Evolution of Internet of Things

Go-to-market strategies for semiconductor companies

by

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Abstract

Internet of Things (IoT) is being touted as the next wave of big opportunity. However, the picture does not seem to be very rosy for semiconductor vendors and chip suppliers who might find it difficult to make high revenues or gain a position of power to drive this market. There are several reasons for this:

i. The IoT devices are made up of relatively less complex, low cost and low profit-margin chip components such as sensors, RF and microcontrollers
ii. The IoT is not a single market, but an umbrella of fragmented markets with many different niche segments and lack of common standards, making it difficult for companies to decide what they are going to do and which segments and opportunities they want to focus
iii. High value and importance is given to software and services in the IoT ecosystem
iv. The steadily shifting of power from companies in the supply chain to service providers
v. The continuing rising cost of semiconductor manufacturing
vi. Increasing SoC design landscape, rather than discreet components

Most of the semiconductor companies are not realizing this and, thus, they don't have a go-to-market strategy for IoT in place, even after making a decision to enter the market.

The thesis aims at identifying the major IoT trends that will determine the prospects for semiconductor companies. In addition, it tries to answer the questions regarding how and where they can add value to this market and, in return, create a sustainable competitive advantage, or maximum ROI, for themselves. In more details, the thesis will address some of the secondary questions as follows:

i. Why having a IoT strategy is so important for semiconductor companies?
ii. Who are the different players in the IoT ecosystem?
iii. How is evolution of hardware capabilities, as well as other technologies including software and firmware, happened and happening in the IoT space?
iv. In the tough economic situations, how can semiconductor manufacturing companies capture more value?

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Motivation

The world is currently witnessing rapid convergence of two very unlike systems – the Internet and everyday physical objects. Known by names such as the Internet of Things (IoT), Machine to Machine (M2M) and the Internet of Everything (IoE), this phenomenon has a huge potential to change our lives by connecting the billions of physical objects that surround our lives to the web. According to Cisco, there will be over 50 billion devices connected to the Internet by 2020 and these devices will include sunglasses, watches, cars, vending machines, etc. Cisco CEO, John Chambers, pegs the IoT market at $19 trillion and says it will have five to ten times the impact on society as the Internet itself.

The IoT requires that every physical object that is accessible through the Internet has a semiconductor chip adapted to its context. Thus, the semiconductor industry will be the key to success of IoT, and IoT will change the face of this industry from design and development to manufacturing and production. Clearly, the industry is at an inflection point where the demand for chips is likely to surpass any previous records, but this momentum will be concentrated across low-end, low-cost corner. As a result, it becomes imperative for the chip companies to understand the changing landscape, correctly prioritize the new product development and identify opportunities in the new and uncharted territory of IoT.

My extensive experience in the semiconductor industry provides me a good insight into the industry and the changes affecting it due to the evolution of the internet of things. It also highlights how chip companies are trying to leverage their existing capabilities in mobile and wireless space to make fast strides in the IoT business. I intend to continue learning about the latest developments in this industry and building my capabilities and understanding. In addition, this is the area I plan to work after graduation, and the experience I would gain by writing by thesis will strengthen my knowledge foundation in this area.

1 Introduction

1.1 Background

The idea of an Internet of Things started many years ago. Nikola Tesla in an interview with Colliers magazine in 1926 stated: "*When wireless is perfectly applied the whole earth will be converted into a huge brain, which in fact it is, all things being particles of a real and rhythmic whole.........and the instruments through which we shall be able to do this will be amazingly simple compared with our present telephone. A man will be able to carry one in his vest pocket.*" However the term "Internet of Things" is coined 73 years later by Kevin Ashton, co-founder and former executive director of the Auto-ID Center at MIT, who declared in an article in RFID Journal that: "*I could be wrong, but I'm fairly sure the phrase "Internet of Things" started life as the title of a presentation I made at Procter & Gamble (P&G) in 1999.*"

In computing, the Internet of Things refers to the networked interconnection of everyday objects [5]. According to International Telecommunication Union (ITU), the basic idea behind the IoT is the connection of any thing at any time from any place that is enabled by a number of technologies (Figure 1-1).

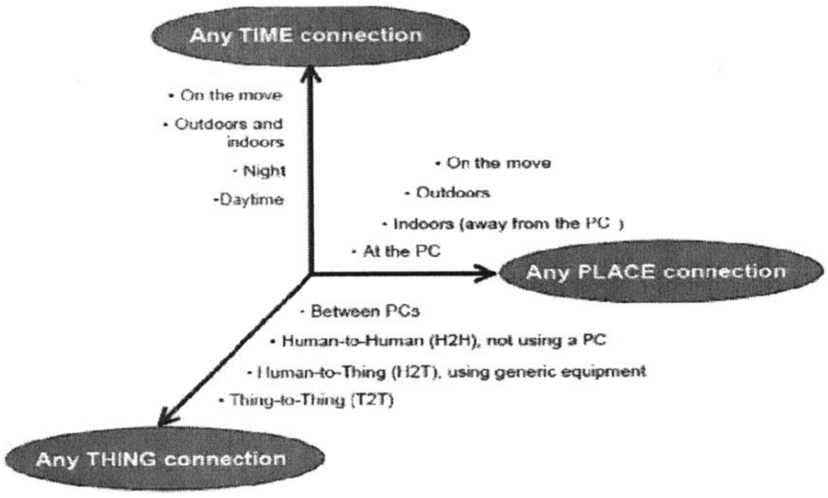

Figure 1-1: ITU-T Internet of Things (ITU, adapted from the Nomura Research Institute, "Ubiquitous Networking: Business Opportunities and Strategic Issues", August 2004)

Cisco IBSG estimates IoT was "born" sometime between 2008 and 2009 when the number of things connected over Internet exceeded the number of people on planet (Figure 1-2).

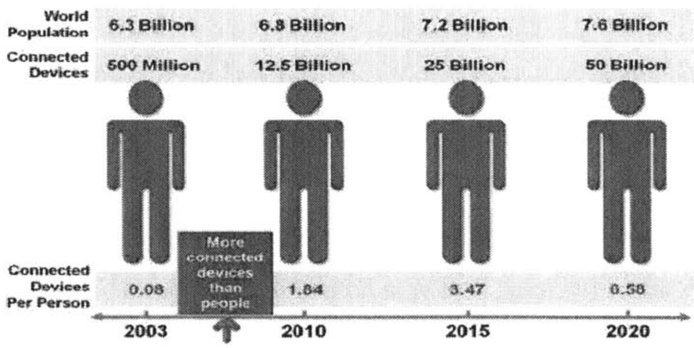

Figure 1-2: Birth of IoT (Cisco IBSG, April 2011)

What if everything seen in day-to-day world, from coffee maker to lighting appliances to refrigerator, can communicate with each other and with mobile phone? As such a future draws closer, the "internet of things" phenomenon has been capturing everyone's attention, and Internet-connected objects, devices and things are proliferating in every domain. The concept has been evolving so fast that what was called "Internet of Things" some time back has been morphed into "Internet of All Things" and "Internet of Everything" in recent literature.

The internet of things conceptually involves using sensors and actuators to track and manage physical assets across network. Though the earliest trend used radio-frequency identification (RFID) tags, it is no longer considered as a single technology, but an umbrella of several technologies. Evolution of M2M, ever-expanding internet, broadening mobile broadband and rising demands of cloud and big data have been driving this change [1]. Simultaneously, rapid decline in the cost of sensors and actuators and an increasing ability to connect to these sensors, often wirelessly, as well as improved capabilities to analyze big data, are leading to rapid adoption of IoT.

However, there is no denying that there remain uncertainties, such as lack of standards, highly immature market and a great number of unknowns, due to which its adoption in several industries have slow and companies are apprehensive of investing in it. Thus, the widespread adoption of the

Internet of Things is expected to take some time, but the time line is advancing due to continuing improvements in underlying technologies.

1.2 Trends driving the Internet of Things

The internet of things is not being driven by a single concept or technology. It has evolved into a way of thinking about how physical world, at large, and objects and devices within it are becoming increasing interconnected. Several concepts and enablers are behind its evolution:

- **Growth in demand of smartphones and tablets.** The market for smartphones and tablets has been growing. The way consumers and businesses use and consider their smart devices has been changing and the change will continue to drive new opportunities such as IoT.

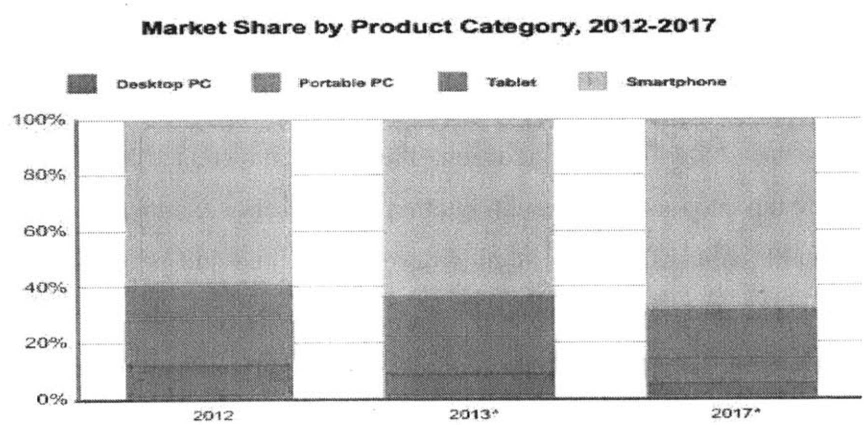

Figure 1-3: Market for smart connected devices (IDC, 2014)

- **Mobile broadband**. High-speed mobile communication standards (such as 4G and LTE), and low power wireless technologies (such as Bluetooth Low Power and ZigBee) are playing crucial role in enabling wireless connectivity among devices.
- **Cloud and physical assets as a service**. Over last few years, the concept of cloud for everything and everyone has become popular. Networks, servers and storage can now be rapidly and conveniently provisioned over Internet.
- **Big data and advanced analytics**. The proliferation of networked sensors through the Internet of Things and smartphones is leading to more activities having a digital footprint and

consequently, more data. Matching step with growth in data is the increasing power of advanced analytics. Combined with advances in cloud, user interfaces and visualization techniques, this progress is increasing the power to rapidly analyze data and deliver insight.

- **Transformation of healthcare**. The emerging "quantified self" movement allows consumers to become highly involved in their health care by using devices for monitoring medical conditions such as high blood pressure or maintaining a continuous record of physical activity. When combined with medical sensors which can relay information via smartphone to a physician, these systems promise to provide a new level of health and disease management that could generate more continuous data to help consumers better manage their own health.
- **Intelligent travel and transportation**. With the increased adoption of smartphones and devices, today's transportation industry has become more intelligent and several statistics such as travel time, speed and origin-destination information is more readily available. The IoT further gives the industry an opportunity to connect people, improve safety, communicate more effectively, and change transportation centers into community hubs.
- **Wearable computing**. Wearable technologies with their in-built use of sensors will fuel the growth of internet of things. In addition, the rich data created by it brings countless opportunities to tap into this data through internet of things. For example, connecting with third parties and health care institutions to provide more tailored and personalized services, and getting a better understanding of consumers.
- **Innovation in retail, supply and payment systems**. The retail, supply and payment sectors in business have been driving the use of less intrusive tracking mechanisms for the assets they manage. While radio frequency identification (RFID) is recognized globally for supply-chain management and in-store security since decades, a relatively new technology known as near-field communication (NFC) is finding its place in short distance tracking and security.
- **Evolution of Machine-to-Machine concept**. Manufacturing, engineering, utilities and production environments have been developing sensors and remote monitoring tools for many years in a field known as machine-to-machine (M2M) communication. M2M is a subset of IoT that enables connectivity in IoT and is concerned with machines connecting and communicating with other machines, devices or sensors – the underpinnings of many but not all IoT applications. The M2M concept has further evolved into machine-type communication

(MTC) whose focus is to connect thousands of devices into one large network and collect and analyze data at a centralized unit [8].

