematics and insurance products for greener and safer driving	Automotive, telematics and insurance	http://www.tomtom.com/en_gb/b2bservices/?WT.Click_Link=hp_link
Garmin, U.S.	Dog Tracking System: o GPS tracking, positioning alarms, location marking	Pets, home an outdoor	Garmin® Astro® DC 40 GPS Dog Tracking System with DC320 Receiver
Tracker Inc., Oulu, Finland	Tracking and telemetry devices: o GPS tracking and data sharing systems for hunters and animals, i.e. hunting dogs and semi-wild animals as Reindeer	Pets, home an outdoor	http://www.tracker.fi/index.php?pPath=6
Ultracom Oy, Finland	Koira GPS: o Ultrapoint Dog GPS 2010 – hunting dogs GPS/GSM tracking color: smartphone, maps (Finland).	Pets, home an outdoor	http://www.ultrapoint.fi/en/homepage/
Electia AB, Sweden (SME, in partnership with Securitas, SE)	C-Fense Home and C-Fence Family o Wireless GSM Smart Alarm System with image capture via MMS/E-mail. Suitable for summer cottages - €404.99, €264.99, €154.99 (without Internet, yet) o Also controls lighting, heating, fire alarm via mobile phone o Accessories: wireless cameras, sensors, smoke detectors, sirens, pressure mats, etc. o Home automation and smart energy	Summer cottages, garages, saunas, boats and other property	http://www.clasohlson.com/uk/Wireless-GSM-Alarm-System-with-image-capture-via-MMS-e-mail/36-4508#moreinfo http://www.electia.se/index.php

Company/ Project	Smart Solutions (Services and Products) Description	Additional Domains (Industries & Sectors)	Source
Nexa Electronics, Sweden	System Nexa: ○ Wireless electric lights, plugs and motion sensors control for intelligent homes (without Internet, yet)	Home & office	http://www.nexa.se/1st-release-for-Nexa-webpage-in-UK.htm http://www.youtube.com/watch?v=6tfgSmJt4o8
ONTECH	Alarms with GSM Remote Control: ○ €184.99 at Clas Ohlson ○ Security of boat, caravan, toolshed, garage, etc. ○ Programmable and controlled through a phone or by SMS ○ Remotely controls radiators, pumps, other electrical devices ○ GSM water leakage detection systems ○ Subscription or cash card	Summer cottages, garages, caravans, boats and other property	http://www.clasohlson.com/uk/Ontech-GSM-9020-GSM-Alarm-with-Remote-Control/36-3750 http://www.ontech.se/ http://www.isocket.eu/examples/

Preliminary outlooks

As we promised, this reasonably fictitious exercise, backed up with some examples, provides a prospective about future IoT applications and smart solutions. Even though the IoT great potential and plethora of applications and smart solutions is obvious, there are not that many real world examples benefiting the end user in everyday life. Clearly, there is a great market potential for the IoT smart solutions; what is lacking are the strong and dedicated market makers (Schlautmann et al. 2011) to create, deliver and capture the value of IoT .

Within the smart home business domain alone, there are several possible scenarios and business opportunities for the ICT context players to become the key players. The CSPs, content and service providers, equipment vendors, infrastructure vendors, and even companies from different industries currently have pretty equal chances to singularly dominate a specific IoT market segment based on their resources, capabilities, strategies and business models.

Most likely, the key players would be partnering among each other, creating specific ecosystems. That appears to be a quite logical and fast developing scenario for everybody. Nevertheless, it should be argued that the emerging market makers, while creating, delivering and capturing value, either singularly or partnering with each other, should follow the simple rules strategy, build the IoT awareness and customer loyalty through introducing the basic IoT solutions first, and then gradually offer more advanced IoT solutions and systems. Perhaps, this could become most coherent way for revealing and bringing the value of IoT to the masses.