- **IPv6 adoption.** The latest incarnation of Internet Protocol (IP) v6 allows an address space of up to 3.4x10^38 unique addresses, thus enabling to connect an ever-increasing number of devices and objects.

1.3 Approach and Organization

There have been a large number of research papers and corporate reports about Internet of Things and other related topics such as wearables, Internet of Everything and machine-to-machine (M2M) communication being published in recent times. However, much of the literature discusses mainly the technologies and their prospects in the future. Little of the literature talks about systematic approach for developing and implementing the go-to-market strategy. Considering the fact that semiconductor companies sit at the bottom of the value chain and require concrete planned efforts to make sustainable returns in the IoT market, it is imperative that these firms develop a go-to-market strategy before they enter the market.

In order to device the strategy, the thesis follows a systematic framework. It starts with forming a technical foundation and developing a reference technical architecture to get an idea about the entities involved in the system, their interfaces, the functional requirements and the technologies prevalent in the market. In the next step, the verticals that have the greatest potential in the IoT market segment are identified. Afterwards, the applications requirements of different market segments are understood. In the last step, the overall IoT ecosystem and the foremost players in that ecosystem are studied and effective go-to-market strategies are framed.

Chapter 1 provides an introduction to the thesis topic and an overview of the thesis research approach and report structure. It also identifies and describes the drivers of Internet of Things

Chapter 2 describes the key theoretical concepts used in the thesis.

Chapter 3 discusses various architectures of the Internet of Things system, as well as relative advantages and disadvantages of the protocols used in the system.

Chapter 4 studies the current state of the semiconductor industry and Internet of Things market, and forecasts the verticals that are expected to have the highest potential in the IoT market in near future.

Chapter 5 provides an overview of the major applications in different IoT verticals and identifies their major requirements.

Chapter 6 discusses evolving ecosystem of the Internet of Things from different perspectives.

Chapter 7 offers analysis of the semiconductor industry and evaluates the go-to-market strategies of global semiconductor companies.

Chapter 8 is a summary of the thesis report and its conclusions.

2 Theoretical Foundation

2.1 The Things in Internet of Things

What is a "thing" anyway? 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. Thus, at the heart of the internet of things lies the ability of said things to interconnect and interact.

Things can have varying degrees of smartness and thus can be classified on the basis of what characteristics it possess.

- **Identifiable Things.** For things to be manageable, they need to be identifiable either in terms of type or as a unique entity. For example it may be enough for a retailer to know (from a bar code) that a shipment of tomatoes is in transit between Montpelier and Nice, or the retailer may require that the specific shipment, the one that was canned three days before at a certain production plant, is now en route.
  Identification by type or by instance is fundamental to the internet of things. In general, identifiers are numerical. For example, retail product indices allocate bar code numbers, books have ISBNs, and so on. Individual items can also be allocated by a number. For example, RFID tags can store Electronic Product Codes as a 96-bit data string. IP addresses or hard-coded numbers (e.g., in firmware) can also be used to identify things.
- **Interactive Things.** Technological advances have made it possible to connect a wide variety of things and devices. However, it is not essential for things to be connected to a network or monitoring device at all times. Passive things such as RFID-tagged books or DVDs need only be able to report their presence from time to time, such as when leaving a store. Meanwhile active things, which have greater processing capability, can be connected all the time or may make a connection only when they need to exchange information (or, conversely, may only

exchange information when a connection is available). Much of what takes place on the thing itself depends on what happens elsewhere.

- **Shadow Things.** The notion of shadowing acknowledges that a virtual instance of a thing can exist in the ether. In practical terms, this means a software program is running somewhere that knows everything it can about the physical item and can act on its behalf. So even a physically dumb object can have a relatively capable virtual representation. This is sometimes termed a cyber-object or a virtual agent.

  For example, a carton of milk can have a unique identifier and the ability to broadcast its presence to a local sensor (in the refrigerator, say). Somewhere else — it doesn't really matter where — a virtual instance of the milk carton can possess data about when it was bought and by when it should be consumed. This information could be reported back to the refrigerator: To the person who opened the door, it could appear that the milk "knows" whether its use-by date has been passed.
- **Sensitive Thing.** As well as being able to report on its own condition, a thing can also report on different characteristics of its environment. A thing may have sensors to report temperature, humidity, vibration, location, or noise levels. A thing may also be able to record and/or stream audio or video information, if sufficient bandwidth is available.
- **Actuator Thing.** Actuators provide a means to act on the environment. They provide a platform to carry out commands and follow through decisions. Humans may still be the primary actuators of existing IoT solutions, but this will not be case for long. Machine-to-machine concept has existed in industrial internet for some time and soon machines and devices will play the role of actuators in consumer internet too.
- **Autonomous Thing.** A final characteristic of things is that of autonomy. Things need to be treated and monitored individually, usually from a remote point, and they must operate independently of a remote control. The concept of statelessness is important here: It is not for any massive computer system to take control of individual things in a totalitarian fashion. Rather, each thing is in some way responsible for itself, not least by maintaining its own view of state, which can then be interrogated by a third party.

Building upon this, things can exhibit various degrees of smartness. It is perfectly reasonable to consider a thing — either with onboard capabilities or in conjunction with its cyber-representation

— to have awareness or even a level of decision-making capability. To keep heat inside a house, for example, a garage door could "decide" to close itself if the outside temperature is dropping and no activity has been sensed for a certain time period.

Things or devices can also be classified on the basis of their hardware architecture [35]:

- **Class 1 Devices**: These are the smallest devices and have embedded 8-bit System-on-chip (SoC) architecture. They typically have no operating system. For example, Arduino Uno platform
- **Class 2 Devices**: These have very limited 16-bit architecture. They usually either do not run operating system or run a cut-down or embedded Linux OS version such as OpenWRT for a very specific purpose such as to route network traffic. A typical application would be small home router. For example, Arduino Zero, Arduino Yun.
- **Class 3 Devices**: These are most capable IoT platforms and run either full 32-bit or 64-bit computing platforms. Due to their superior capabilities, they can run a full Linx OS or another operating system such as Android. For example, Raspberry Pi. They can be used as mobile phones or cloud gateways/bridges for them.

2.2 Go-to-market strategy

Having an effective go-to-market strategy is very important for a company to earn sustained and superior returns. When developing a go-to-market strategy, the goal is usually to create a detailed plan that answers four questions:

1) What are your offerings?
2) Who are your customers and/or partners?
3) What is your target market?
4) How and where the offerings will be promoted and delivered?

While making a go-to-market strategy, it is very important for a firm to focus on what it is good at. This is especially important for semiconductor firms who want to enter and/or compete in the Internet of Things (IoT) domain. IoT is a broad market that consists of several domains and numerous applications. In addition, semiconductor companies currently sit at the bottom in the IoT value chain, and most of the IoT devices are manufactured using low-cost and simple discreet components, making it very difficult for semiconductor firms to reap higher profits.

An effective go-to-market strategy helps company earn sustained returns in a number of ways [34]:

i. By offering products and/or services that allow the firm to do what it is best at, compared to its competitors

ii. By allocating productive and informational tasks (e.g. design, distribution) in a way that maximize value for all in the ecosystem– self, suppliers and customers

iii. By getting better at tasks that you are good at, by learning or taking help from others in the ecosystem

iv. By focusing on the right product design and right set of services

v. By focusing on the allocation of manufacturing tasks and distribution

vi. By focusing on price, promotion and customer acquisition

In business literature, two main tools are available to companies for developing as well as executing go-to-market strategies:

1. Cooperative game theory

This is based on creating value through effective business formats and channels. In recent time, it has been replaced by cooperative competition or coopetition. In today's complex world, companies including competitors try to cooperate with each other to reach a high value creation. The value created could be defined in a number of ways. From customers' perspective value is "benefit at cost". From a firm's perspective, the value created can be defined as [34]:

Value created = Customer willingness to pay (WTP) – Supplier willingness to supply (WTS) – Firm's manufacturing and marketing costs (MM) – Customer search costs (SC)

The above formula can also be shown as a figure:

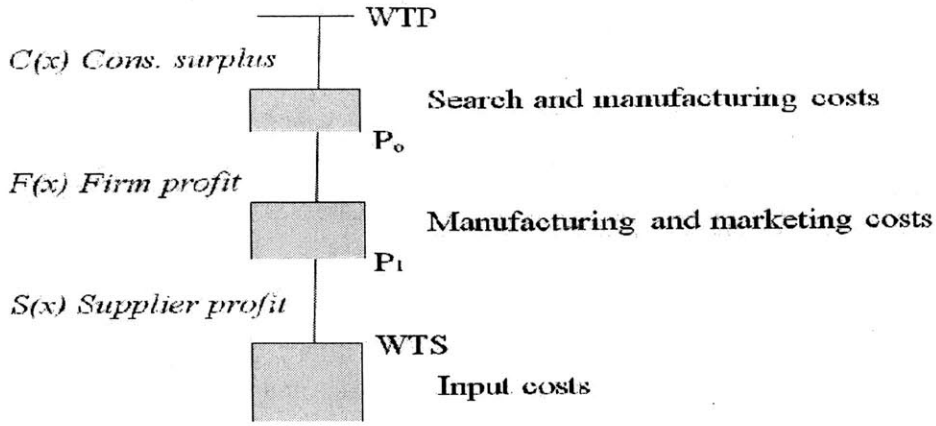

Figure 2-1: Value components

By effectively coopetition, a firm can increase the overall value it creates by increasing the customer's willingness to pay, while reducing the supply, manufacturing, marketing and customer search costs at the same time.

2. Resource-based view of the firm

This is based on leveraging and developing resources. It assumes that every firm is different and thus managing its resources will go long way in creating value. A resource here is broadly defined as the strengths that differentiate firms from its competitors. Those strengths are taken into account that create positive value for the firm over a period of time. This requires that the resources cannot be imitated without incurring time, efforts and/or money.

This view assumes that a firm can create value only if it has resources. The resources allow firm to do something that is unique (or at least scarce) and that is directly (or indirectly) valued by customers. This, value creation depends on resources. How does the firm create value, what is unique about what the firm does and what resources allows it to do so – everything is decided by resources.

3 A Reference IoT Architecture

It is important to understand the architecture of Internet of Things in order to understand its business ecosystem and devise an effective go-to-market strategy. Business ecosystem is typically mirrored in the technical architecture.

The Internet of Things is an umbrella term that includes multiple domains and applications. The result is that there is no architecture that suits all these domains and the requirements each domain brings. However, it is possible to suggest a reference architecture that is scalable and supports adding or subtracting capabilities. It can be used as a starting point for architects looking to create IoT solutions. On the basis of the needs of the market, companies need to decide which capabilities are most important and need to be present in the architecture.

3.1 Entities

The IoT system architecture can be broadly divided into three parts:

- **Devices.** Devices in the IoT literature can refer to a wide variety of embedded objects (or embedded systems) called "Things" that transmit and receive information over network. It could be heart monitoring implants, biochip transponders on farm animals, electric clams in coastal waters, automobiles and homes with built-in sensors, or field operation devices that assist fire-fighters in search and rescue. These devices collect useful data with the help of various existing technologies and then autonomously flow the data between other devices. Current market examples include smart thermostat systems and washer/dryers that utilize Wi-Fi for remote monitoring.
- **Server side cloud architecture.** Industry analysts forecast the creation of billions of devices by 2020, and these devices would produce huge data. The companies would need infrastructure to manage and process this data. Most of the companies are expected to take third-party infrastructure through cloud to handle this 'big data'. Another vital feature of the backend server service will be to provide firmware upgrades remotely and securely to IoT devices.
- **Gateway.** Having a gateway in the overall architecture is not mandatory. It is not needed if the device allows to connect with the Internet. However if this functionality is not supported by

the devices, a gateway can sit between the device and the wider Internet or cloud. In addition, it can also perform aggregation, event processing, bridging etc. for multiple devices in the local ecosystem.

Thus the architecture can take any of the forms shown in Figure 2-1 and 2-2.

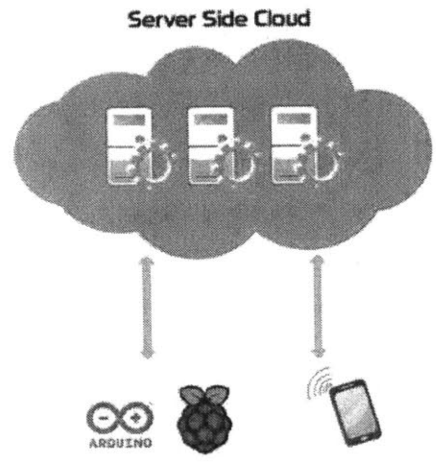

Figure 3-1: IoT Architecture Option #1

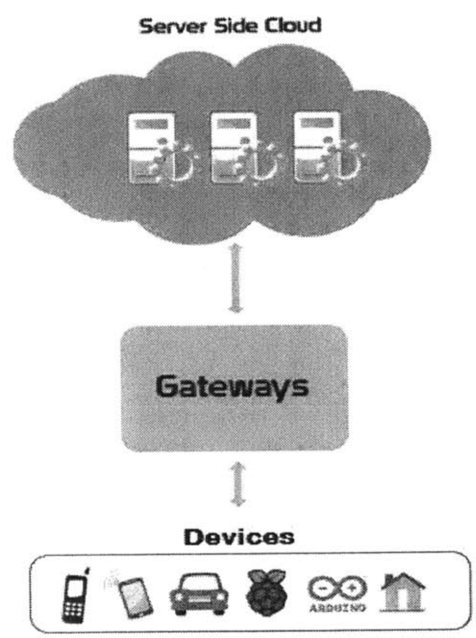

Figure 3-2: IoT Architecture Option #2

3.2 Interfaces

The interfaces between devices and cloud, or between devices and gateways can take several forms. The OSI sever layer reference model [36], shown in Figure 2-3, is used to represent these interfaces. Though the OSI model formally uses the names "Presentation" and "Session" for Layer 6 and Layer 5 respectively, the thesis considers the layers 5, 6 and 7 as Application layers for simplicity.

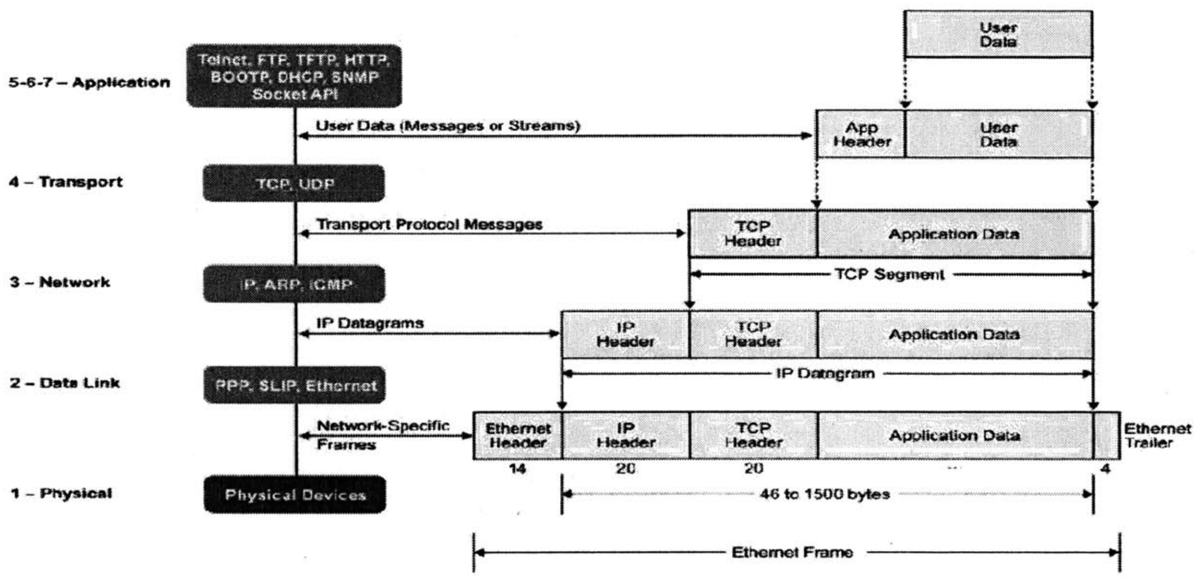

Figure 3-3: OSI Reference Model

Lower layers

At physical and data link layers, the most common interface protocols used for connecting entities are:

- Ethernet (10, 100, 1G, 10G)
- WiFi (IEEE 802.11b, g, n)
- Bluetooth low energy (BLE)
- Near Field Communication (NFC)
- ZigBee or 6LoWPAN (IEEE 802.15.4)
- SPI or I2C wired bus
- Serial with PPP (point-to-point protocol)

- GSM, 3G, LTE, 4G

Higher layers

At the Network Layer, the IP addresses are assigned to IoT devices. Above the Network Layer at Transport Layer, there are two options for IoT devices – either use TCP or UDP, the two transport protocols. TCP is used for most of our human interactions with the Web (e-mail, Web browsing, and so on). And so many people believe that TCP should be the only protocol used at the Transport layer. It is true that TCP provides the concept of a logical connection, acknowledgement of transmitted packets, retransmission of lost packets, and flow control. However, for an IoT embedded system, TCP can overkill due to over consumption of bandwidth. This is why UDP, even if it has long been relegated to network services such as DNS and DHCP, is now finding a new home in sensor acquisition and remote control. UDP is also better suited for real-time data applications such as voice and video. The reason is that TCP's packet acknowledgment and retransmission features are useless overhead for those applications. If a piece of data (such as a bit of spoken audio) does not arrive at its destination in time, there is no point in retransmitting the packet. It would arrive out of sequence and garble the message.

The Application Layer is the OSI layer closest to the end user, which means both the OSI application layer and the user interact directly with the software application. This layer interacts with software applications that implement a communicating component. Such application programs typically fall outside the scope of the OSI model. HTTP(S) and WebSockets are the common existing standards at the application layer that can be used to deliver XML or JavaScript Object Notation (JSON) in the payload. JSON provides an abstraction layer for Web developers to create a stateful Web application with a persistent connection to a Web server. Major application layer protocol options for IoT are discussed below:

- **HTTP.** It is the foundation of the client-server model used for the Web. A secure method to implement HTTP for IoT system is to include only a client in the device, not a server. In other words, it is safer to build an IoT device that can only initiate connections, not receive. This will ensure that no one outside the local network can have access to the IoT device.

RESTful HTTP over TCP is particularly attractive for connecting consumer premise devices, given the near universal availability of HTTP stacks for various platforms. The RESTful HTTP approach has found success in smaller scale LLNs requiring message latencies of several seconds (home energy management, etc.).

- **WebSocket.** It is a protocol that provides full-duplex communication over a single TCP connection between client and server. It is part of the HTML 5 specification. The WebSocket standard simplifies much of the complexity around bi-directional Web communication and connection management.

- **XMPP** (Extensible Messaging and Presence Protocol)**.** It is a good example of an existing web technology finding new use in the IoT space. XMPP has its roots in instant messaging and presence information. It has expanded into signaling for VoIP, collaboration, lightweight middleware, content syndication, and generalized routing of XML data. It is a contender for mass scale management of consumer white goods such as washers, dryers, refrigerators, and so on.

  Since it assumes a persistent TCP connection and lacks an efficient binary encoding, it's typically not been practical over LLNs (Low-power and Lossy Networks). But the recent work of XEP-0322, XEP-323, and XEP-324 aim to make XMPP suited for IoT.

- **CoAP** (Constrained Application Protocol)**.** Although Web protocols are available and usable for IoT devices, they are too heavy for the majority of IoT applications. The CoAP was designed by the IETF for use with IoT system which are usually low-power and constrained networks. CoAP is a RESTful protocol. It is semantically aligned with HTTP, and even has a one-to-one mapping to and from HTTP.

  CoAP is a good choice of protocol for devices operating on battery or energy harvesting. It uses UDP and exchange request and response message asynchronously. All the headers, methods and status codes are binary encoded, which reduces the protocol overhead. Unlike HTTP, the ability to cache CoAP responses does not depend on the request method, but the Response Code. CoAP fully addresses the need for an extremely lightweight protocol and the ability for a permanent connection and it is easy to learn for professional with a Web background.

- **MQTT** (MQ Telemetry Transport)**.** It is an open source protocol for constrained devices and low-bandwidth, high-latency networks. It is a publish-subscribe based messaging protocol that is extremely lightweight and ideal for connecting small devices to constrained networks.

MQTT is bandwidth efficient, data agnostic, and has continuous session awareness. It helps minimize the resource requirements for IoT system, while also attempting to ensure reliability and some degree of assurance of delivery with grades of service. It targets large networks of small devices that need to be monitored or controlled from a back-end server on the Internet. It is not designed for device-to-device transfer. It is also not designed to "multicast" data to many receivers. MQTT is extremely simple, offering few control options.

Following table summarizes the IoT application layer protocol landscape for interfaces.

Protocol	CoAP	XMPP	RESTful HTTP	MQTT
Transport	UDP	TCP	TCP	TCP
Messaging	Request/Response	Publish/Subscribe Request/Response	Request/Response	Publish/Subscribe Request/Response
2G, 3G, 4G Suitability (1000s nodes)	Excellent	Excellent	Excellent	Excellent
LLN Suitability (1000s nodes)	Excellent	Fair	Fair	Fair
Compute Resources	10Ks RAM/Flash	10Ks RAM/Flash	10Ks RAM/Flash	10Ks RAM/Flash
Success Storied	Utility Field Area Networks	Remote management of consumer white goods	Smart Energy Profile 2 (premise energy management/home services)	Extending enterprise messaging into IoT applications

Table 3-1: IoT application layer protocol interface for interfaces (Paul Duffy, Cisco view on IoT protocols, 2013)

3.3 Functions and Processes

The IoT architecture is expected to fulfill following key requirements in terms of functions:

i. **Device Management.**

While many IoT devices are not actively managed, this is not necessarily ideal. We have seen active management of PCs, mobile phones and other devices become increasingly important, and the same trajectory is both likely and desirable for IoT devices.

The following list covers some widely desirable requirements:

- The ability to disconnect a rogue or stolen device
- The ability to update the software on a device
- Updating security credentials

- Remotely enabling or disabling certain hardware capabilities
- Locating a lost device
- Wiping secure data from a stolen device
- Remotely re-configuring Wi-Fi, GPRS or network parameters

ii. **Connectivity and communications.**

The architecture need to support interfaces for connectivity and communications. Existing protocol such as HTTP have a very important place for many devices. Even an 8-bit controller can create simple GET and POST requests, and HTTP provides an important unified and uniform connectivity. However, the overhead of HTTP and other traditional Internet protocols can be an issue for two reasons. Firstly, the memory size of the program can be issue on small devices. Secondly, the power requirements can go over the budget. In order to meet these requirements, a simple, small and binary protocol is needed.