3.4 Preliminary Delphi results

By Mervi Rajahonka, Riikka Siuruainen, Seppo Leminen

Delphi method

The Delphi method is a systematic, interactive forecasting technique, which relies on the panel and group discussions of experts and participants involved in the study. Delphi is based on the

idea that the forecasts or decisions originating from a structured group of individuals are more accurate than those from unstructured groups. In the standardized Delphi study version, the experts answer to a questionnaire in two or more rounds. After each round, the facilitator summarizes the answers. In the following round, experts are encouraged to revise their earlier answers after going through these summaries. It is believed that, during this process, the variety of the answers will diminish and the answers will converge towards mutual understanding. (Rowe and Wright, 1999)

The purpose of the IoT Delphi study was to map Finnish experts' views on the current and future IoT business models. The summary of the first round consisted of seven cases: automotive industry, food industry, homeowner's digital service, waste management, healthcare industry, IoT adapted manufacturing processes, and shopping mall services. The first round of the Delphi study was launched in June 2012, and the answers were summarized in August 2012. The second round was launched as part of the Sprint 3 phase. The second round concentrated on the feasibility of the cases.

The main questions for the first round of the Delphi study were as follows:

1   Please, describe a case example of a current IoT business model that you perceive the most interesting (from the media, literature, your own experience etc.).

2   Please, describe a case example of a future IoT business model that you perceive the most interesting (from the media, literature, your own IMAGINATION or experience etc.).

Summary of the answers to the Delphi Study

In the following, we describe some of the possible business models in different industries as obtained through the Delphi Study.

Automotive industry (Traffic Data Services)

One of the most interesting and possible business models or preferable chain of models is related to the so-called Traffic Data Marketplace or Databank or Service Bank, which is provisioned by a system integrator or service provider. This actor of the business model will take care of the network. In this business model, the whole chain ranges from data collectors to data storages and further to value added service providers and developers that can use the collected data commercially to build end-user services. The business model should be always scalable from local to global. In this business model, the technologies would mainly be based on open standard interfaces and there would be an actor, such as the marketplace owner, that will manage the data storages and the interfaces to and from the storages. For all this to succeed, political support is one of the key issues and will be definitely needed. The databank would include both privately and publicly collected data. The users and value added service providers pay for the raw data, and their customers (end-users) pay for the value added services and products. All actors would be involved in this business model, and those providing data would have their share of the revenue. The data offered would be real-time data related to traffic, environment, weather, road condition, and incidents, and collected from all possible sources, both public and private. The customers would include the value-added service providers and the users of their services/products. The business model would first be national, yet scalable. The focal actor would be the "owner and operator of the databank/marketplace".

Food industry

Food security receives great attention worldwide, especially in China. With the existing information systems, it is difficult to trace the processed food products all the way from the original producers to the consumers. The IoT network, as an excellent future of ambient computing, could be one of the solutions for this challenge. The new IoT solution and its business models would involve multiple IoT service providers. The actors from food industry could be, for example, food manufactures, food vendors, importers, exporters, retailers, standardization organizations, or government authorities. In the system, an international steering group or actor would be needed to manage the network.

Homeowner's digital service

Homeowners would have a digital service to monitor and manage the facilities, including the extended home such as the summer cottage, office or grandparents' house. The service would be provided and organized through plug-and-play devices and access points available to the customer as an installation package. Open and user-friendly applications would be provided, as would be the possibility to pool services in the neighborhood, for example, during vacation. The service operator would be a central stakeholder, no expensive built-in technologies would be required, and therefore, construction companies would not play a role in the business model. Another version of the service could be directed to publicly owned properties, expanding the present security and maintenance services.

Waste management

This business model example concerns products or services that are related to real-time waste monitoring and management using sensors, to reduce the costs of waste collection. Customers could be waste management companies. Direct contacts are relevant channels and this business model is likely to be local or regional, but can be globally scalable. The technology is likely to be proprietary, potentially using commercial off-the-shelf (COTS) components. The focal actor would first be a waste management company and later on, the business unit responsible for the solution. This unit can become a spin-off. The supply network would be closed and include, for example, component providers, communication module providers, communication network providers, possibly also solution providers or integrators, unless this network is not accomplished as an in-house solution. Key success factors for this business model would be, for example, the cost of solution, the cost of communications, and the reliability and durability of solution. The end user and paying customer would be the waste management company. Those who are paying for waste collection (both private households and businesses) would also benefit from reduced costs of waste collection.