In addition, there is a requirement for the architecture to support transport and protocol bridging. For example, a device can use binary protocol for interfacing, and might need a bridge to allow an HTTP-based API when exposed to third-party network.

iii. **Data collection and analytics.**

A few IoT devices have some form of UI, but in general IoT devices are focused on offering one or more sensors, one or more actuators, or a combination of both. The requirements of the systems are that we collect data from very large number of devices, store, analyze it and then acted upon it. So there is a requirement for a highly scalable storage system that can handle diverse data and high volumes. In addition, either the device, gateway or server also needs to be able to analyze and act on data.

iv. **Scalability.**

Any server-side architecture would ideally be scalable and be able to support millions of devices all constantly sending, receiving and acting on data. However, many scalable architectures come with high price. Elastic scalability and ability to deploy in a cloud like Amazon EC2 are essential.

v. **Security.**

Two very important specific issues for IoT security are the concerns about identity and access management. These issues are different from a typical Internet system due to the involvement of M2M communication. They can be handled by: (a) replacing the use of user ids and passwords with managed tokens such as OAuth/OAuth2 [38], (b) supporting powerful encryption of devices, (c) policy based and user-managed access control based on XACML [39].

On the basis of the above mentioned functions, a layered IoT architecture can be shown as given below in Figure 2-4. The relationship between the functional architecture (Figure 2-4) and the formal architecture (based on forms, Figure 2-1 and Figure 2-2) is not straight forward. All functions, except device management and event processing & analytics, are typically unrelated to server-side cloud and mapped to devices and/or gateway. On the other hand, event processing and analytics can be mapped to devices and gateway along with server-side cloud, as needed by the application.

It is worth considering that device management is handled always by all of the entities involved - devices, gateway and server-side cloud. The server-side system communicates with the devices through gateway which implements the bus layer and takes care of aggregation, brokering and protocol mapping.

It is to be noted that the communications layer is used for connectivity between devices as well as between devices and gateway. It is not used for communication over cloud and Internet. The top layer called External Communications Layer is the one which is used for communication between devices and Internet/cloud.

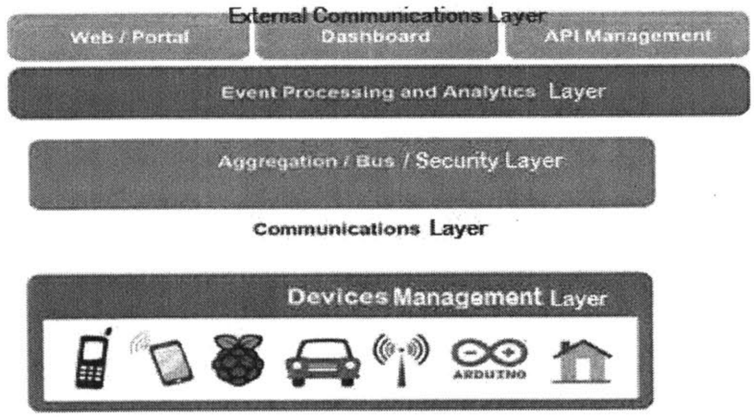

Figure 3-4: IoT Functional Architecture

Each of these layers are explained below:

Device Management Layer. Devices can be of various types. In order to be treated as IoT devices, they must be able to communicate over Internet directly or indirectly through gateway. In addition, each device needs to have an identity. This can be done in one or several ways:

a) A unique identifier (UUID) burnt into the device as a system-on-chip

b) A UUID provided by a radio subsystem such as WiFi MAC address or Bluetooth identifier

c) An OAuth2 Refresh/Bearer token

d) An identifier stored in non-volatile memory such as EEPROM

It is recommended that every device has a UUID provided by hardware as well as an OAuth Refresh/Bearer token stored in EEPROM. The aim of the OAuth2 token is to provide a secured identity token separate from the core immutable identity of each device. The Bearer token is used initially and passed to any server or service that needs identification. It has a shorter lifetime than then Refresh token. If the Bearer token has expired, the Refresh token is passed over to the Identity layer and this creates an updated Bearer token.

Communications Layer. The communications layer supports the connectivity of the devices. There are multiple potential protocols: HTTP, MQTT and CoAP. On the basis of specific needs of the applications, one can select the best possible option (Table 3-1).

One important aspect with IoT devices is that it is not the devices which can send the data over the cloud; the reverse is also possible. MQTT has an advantage in such scenario. Since it uses a brokered model, clients can make an outbound connection to the broker, whether device is acting as publisher or subscriber.

Aggregation/Bus Layer. This layer aggregates and brokers communication between server-side cloud and devices. This might require supporting HTTP server and/or MQTT broker, aggregating communication from different devices, routing communications to a specific device and bridging between different protocols.
It also handles the security aspect of the IoT by acting as an OAuth2 server and a Policy Enforcement Point for policy-based access.

Event processing and Analytics. This layer takes the events from the bus layer and provides the ability to process and act upon those events. A core capability here is the requirement to store the data into the database. The traditional model would be to write a server-side application. An agile approach would be to use a cloud-scalable big-data analytics platform that supports technologies such as Apache Hadoop to provide map-reduce analytics on data coming from devices.

External Communications Layer. This layer allows devices to communicate outside the device-oriented system. This requires three sub-functionalities: a) an ability to create web-based UI and portals that interact with devices and event processing layer, b) ability to create web-based UI and portals that offers view into analytics and event processing, and c) M2M APIs to connect with systems outside the device system.

4 IoT Market Segments

4.1 IoT technologies

According to ITU 2005, various IoT technologies can be conventionally categorized into:

- **Tagging technologies.** They provide seamless and cost-efficient item identification, allowing the things to be connected with their records in databases.
- **Sensing technologies.** They enable measuring and detecting changes in the physical status of the environment.
- **Embedded technologies.** They 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) [9]. The MTC technologies include all mobile and wireless technologies such as LTE, WiFi, Bluetooth, Zigbee and various cellular standards including 3G/4G/5G, etc.

4.2 IoT market segments, their size and growth

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, as explained below.

<u>Number of connected things:</u>

The number of connected devices is expected to grow from 9 billion in 2011 to 24 billion in 2020. As shown in Figure 4-1, 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.

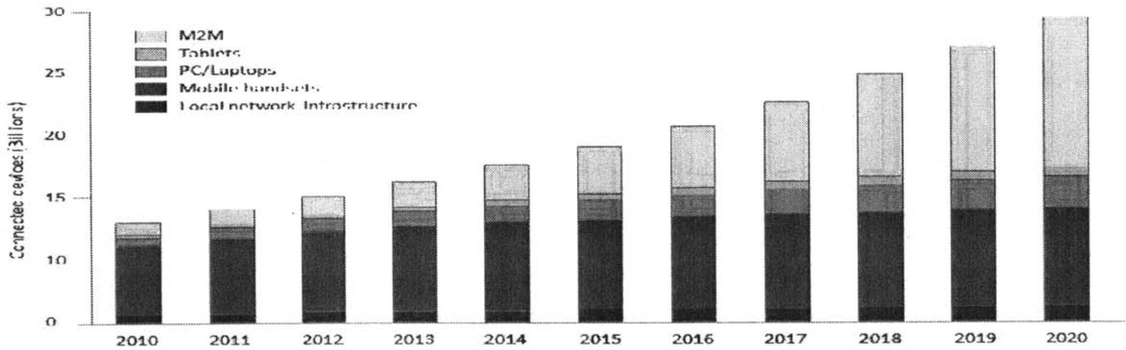

Figure 4-1: Expected growth in the number of connected devices (GSMA 2011)

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).

Expected revenues:

The total revenue generated by connected devices will also grow significantly; according to 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, forecasted to 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 4-2 portrays the expected revenue growth in different M2M vertical sectors during 2011-15. 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.

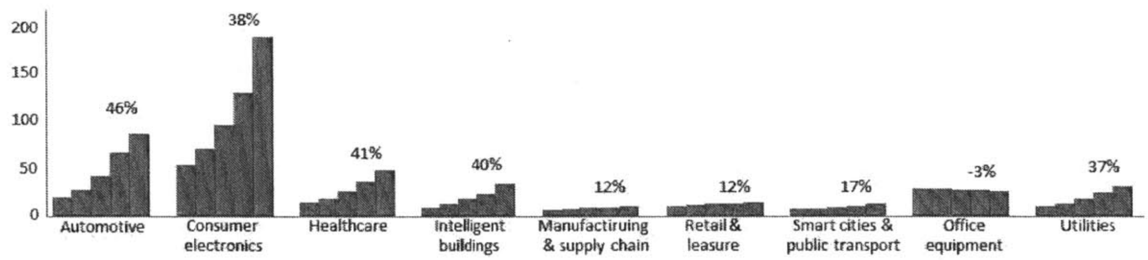

Figure 4-2: M2M global revenue forecast 2011-2015 in USD billions and CAGR (Machina, M2M Global Forecast & Analysis 2010-20, October 2011)

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".

Growth rates:

One way to forecast growth of IoT is to identify the number of tags (RFID) and other connected devices available, shipped or sold and associated revenues. As shown in Table 4-1, 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.

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 4-1: Number of "things" available, in billions (O Mazhelis, IoT SOTA Report 2013)

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 (Wireless Personal Area Network) devices, such as the ones based on Bluetooth, NFC, WiFi, etc., will probably grow fastest, as shown in Table 4-2.

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

Table 4-2: Number of connected devices shipped or sold, in billions, by type of communications and vertical segments (O Mazhelis, IoT SOTA Report 2013)

However, as shown in Table 4-3, 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 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).

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

Table 4-3: Revenue from tags and connected devices by vertical segment (O Mazhelis, IoT SOTA Report 2013)

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, greatest revenues are expected for the vertical value-added applications, followed by 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%).

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) and residential security
- **Healthcare**: monitoring solutions to support wellness, prevention, diagnostics or treatment services

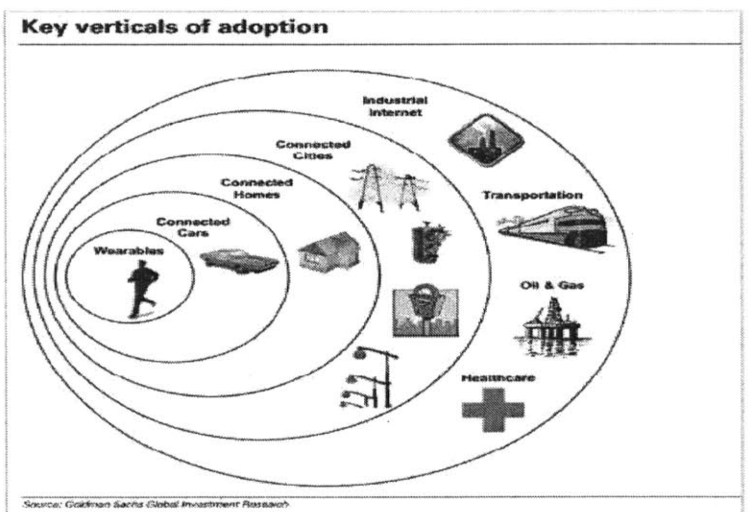

Figure 4-3: IoT Key vertical areas of adoption (Source: Goldman Sachs)

These results are in line with the research done by Goldman Sachs. According to Goldman Sachs Investment Research, IoT can be broken up into five key verticals of adoption: Connected Wearable Devices, Connected Cars, Connected Homes, Connected Cities and the Industrial Internet (Figure 4-2).

4.3 Consumer Insights

In order to confirm the finding of section 4.2 that automotive/transportation, digital home and healthcare are the three segments with the greatest market potential in the Internet of Things context, the consumer behavior is tracked.

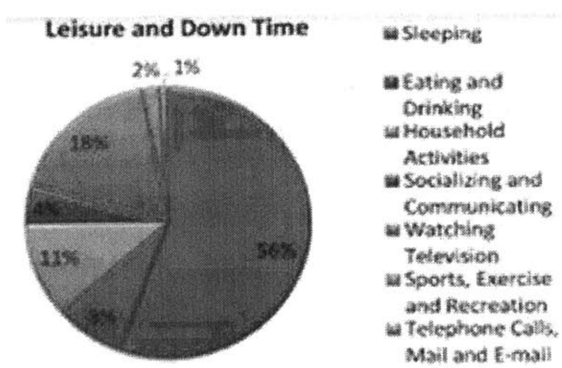

Figure 4-4: Leisure activities of an American (Source: ATUS)

First, research is done to find out how an average person spends his day and which activities most of his time. According to American Time Use Survey (ATUS), commuting (and working) as well as leisure are the two activities, besides sleeping, that consume most of the day time of an average American (Figure 4-5). In addition, watching television and household activities are the two activities that consume most of the time an average American spends in leisure (Figure 4-4).

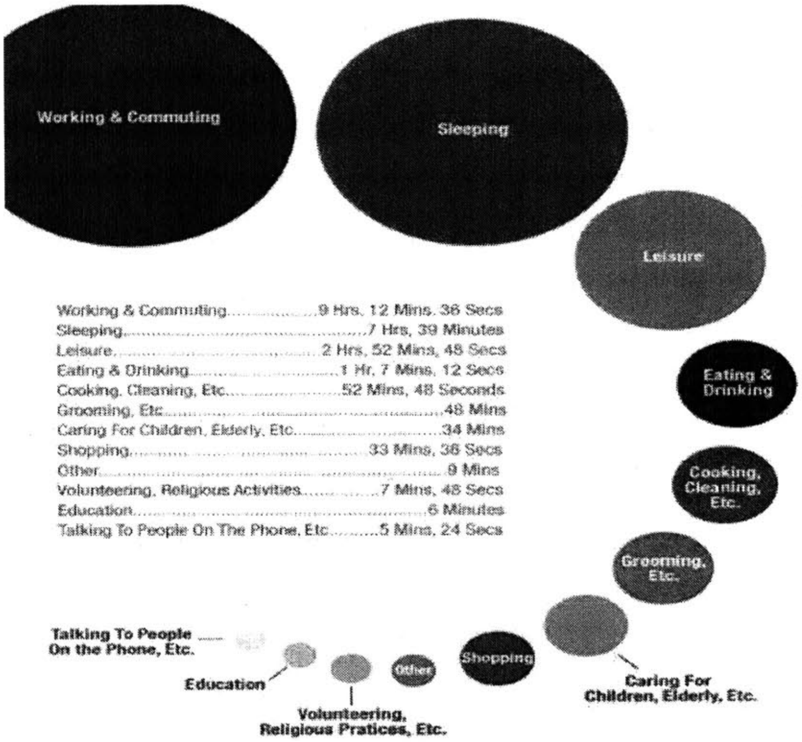

Figure 4-5: Average workday of an American (Source: ATUS)

Second, data is gathered to find out which activities consume most of the spending. According to New York Times, transportation and healthcare consume a considerable part of overall spending of an average American.

Thus, data from consumer confirms the findings from section 4.2. Automotive/transportation, digital home and healthcare are the three segments which are expected to bear the greatest potential within the Internet of Things market.

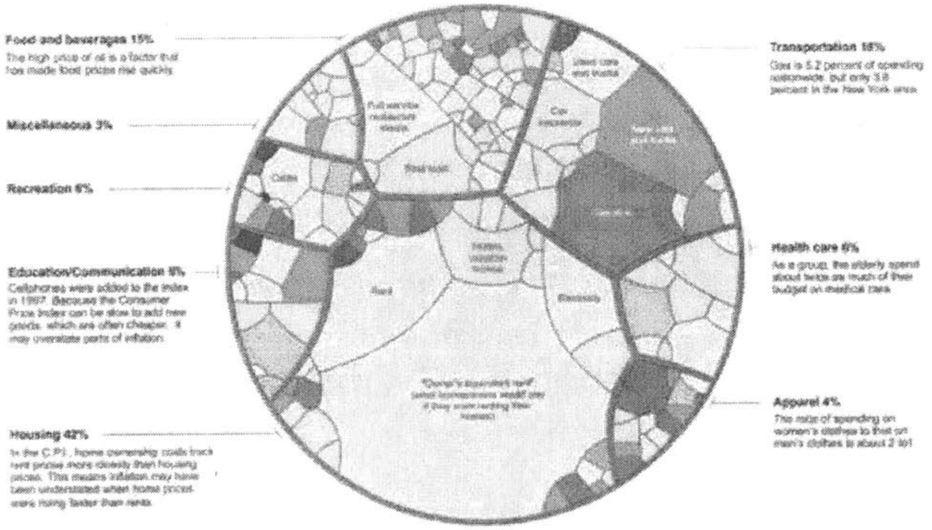

Figure 4-6: Average workday of an American (Source: NYTimes)

4.4 IoT market evolution

Gartner, in its Hype Cycle Report, July 2014, moves the Internet of Things to the top of the hype cycle (Figure 4-7). In 2012 and 2013, Gartner predicted that the Internet of Things had more than 10 years to reach the "plateau of productivity", but this year it has advanced the predicted time and confirmed that it will take five to ten years to reach this final stage of maturity.

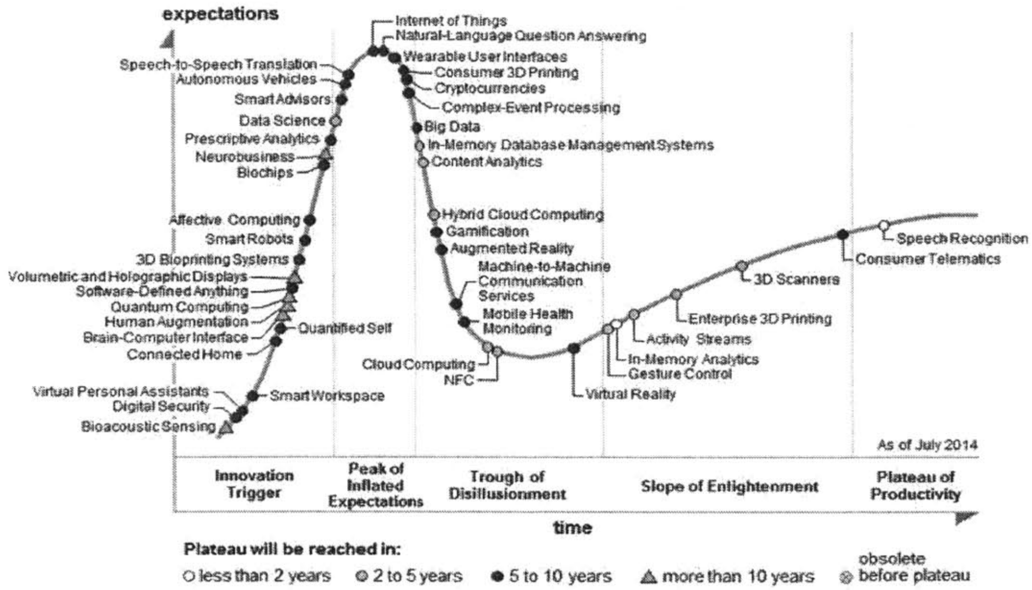

Figure 4-7: Gartner Hype Cycle 2014 (Gartner, July 2014)

Gigaom's recent report on Internet of Things reports that the IoT market will evolve in an incremental fashion [3]. To explain this, the things are divided into different levels, from passive to active to autonomous things. As innovation proceeds from one level to another, the internet of things market move from where it is currently, involving higher volumes of largely passive things, to a market that incorporates large volumes of autonomous things in four to five years' time.

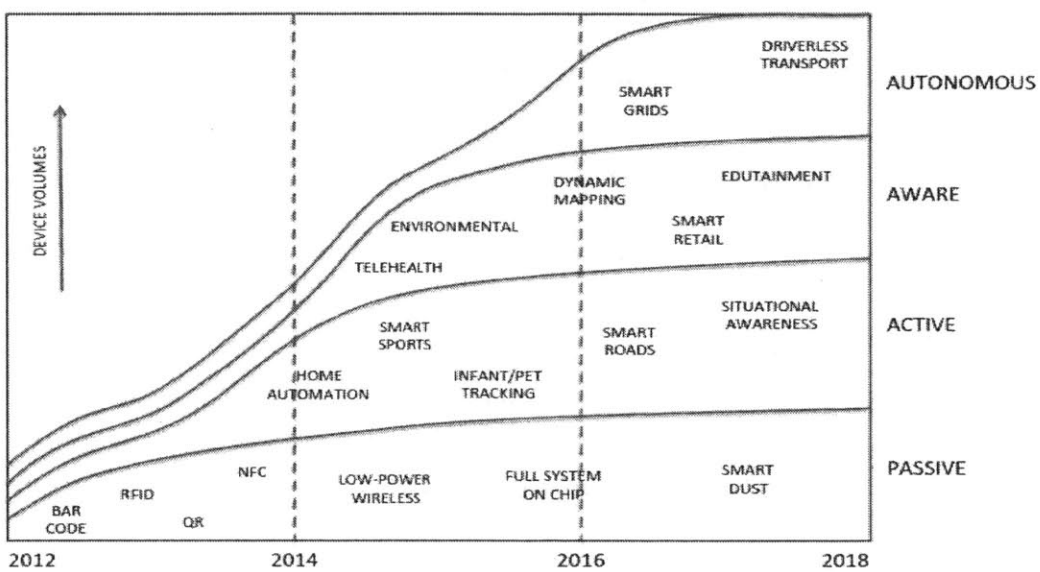

Figure 4-8: IoT Market Evolution (Gigaom Pro Report, 2013)

As seen in Figure 4-8, volumes shipped are incremental because market development of aware things will not reduce the volumes of active things shipped. All things are not expected to achieve autonomous status. For many requirements, it simply isn't necessary to do so. However, over time an increasing level of smartness will be seen across the board.

According to a May 2013 report from research firm, MarketsandMarkets, the internet of things and M2M communications market will reach $290 billion by 2017, growing at 30 percent per year. Given the incremental nature of the market, it is suggested that:

- **Shorter-term opportunities** (1–3 year time frame) will come from active and aware things. This means more focus on the things themselves: Look for the things equivalent of the killer app, with less emphasis on backend or cloud-based management and analytics.
- **Medium-term opportunities** (2–5 year time frame) will come from aware and autonomous things. This implies more focus on infrastructure and platforms that can pull together the management of things and the data they create.

5 Domain specific applications and their requirements

Finding a match between market and technologies used in the product is necessary for a product to be accepted in the market. According to Mendyk and Kridel [14], and OECD [15], market drives the application requirements, which in turn drives the technologies. In business literature, this is very similar to the *market pull* concept, in which market drives technology. There is another concept known as *technology push.* In this concept, a firm begins with a new technology and then looks for an appropriate market to apply it. The technology push is not yet seen in the Internet of Things domain.

5.1 Challenges with IoT

Finding a perfect match between market requirements and technologies is tricky for IoT. On one side, it involves a number of technologies. On other side, it brings together machines and humans that are fundamentally different in terms of their needs.

A research report from *Heavy Reading Mobile Networks Insider* 2010 [14] mentions that humans and machines are fundamentally different in terms of their wireless needs, and understanding these differences is an important first step toward success in the new, broader M2M market. For example, consumers and business users have been rapidly upgrading to 3G and WiMax in order to use bandwidth-intensive applications, while most M2M services – even video surveillance – work just fine on 2.5G. While humans typically replace their handset every 18 to 24 months, M2M applications frequently use the same module for five to 20 years. For example, 10 years is common in residential security, while automotive, trucking, and utilities modules often remain installed for 15 years.