Healthcare industry

One case example is from the healthcare industry, health related products and services (sensors). This is naturally one of the increasing IoT businesses since health is primary need for all the population. Moreover, population is ageing and costs will rise significantly while the services cannot be outsourced to cheaper countries. Everyone is and will be a customer, since healthcare affects us all from early ages to elderly people through both public and private channels. Public institutions should make health as a primary concern, starting from the early ages, in order to improve quality of life and reduce sicknesses and the associated costs later in life. Private channels can offer specific services on a commercial basis, but healthcare should be a universal, publicly offered service. The business model is global and it is easy to copy and deploy. Government and public health institutions would be the actor that will trigger the deployment and raise awareness in the population. The technology of products and services

would be based on (smart) sensors and IoT communications infrastructure together with medical expertise. Key success would come from the right boost, at least, initially from government. The benefits would include reduced costs of health services. Private companies could leverage the deployment by offering tailored services and applications for wealthy people. The product would be health counseling service. Young and middle-aged people could receive sensors to monitor certain key parameters and these parameters would be analyzed by medical experts periodically. Customers and users will receive information about warnings concerning certain parameters and proposals how to reduce them and improve one's health status. Technologies for these products and services would include sensors and IoT connectivity. Earning would come from private services that provide specific information and additional checks performed by medical experts.

IoT-adapted manufacturing processes

In IoT-adapted manufacturing processes (with situation-aware smart machines and robots), manufacturing lines can customize products during the production process. This is cheaper, more flexible, and there is less need for human interaction. Situations can be analyzed in real-time by gathering data from sensors. This also facilitates decentralization of business processes to decrease the complexity of supply-chain processes. The customers are owners of production lines, warehouses, automated storage facilities, or similar. Systems need to be set up by B2B partners, so B2B channels are used to reach customers. The business model is locally set up and can be globally applied for different kinds of production lines. The model is very scalable, adaptable, and fairly easy to copy. Sensors, actuators, sensor networks, robots, and data warehouses are among the technologies used. Focal actors in this business model would be the producers of smart supply chains and robots or machines for supply chains. The supply network would comprise manufacturers of equipment for smart objects, producers of industrial robots and supply chains, data warehouse providers, and companies delivering the needed materials. The network would be open for all companies, but most likely not affordable for small companies. Critical success factors in this business model include the interoperability of production line elements with existing IT environment: IoT-adapted production lines must be considerably faster adaptable as compared with traditional ones. Challenges or risks include that the change of existing traditional production lines to new IoT-adapted lines is very costly. Also, if the technologies used are not standardized, it would cause problems when integrating new machines from other vendors (vendor lock!). Human-free production lines could also be a general problem. Revenues and cost savings would be gained with this business model because more efficient production lines require fewer employees, and higher average production output generates more revenue. Money for other companies in the network would come from selling turn-key products (assembly lines or single smart machines/robots) and maintenance services. Main costs of the model would be the purchase and maintenance of smart infrastructure; the end user of produced or delivered items may benefit (quality and costs) from fully automated smart systems.

Shopping mall services

In fully transparent shopping mall services, customers may use electronic shopping assistants. By pointing on a particular product, key information about this product is listed: price per unit, production/expiration date, ingredients and origin of subcomponents, calories, origin, "green" information (e.g., emissions caused by delivering the product to the shop), the cheapest price of the same product in surrounding super markets, public health warnings regarding the product, alternatives for the product in the same shop (comparison of price, calories, emissions caused etc.), and the country of origin (for political reasons users may not like to buy products from particular countries). Customer needs addressed in this business model would be transparency, as well as fast, reliable and independent information, and customized

warnings (for diabetes, lactose intolerance etc.). The customers of this model would be conscious shoppers, private customers, practically anyone who goes shopping. Customers will be reached in shopping malls, and readers would be sold to the end-users by technology companies or Internet based companies. This business model is locally applicable, but globally valid. The number of products with product description is scalable. The product information system is hard to implement and hard to copy. The technology used would combine data warehousing information with sensor data (read by the device that the user acquired through the wireless reader). Devices are available for everyone. Focal actors would be supermarkets, governments or the WHO (World Health Organization). Supply networks include database, device and smart object manufacturers. Their roles would be data warehousing, device production, and object identification. Critical success factors include the fact that consumers and governments must express a wish for full transparency. Risk is that the business model most likely could not be implemented without legislation. In this business model, money would come from selling of product information devices and eventually from selling software updates (for new product info). The customer pays for the device, but wins by finding the same product at a cheaper price in surrounding markets. The customer would be willing to pay money for environmental-friendly and healthy products. Cost structure would consist of device production costs and SW development costs (if integrated in smartphones). There may be high costs for collecting data information. Monthly income may be collected by charging end-users a license fee for data updates.