Longevity also affects technology choices. For example, some M2M users are concerned that carriers will start phasing out their 2G and 2.5G networks over the next few years to focus on 3G and 4G. This fear has a precedent: Several years ago, the two largest US carriers shut off their analog and cellular digital packet data (CDPD) services, and Telstra Corporation closed its CDMA network in 2008 to focus on UMTS/HSPA. Today, a growing number of M2M users and their suppliers are considering upgrading to 3G technology simply because those networks are likely to remain in operation for at least another 10 to 15 years.

The different needs also show up in the sums that M2M users are willing to pay for hardware and connectivity. 2G and 2.5G technologies are widely used partly because they have had 10 to 20 years to ride down the cost curve, making them more attractive for price-sensitive M2M applications than 3G and WiMax. But WiFi and some private radio technologies have an even greater cost advantage, which is why they remain major players in M2M.

WiMax is emerging as a major force in M2M, for a couple of reasons. First, its newcomer status allays fears of 2G and 2.5G phaseouts, at least among M2M companies that are not equally concerned that many WiMax operators and vendors will defect to LTE. Second, WiMax is a good fit for bandwidth-intensive applications, such as two-way digital signage and in-vehicle infotainment.

One big drawback is that WiMax's geographic coverage will remain spotty compared to 2G, 2.5G, and 3G for at least another two years. So for applications where the device is portable or mobile, WiMax requires a fallback technology – usually 3G – which drives up the cost of the module and service. But for applications that do not need a fallback, WiMax is attractive because it is surprisingly cheap from a module perspective. At the end of 2009, single-mode WiMax chipsets – that is, with no other wireless technology as a fallback – cost about $20 in volume. Some chipset vendors expect prices to drop to $12-$14 by the end of 2010. Add in the rest of the hardware required to create a module, and WiMax costs about $35-$40 in volume. By comparison, a GSM/GPRS module goes for about $25, while CDMA 1X runs $50-$55. HSPA costs about $85.

Some in the industry might be surprised by the competitive price of WiMax modules, if only because the technology is relatively new and thus has not had a decade or more to build volumes. One reason the price is already so low and falling is that WiMax does not have the burden of royalty payments to companies that have patented certain aspects. For some rival technologies, that royalty can be 5 percent.

The catch is that no one is sure how long WiMax will enjoy this advantage. Many companies have intellectual property (IP) for WiMax but have not yet pursued royalties, perhaps because the market isn't big enough yet to translate into a lot of money. "I wouldn't be surprised if at some point, those companies say: 'I've got a lot of IP in them. I should be compensated,'" one WiMax chipset vendor says privately. That's something everyone from investors to M2M end users should keep in mind when assessing WiMax.

The upshot is that as the M2M market expands, so does the number of technologies and companies competing for a piece of the action. But one thing hasn't changed: The choice often comes down to price.

5.2 Performance dimensions and tradeoffs

An ideal communication technology to enables connectivity in M2M and IoT would allow instantaneous secure access to the Internet anywhere in the world at any speed. It would work equally well indoors as outdoors, it would have unlimited range, zero latency and unlimited throughput, while costing virtually nothing and consuming no energy. It would provide access and management to data necessary to use M2M efficiently while ensuring the protection of privacy. Unfortunately this is not the case and therefore all technological choices are tradeoffs. It is these trade-offs that can make the choice of a networking technology challenging. For smart meters, for example, the industry has looked at wireless personal area networks, wireless mesh technologies, piggy backing existing networks, CDMA450, GSM/GPRS and powerline communication.
Some general performance parameters are:

- **Expected lifetime**: Every device, depending on the application it is supporting, can have a different expected lifetime. For example, a M2M device can have a 20 year or longer lifetime, whereas a consumer mobile phone device usually has a lifetime of 2 years.
- **User interaction**: The user should be able to configure and operate the device without any hurdle. Ideally, technology should start working as soon as the devices are switched on.
- **Network characteristics**: Application requirements usually drive the network characteristics. Star, mesh, tree, peer-to-peer are different topologies, each with its own advantages and

drawbacks in terms of delays, robustness, durability, reliability, availability, usability, throughput, range, etc.

- **Ease of roll-out and maintenance**. The easier it is to roll out and maintain a technology, the better it is.
- **Types of applications supported**: Most technologies are designed with a specific set of use cases in mind. M2M, however, scales from short messages sent once a month to complex interactions supported by voice and video.
- **Range and penetration**: The more range and better penetration of walls, windows and foliage, the easier it is to deploy a technology in a wider area. However, range is inversely correlated with power consumption and throughput.
- **Power consumption**: The lower the power consumption the better for battery-operated devices. But lower power use often results in lower throughput and range.
- **Speed/Throughput**: The higher the throughput the better it is, however this is often inversely related to battery life and area covered.
- **Number of devices supported**: The more devices that are in a particular area the more they need to share resources, which affects performance.
- **Open or closed**: Whether the data is available only to the owner of the device or if others need to be able to interact with it.
- **Local and global use**: Some technologies can only be used in some countries, because of regulations or technical issues.
- **Mobility**: It should work at any speed or any location/environment in the world.
- **Failover or recovery capabilities**: If a network fails, users will want a backup or recovery solution.
- **Multi-protocol support**: the support of multiple networks would allow to choose the network that best fits the situation.

The application directly or indirectly drives the above performance dimensions (Figure 5-1).

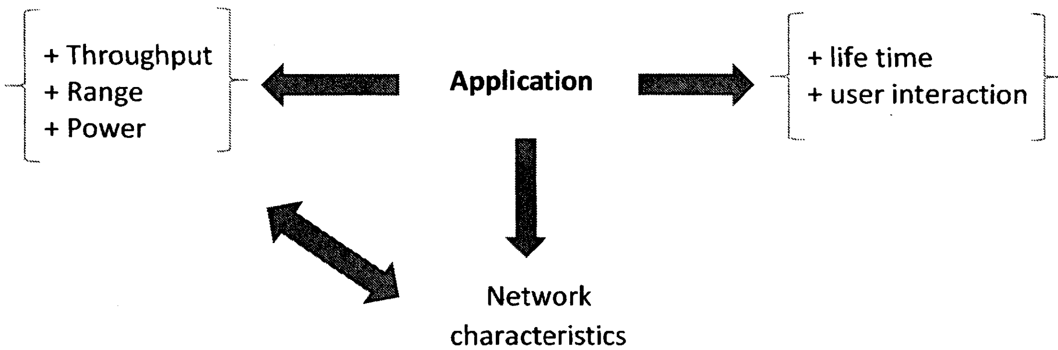

Figure 5-1: Application Requirements

5.3 IoT Application scenarios, trends and requirements

It is clearly evident from section 4.2 that automotive, consumer electronics and healthcare are expected to bear the greatest potential within IoT market. The main applications within these domains are listed below.

1. **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
2. **Digital/Connected home**: Consumer electronics, home automation, utilities/automated meter reading (AMR), and residential security
3. **Healthcare solutions**: Monitoring solutions to support wellness, prevention, diagnostics, or treatment services

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. The key dimensions are:

- 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

These dimensions will be used for considering the specific needs and requirements of transportation, healthcare, and connected home application domains. Further dimensions to consider would include failover capabilities, the control over the technology and customer interfaces and their costs, proven track of successes at large scale, and the availability of vendor solutions and suppliers in the market. However, for the sake of simplicity, these dimensions are excluded from the analysis.

5.3.1 Transportation

It is predicted that by 2025, all vehicles will be equipped with either embedded or tethered connectivity (GSMA) [20]. This connectivity will enable a number of applications and services to be provisioned to the drivers, including telematics and navigation services (Figure 5-2).

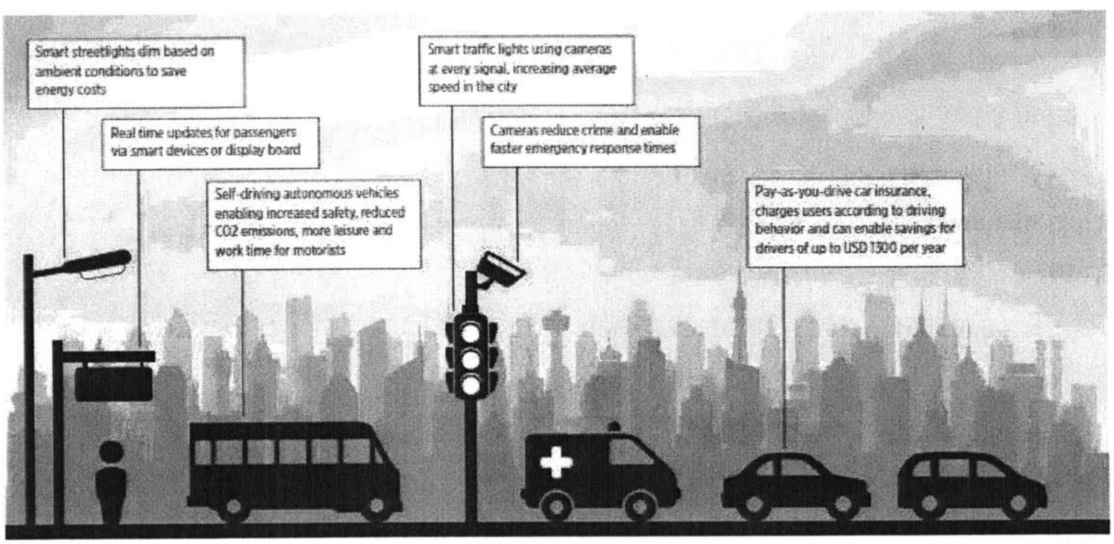

Figure 5-2: IoT Transportation Applications (Source: McKinsey, GSMA)

Some examples of telematics and infotainment services are given below [19, 20, 21, 23].

TELEMATICS	INFOTAINMENT
Navigation services	High bandwidth services
• Navigation (point of interest, parking, fuel prices, weather) • Traffic/journey times • Travel and traffic assistance / off-board route assistance • Location-based services	• On-demand and real-time content – Radio, music, news, video • Augmented reality point of interest • Cloud computing based in-vehicle services
Vehicle-centric services	Low bandwidth services
• Remote control of vehicle environment and car features • Remote diagnostics • Breakdown services (bCall) • Safety general eCall • Eco driving • Electrical vehicle use case: battery charge monitoring and control	• Email • Stocks • Apps store • Internet services • Social networking • Multimedia
Miscellaneous services	
• Insurance pay-as-you-drive • Stolen vehicle tracking • Fleet management • Tolling • Payment and parking	

Table 5-1: Connected cars: Telematics and Infotainment services (GSMA, 2012)

The value propositions and business models for transportation and connected car need to take into account following important dimensions:

- ***Connectivity and service level***. Connectivity decisions are an important factor in connected car services. The connectivity solution alternatives for in-vehicle services include:

a. *Embedded solution*: Both modem and smartcard/sim (Universal Integrated Chip Card, UICC) and the intelligence is built directly into the vehicle.

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.

b. *Tethered solution*: The intelligence remains embedded in the vehicle while the connectivity is provided through either an embedded modem with a customer's SIM or external Modem using the customer's mobile device via a USB cable, Bluetooth profiles or WiFi USB key tethering.

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). In addition, it 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.

c. *Integrated solution*: Connectivity is based upon integration between the vehicle and the owner's handset, in which all communication modules, the UICC and the intelligence remain on the handset. However, the human machine interface (HMI) generally remains in the vehicle.

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.

Infotainment services can be offered by all connectivity options. Tethering and smartphone integration have the advantage of providing lower-cost solutions with frequent technology upgrades (as handsets are replaced). These solutions are considered particularly important as different regions roll out the widespread mobile broadband coverage needed for high bandwidth infotainment services. Embedded solutions provide a seamless user experience, but involve a higher hardware cost and support for split service-based/end user charging to provide automakers with flexible charging options for these elastic demand services.

Navigation services are easily provided by all connectivity options. Telematics (vehicle-centric services) are ideally provided by embedded solutions, but some can also be provided reasonably through tethering or smartphone integration. However, some services, such as stolen vehicle tracking, insurance, fleet management, tolling or eCall, do not lend themselves readily to tethering or smartphone integration.

According to the study by GSMA [23], 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:

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

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

a. *Higher bandwidth* (often exceeding 1 Mbps)

b. *Low latency*
c. *High reliability* or *privacy*
d. *Short coverage* of the connection

- ***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 [23]). Another implication of the specific requirements is the higher average price for the automotive communication modules, as compared with those in consumer electronics.

- ***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.

- ***Costs of components and communications.*** 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.

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 in Europe 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).

5.3.2 Connected 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" (GSMA).

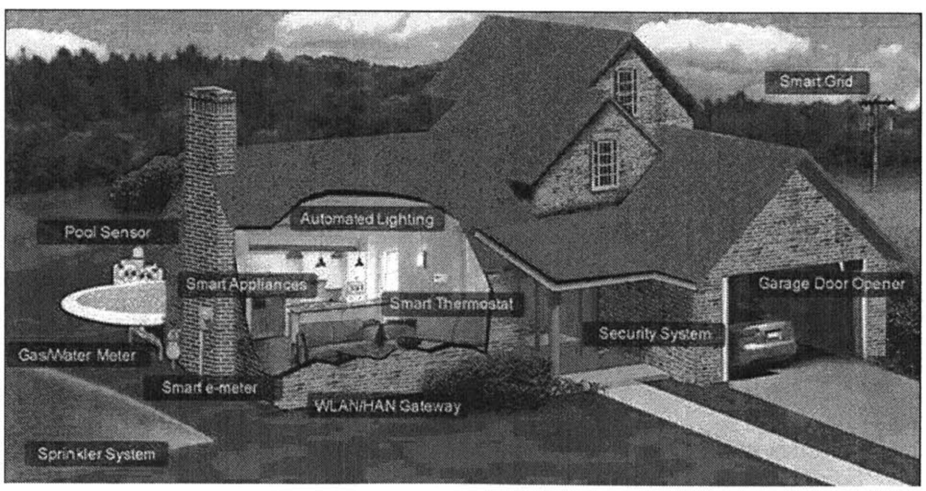

Figure 5-3: IoT Connected Home Applications (Source: McKinsey, GSMA)

Following are the major 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 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.

Consumer electronics products, such as cameras and camcorders, are getting connected over Wi-Fi. Home appliances such as refrigerators, washing machines, dishwashers are getting connected as well. 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, industry standards or using third-party client software.

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. 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.

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 by Motorola Mobility (now owned by Arris [27]), based on its 4Home platform, comes with a (free) application to control the connected home devices; however, the customers are charged for adding each new connected device, in addition to paying in service fees to Verizon.

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. Dealing with video streams, video surveillance may also have high (uplink) bandwidth demands; however, often the cameras use compression and stream only when a motion is detected, thus reducing the required bandwidth below 1Mbps. 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). 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. 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.

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. 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.

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
- Remote management support for remote operations, customer care procedures, managed services provisioning
- Remote performance monitoring and diagnostics, in response to a problem report by a customer

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.

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. 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.

5.3.3 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.

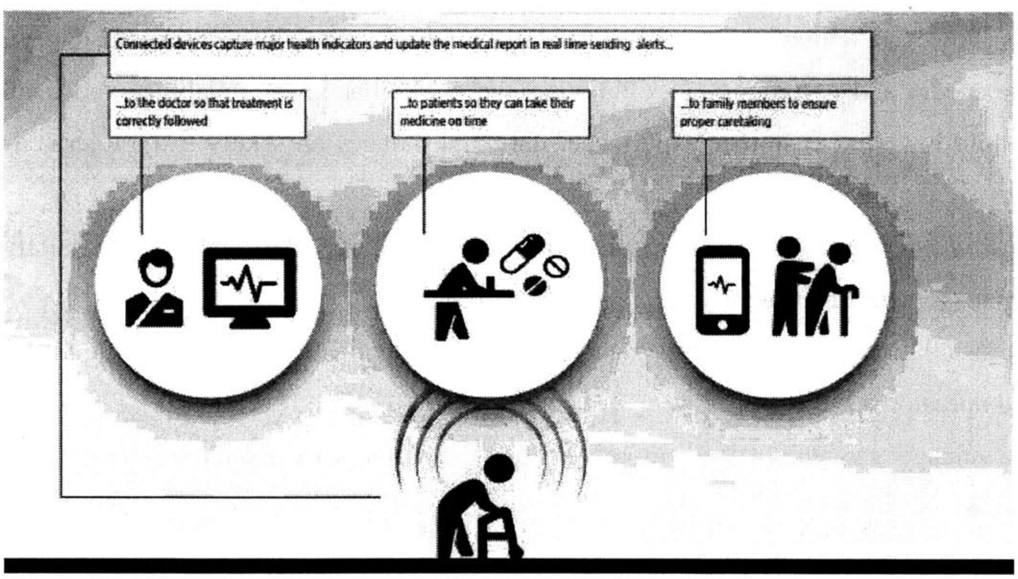

Figure 5-4: IoT Healthcare Applications (Source: McKinsey, GSMA)

Such (mobile) health services are categorized into patient pathway solutions (wellness, prevention, diagnostics, treatment, and monitoring) and healthcare strengthening services (Vishwanath et al. 2012 [26]). 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).

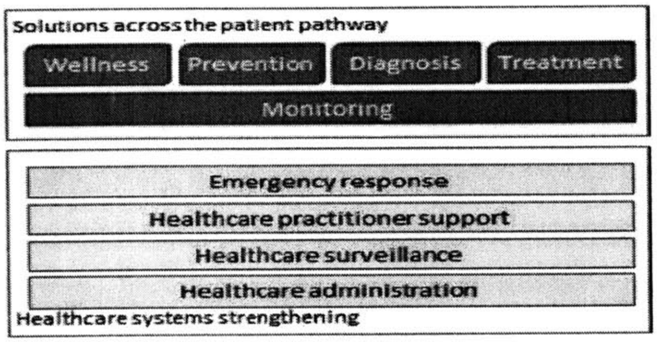

Figure 5-5: IoT Healthcare Applications

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" [26]. 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 5-2 summarizes the connectivity options of contemporary monitoring devices. A vast majority are connected (mainly over the Bluetooth) to a smart device or a dedicated gateway which will further relay the information.

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 %

Table 5-2: Connectivity in mobile health devices (Source: GSMA)

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 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.
- ***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.
- ***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, 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%. 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.

6 IoT Ecosystem

An ecosystem typically is a network of buyers, suppliers and makers of related products and services, including the socio-economic environment, the institutional and the regulatory framework. It is the primary mechanism for innovation, and determines success or failure of the business. It can be considered as a system in which companies co-evolve capabilities around a new innovation, they work co-operatively and competitively to support new products, satisfy customer needs, and eventually incorporate the next round of innovations [33].

Figure 6-1 shows the typical roles in telecommunications businesses and their relationships, as identified by the European ECOSYS project that aims at developing European sustained leadership in telecommunications [28]. Telecommunications is likely to play a major role in IoT and thus this model is applicable to IoT.

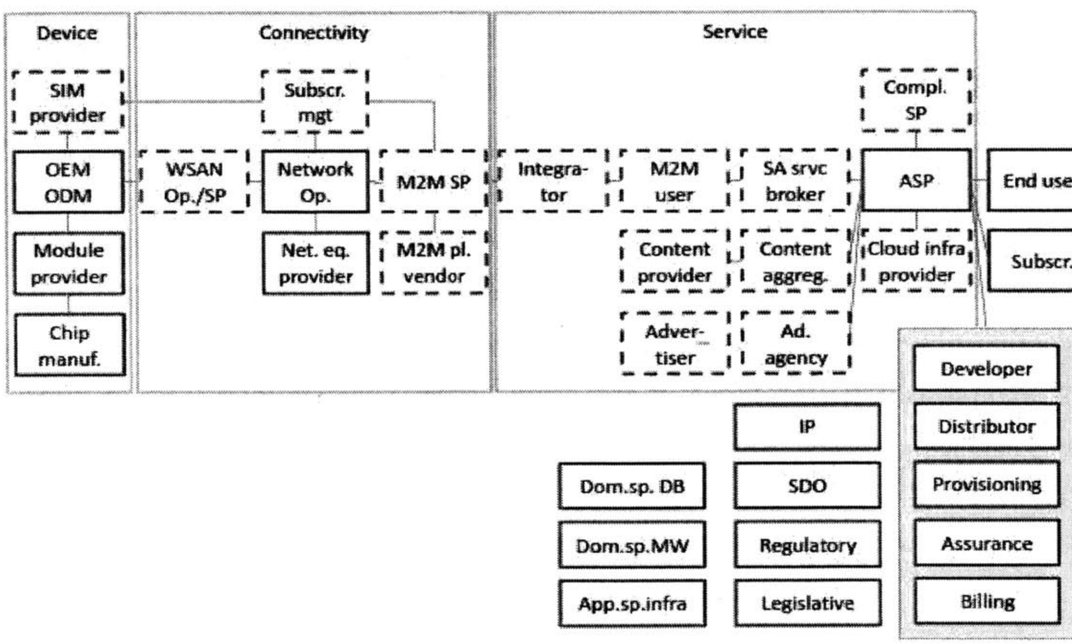

Figure 6-1: Telecommunication ecosystem

ABI Research soponsored by Cisco [29] suggests a mobile M2M value chain, shown in Figure 6-2. The research differrentiates different players- MNOs (Mobile Network Operators), MVNOs (Mobile Virtual Network Operators in M2M market), MMOs (Mobile Messaging Operators) and ASPs (Application Service Providers).

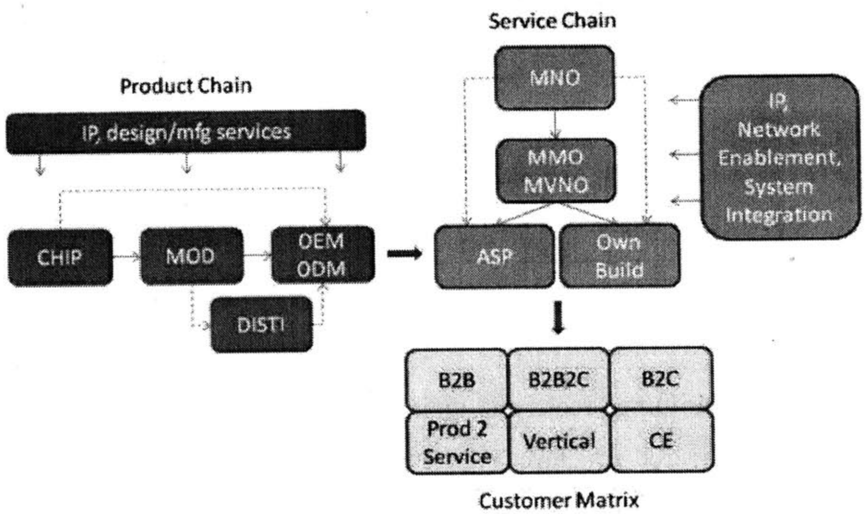

Figure 6-2: M2M value chain

This research suggests that new relationships are emerging between MNOs, MVNOs/MMOs and ASPs within the M2M market. MNOs are increasingly working directly with ASPs and companies have started developing their own M2M solutions, in addition to workign with MMOs and MVNOs.