3.5 Interactive workshops: the process and preliminary results

By Alexey Shveykovskiy

The research team at the Oulu Business School (OBS), Department of Management and International Business, has developed the interactive workshop process methodology and action research approach for studying, creating and assessing new and emerging business models and ecosystems within the fast changing ICT business environment. This methodology and approach have been successfully used in the cloud software and cognitive radio (CORE) research projects. As our research team follows several companies' IoT research and trial preparations, the interactive workshops have become a valuable tool for designing and assessing their emerging business models and ecosystems. Besides, the team also aims to provide the entire IoT research community with comprehensive understanding about the new unique and agile IoT business models and ecosystems.

During the IoT project's Sprint 1 and Sprint 2 periods, the OBS research team conducted two interactive workshops that focused on the future scenarios and related business opportunities for the IoT Home and Health environments, respectively. These two workshops became the first important research rounds of the overall business model and ecosystem workshop process, and research work conducted by OBS within the IoT project. The IoT Home and Health workshops involved two separate groups for the purpose of gaining more diversity and creativity in thinking, as well as observing certain degree of validity of the workshops' outcomes and their descriptions.

The quality of participation component was of high importance to the workshop process and success; and it was achieved by the active participation, creativity and thinking collaboration between the ICT engineers, companies and industry representatives, and business scholars of the IoT project. Both the home and heath IoT environment workshops had a similar structure, purpose and approach for defining the future business context, i.e. business models and

business ecosystems. All of that was achieved through a focused scenario process that helped to build a coherent picture of the respective future business IoT environments.

The scenario process had nine important steps, starting with the generation and classification of the initial context variables, followed by the selection of critical variables and their thematic grouping (steps 1-5). The next steps involved the identification of dimensions and extremes, and the selection of the two most important dimensions (steps 5-7). In the final steps, the scenario matrix was drawn up and the scenarios were described (steps 8-9). Each initial context variable was important for the workshop process, because they reflected valuable individual opinions of each participant on what they thought would influence the development of future businesses and environments. Selecting and grouping of the critical variables were also quite crucial, because the identification of extremes and dimensions, as well as selection of the two most important dimensions were based on them. Both the initial and critical variables, as well as the workshops' results are available on the WP5 IoT Wiki pages.

It should be noted that: 1) selection of the two most important dimensions was perhaps the most difficult task for the groups, because they had to give up and/or combine several dimensions into one in order to draw the matrix; 2) drawing up and describing the scenario matrix was relatively easy for the groups, but, interestingly, the final names of the extremes' opposite ends and the names of the most important dimensions differ from the initial lists of dimensions and extremes (Table 17 and Table 18).

Table 17. Identifying the dimensions and extremes

End 1	Dimension	End 2
High	Integration	Low
Services	Interoperability	Devices
Const./Flat "Bit Pipe"	Cost / Pricing / (Connectivity)	Value-based
Consumers	Customer willingness to pay (who pays?)	Someone else
Low	Consumer technology knowledge	High
Customized/Segmented/Local	Type of service	For masses/Global
Static / Non-enterable	Service design	Mobile / Enterable
Vertically integrated Few players Proprietary (IPR) Driven by incumbents	Ecosystem	Non-vertically integrated Many players Open standards Driven by new entrants

For instance, in the **first workshop**, focusing on the IoT Home environment, Group 2 came up with a list of eight dimensions and several respective extremes (Table 17), which were later condensed into a list of the two most important dimensions and four respective extremes (Table 18). The combination and modification of names of the final dimensions and extremes reflect the collective thinking process and collaboration of participants. Group 2 came up with interesting tentative results, or four scenarios, shown in the scenarios matrix (Figure 18). The first critical dimension is "Services" with "Improving existing services" and "Creating new services" as corresponding extremes (the horizontal axis in Figure 18); the second critical dimension is "Ecosystem" with "Closed" and "Open" as corresponding extremes (the vertical axis in Figure 18).

Table 18. Two most important dimensions

End 1	Dimension	End 2
Improving existing services	Services	Creating new services
Open	Ecosystem	Closed

The first scenario, "Wild West" (Figure 18), reflects that the IoT Home environment could be an open ecosystem that facilitates the creation of new services and solutions. An open gateway applications provider like Pachube could serve as an example of such a company. The "Wild West" scenario could also be characterized by a high degree of competition, plethora of horizontal applications, easy access for new entrants, platform-based, cloud infrastructure-API, vertical services, and low cost. The second scenario, "Blue Ocean", is a more closed ecosystem that facilitates the creation of new services. An example would be a high-liability patient and health monitoring IoT health service provider. The "Blue Ocean" scenario is characterized by partnership and co-opetition, harmony among incumbent players, "rule" of service providers, high barrier of entrance, and high cost. The third scenario, "Community", was envisioned by using an example of a WiFi home network where a community of trusted individuals could monitor their homes, property, pets, gardens, etc. via improving the existing IoT solutions. The fourth scenario, "Red Ocean", as an opposite of the "Blue Ocean", reflects the major incumbent player's strategy favoring low competition and with the most difficult entrance for newcomers, which could be eaten in the "Red Ocean". An example of a "Red Ocean" company could be the AMR LCD displays manufacturing company, which strives for a closed ecosystem where existing services are improved gradually, under low competition and without any disturbance from new entrants.

The second workshop addressed the future scenarios and related business opportunities for the IoT Health environment, and, specifically the existing and emerging IoT solutions and technical applications for healthcare and well-being, sports, homecare and assisted living, and eHealth. In this workshop, Group 2 came up with a total of nine dimensions, or pairs of extremes (Table 19). Noticeably, this time some dimensions were not named, although the associated extremes were quite important. Evidently, after combining several dimensions and extremes into the two most important (Table 20), the group struggled and decided not to give names to the two dimensions, because, most importantly, the group members were satisfied with the results, that is, the four possible scenarios of the IoT Health environment, with related business models and ecosystems (Figure 19). The results for Group 2 were quite interesting and applicable to future research and work on business model generation.
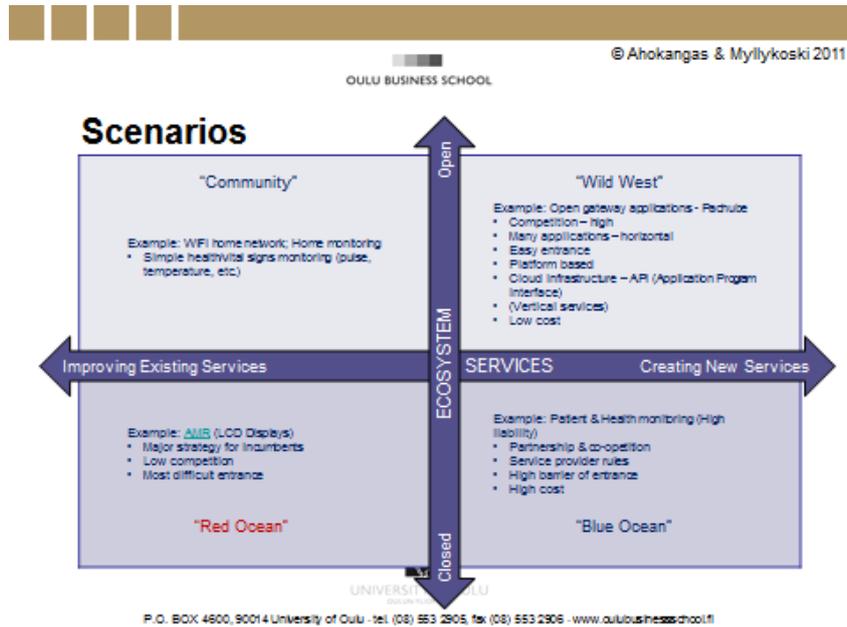
Figure 18. Four scenarios by Group 2 in Workshop 1 (tentative results)

The "Health Awareness" scenario (Figure 20) is positioned between the "Public" extreme of the Private vs. Public healthcare dimension (the vertical axis) and the "Healthertainment" extreme of the Professional health vs. Healthertainment dimension (the horizontal axis). "Healthertainment" is a new emerging and quite a catchy term, meaning the provision of wellness, self-strengthening, athletic and sport programs and, sometimes, even basic health treatments by non-medical professionals, enthusiasts and individuals, where it is appropriate and not harmful for humans and the environment. That is why the "Health Awareness" scenario is characterized by lifestyle coaching, autonomous diagnostics, community and social media diagnostics services and applications in the individual, public and the third sector, i.e., non-profit and NGO, domains.

Table 19. Identifying the dimensions and extremes

End 1	Dimension	End 2
Professional	**Service provision**	**Peer support**
Hospital care	Semi-professional Internet service	Social media
Highly usable by professionals	N/A	Professional tools
"Serious tools"	N/A	Fun, gaming
Automated: alarms, emergency	Recommendations	Self-initiated

End 1	Dimension	End 2
Expensive – paid by insurance, state	**Cost**	Affordable – paid by customer
Full financial, tax breaks	**Governmental involvement**	No support, extra taxes
Legal, data protection responsibility		Legislation involving business
Secure data, security feeling though technology	**Security**	No protection, insecure feeling
Personal Collection of devices	**Personalized health**	All-round technology single device

Table 20. Two most important dimensions

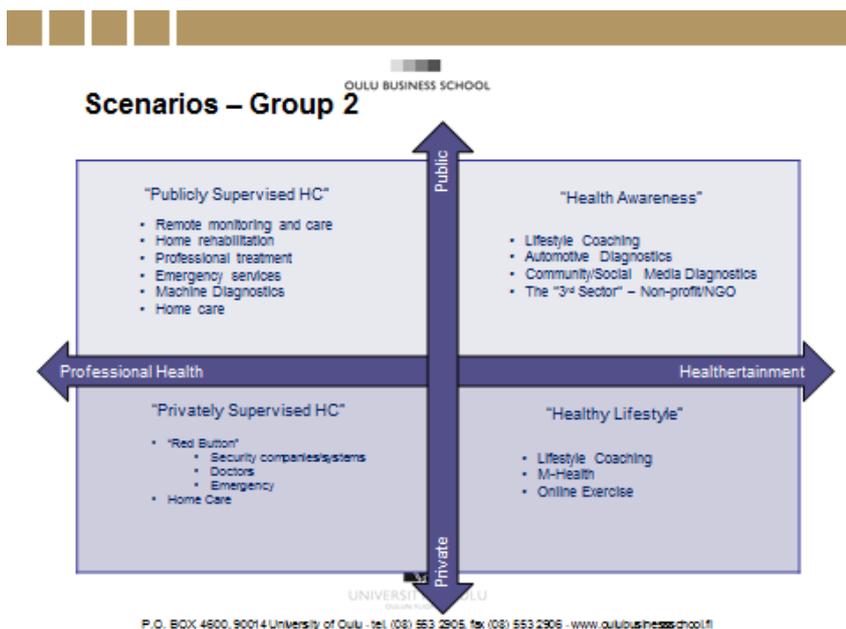| End 1	Dimension	End 2
Professional health		Healthertainment
Private		Public

Figure 19. Four scenarios by Group 2 in Workshop 2 (tentative results)

The second scenario, "Healthy Lifestyle" (Figure 20), is characterized by lifestyle coaching, m-Health, and online exercise and treatment programs, most commonly found in the "Private" sector (vertical axis in Figure 19), and being heavily influenced by the healthertainment phenomena. The third scenario, "Publicly Supervised Healthcare", is characterized by the remote monitoring and care, home rehabilitation, professional treatment, emergency services, machine diagnostics, and home care services and applications. All of these are implemented in the public sector healthcare and by professionals only, due to the seriousness and liability of provided services and applications. The fourth scenario, "Privately Supervised Healthcare", is similar to the third scenario in terms of services and applications provided, but with addition of the "Red Button" set of services and applications provided by the "Private" sector. In Finland, the provision of the "red button" type of services is more feasible within the private sector, because of the existing healthcare system and as a result of close cooperation between private security companies and systems, doctors and emergency services.

The first rounds of the OBS interactive workshops have awakened serious interest among the WP5 and other IoT project members. It facilitated creative and collective thinking among the participants, and generated several interesting results in the form of future scenarios for IoT Home and Health environments. Noticeably, generated tables of dimensions with corresponding extremes, and, especially, the tables with initial and critical variables also present certain value and interest for the current and future research. The positive outcome, active participation, and the general and specific interest among the IoT project members all point toward the facilitated continuation of the overall OBS workshop process within the IoT project, because it provides helpful methodology and mechanisms for dealing with uncertainty of the future IoT environments through the generation of scenarios, business models and ecosystems for the IoT business and technology domains. More details about the OBS interactive workshops and their results are available on the WP5 Wiki pages.

Chapter 4.   Discussion

By Petri Ahokangas, Alex Shveykovskiy, and Seppo Leminen

Reflecting over the review and research on the business and technological opportunities, on the "things" to be or already connected to the Internet, as well as solutions and services created around these things, it is clear that Internet-of-Things is still in its infancy as a distinguishable industry, let alone as a substantial main-street market, or an area filled with killer applications or widely adopted services. Rather, IoT currently comprises a myriad of embryonic, partial, overlapping, or competing technical solutions and platforms offered for the early adopters within various vertical business domains, building often on emerging or de-facto rather than approved industry standards, and where the business models and ecosystems of the various players have yet to be tested and stabilized. As such, IoT represents a typical ICT sector with the specific feature of being fragmented – even within the various business verticals discussed in this report – and competitive, as well as lacking dominant technologies and ecosystem players. Bearing this in mind, one should remain doubtful when reading and analyzing various market research reports and estimations around the IoT. This does not, however, mean that IoT is not a growth market. Given its current structure, it provides both start-ups and incumbent players with great opportunities to build up new businesses and markets, as well as to look for new efficiency.

The "IoT framework" or "IoT perspectives", depicted in Chapter 3.1, outlined the following four levels of analysis as relevant when discussing IoT businesses: 1) the digitalization and cloudification of services, 2) the business and physical domains, 3) the business and use models, and 4) the ecosystem and solution life-cycles. The digitalization and cloudification of services can be seen as the fundamental transformational drivers for the majority of IoT businesses representing the three vertical domains analyzed in this report. On one hand, regarding the cloudification aspect, home and personal clouds, in particular, emerged in the research as providing business opportunities. On the other hand, (customer) diversified and device-bundled services were found most promising from the digitalization of services point-of-view. As regards the levels of business and physical domains, the fragmentation and diversification of the IoT businesses appeared most prominently. As a market, the IoT applications and services currently provided and planned to be provided seem to resemble a bowling alley, as described by Moore in his book Crossing the Chasm (Moore 1999); a market where it seems to be very difficult to serve several customer segments or verticals simultaneously with one market approach. The question remains as to when the technological platforms and things, combined with a compelling value proposition, will actually open up opportunities for creating widely adoptable services and main-street markets.

According to the view adopted in this report, business ecosystems comprise synergistically connected business models. Looking at individual business models of the companies, no single business model seems to be dominating in the IoT field. Rather, the business models analyzed here do not yet appear as having become calibrated, neither in terms of their usage model, i.e., in what ways customers use and enjoy the services and what kind of things are included in the business case, nor regarding the other business model elements. On one hand, this indicates that the ecosystems themselves contain loosely coupled value propositions and rather unstable cooperation-competition structures between the companies involved in them.

Currently, many of the studied ecosystems are being led by an incumbent dominant player, and they are closed or otherwise integrated, but remain rather small and fragmented in terms of business. On the other hand, regarding the solution life-cycle, the number of existing to-be-

matured platforms and beta-version service concepts leads one to think that it may take a while until the ecosystems have become developed and stable.

The IoT market will develop from close vertical industrial applications to 1) open vertical applications within a single industry, 2) open horizontal applications crossing different industries, or 3) a World of IOT applications, in which the dominant resource integrator offers divergent services integrated by dominant resource integrators (Leminen, et al. 2012b). As with the markets, the question remains when the technical side will have developed enough to enable a major business to emerge within the IoT field.

Modularity of IoT will play a major role in the development of the IoT industry and ecosystems since IoT links not only IoT technologies and systems together, but also different vertical and horizontal service applications of the diverse business models in industries. A thing, a business, and a consumer can be interlinked to each others in several ways, which creates numerous possibilities for new business opportunities (Leminen, et al. 2012a).

To conclude, it might be beneficial for the companies interested in IoT to pay attention to the following:

- Inter-industry and inter-ecosystem opportunities and trends
- Co-opetitive opportunities for value co-creation and co-capture
- Opportunity triggering technologies within existing businesses
- Open and closed networked business models
- Creating and seizing an opportunity in becoming the IoT market makers
- Bundling things with easy-to-use-and-adopt services
- Providing smart solutions addressing the end-user's needs, wants and desires
- Identifying the compelling value proposition, especially regarding price or efficiency.

The list is far from exhaustive, and further research is needed within this field. The use of future scenario planning and Delphi techniques, combined with business model creation, transformation processing and learning by trial and error from the existing cases and pilots, will provide us with valuable insights into the development of IoT business ecosystems and related business opportunities.

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