Another research [31] suggests that business ecosystems are mirrored in technical systems and their architecture. This is apparent from the fact that today's products are rarely stand-alone items, rather they are components of broader systems or architectures. Harnessing the full potential of the technology and ecosystem necessarily involves cooperation amongst industry participants, many of whom might also be competitors [32]. This view of the ecosystem is really important, as it gives the holistic idea about the overll ecosystem and the players involved. In order to consider this view, it is imperative to take into the account the technical architectures developed in the Chapter 3 (Figure 6-3).

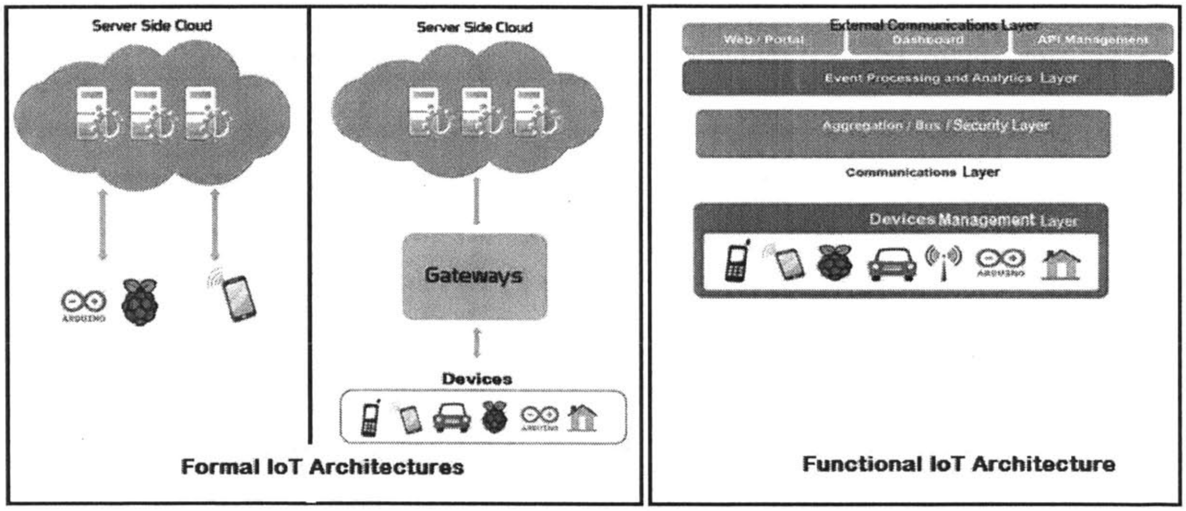

Figure 6-3: IoT Technical Architectures

On the basis of the IoT building blocks and their inherent capabilities, the overall IoT ecosystem can be summed up in a layered structure (Figure 6-4).

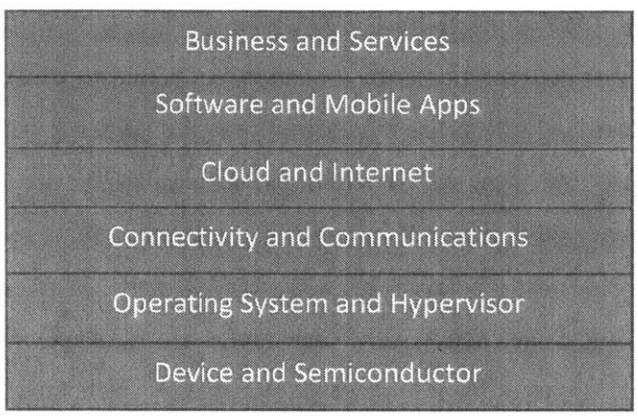

Figure 6-4: IoT Ecosystem – layered structure

The semiconductor and hardware industry responsible for designing and manufacturing the IoT devices make up the lowest layer. At the next layer, there will be companies developing the operating systems and hypervisors that help manage hardware, cloud and software for efficient operation of IoT. In order for devices to be able to communicate with each other, there is a need of connectivity and communication infrastructure that form the next layer. Cloud, software and services form the top layers of the ecosystem. Billions of IoT devices will generate humongous data that needs to be collected and processed. Most of the companies generating this data will lack the infrastrcuture needed to process such big data and thus will require cloud services. At the top layer, there will be companies developing software and apps specific to the needs of the market verticals.

6.1 IoT Ecosystem by FirstMark Capital

According to a report by FirstMark Capital [40], the IoT ecosystem can be divided broadly into three areas: building blocks, verticals and horizontals (Figure 6-5).

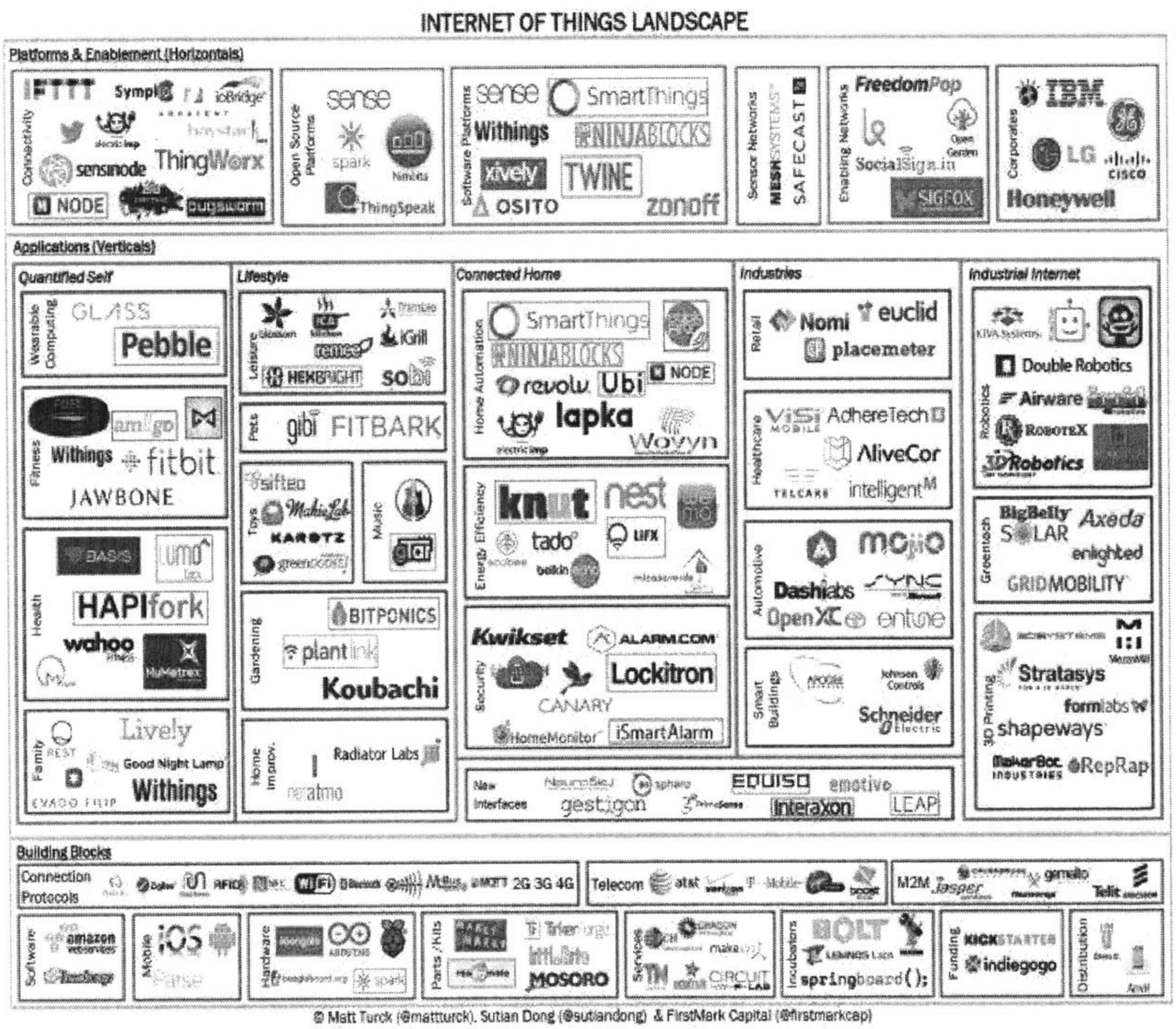

Figure 6-5: IoT Ecosystem (Source: FirstMark Capital)

Each of these areas of the IoT ecosystem are explained below.

6.1.1 Building Blocks

The concept of the Internet of Things is not new, but it is now in the process of becoming a reality thanks to the confluence of several key factors. First, while still challenging, it is easier and cheaper than ever to produce hardware – some components are open sourced (e.g. *Arduino* microcontrollers, *Raspberry* microprocessors); 3D printing helps with rapid prototyping; specialized providers like *Dragon Innovation* and *PCH* can handle key parts of the production process, and emerging marketplaces such as *Grand St.* help with distribution. Crowdfunding sites like *Kickstarter* or *Indiegogo* considerably de-risk the early phase of creating hardware by establishing market demand and providing financing.

Second, the world of wireless connectivity has dramatically evolved over the last few years. The mobile phone (or tablet), now a supercomputer in everyone's hand, is becoming the universal remote control of the Internet of Things. Ubiquitous connectivity is becoming a reality (Wi-Fi, Bluetooth, 4G) and standards are starting to emerge (MQTT). The slight irony of the "Internet of Things" moniker is that things are often connected via M2M (machine to machine) protocols rather than the Internet itself.

Third, the Internet of Things is able to leverage an entire infrastructure that has emerged in related areas. Cloud computing enables the creation of "dumb" (simpler, cheaper) devices, with all the intelligence processed in the cloud. Big data tools, often open sourced (Hadoop), enable the processing of massive amounts of data captured by the devices and will play a crucial role in the space.

6.1.2 Verticals

Unlike the Big Data space, where the action is gradually moving from core infrastructure to vertical applications, the Internet of Things space is seeing a lot of early action directly at the vertical application level. Some notable players like *Nest Labs* seem to have adopted a deeply integrated vertical strategy where they control key pieces of the product, including both hardware and software, in order to have complete control over the end-user experience.

Beyond the Nest, *home automation* in general has become the central battlefield of the Internet of Things, with some of the most exciting startups in the space jockeying for position. Another hot consumer-facing area is obviously *Quantified Self*, which is playing a huge role in developing consumers' awareness of the potential of the Internet of Things.

Beyond consumer, B2B/enterprise vertical applications of the Internet of Things, fueled in part by robotics, hold considerable promise in a number of areas such as manufacturing, transportation, healthcare, retail and energy. Some of clearest revenue opportunities for IoT startups are in the enterprise area.

6.1.3 Horizontals

While a lot of the action is happening at the vertical application level, the ultimate prize for many ambitious players in the space is to become the software platform upon which all vertical applications in the Internet of Things will be built. For example, several of the home automation providers (*SmartThings*, *Ninja Blocks*, etc.) also provide a software platform, and seem to be leveraging their vertical focus as a way to kickstart activity on the platform.

Large corporations (GE, IBM, etc.) are very active in the space and are developing their own platforms. Carriers (AT&T, Verizon) have a large opportunity in the area, as well. One open question is whether a platform developed for a vertical will easily translate to another vertical. In addition, whether the winning platforms are open or closed will play a huge role in the future of the space. The related area of connectivity (connecting objects to the network/Internet and to one another through all sorts of rules) is also a very significant opportunity. The space is extraordinarily exciting, but still very much in its infancy. Therefore, this ecosystem relationship might change dramatically in near future.

The IDC suggested a similar taxonomy of the Internet of Things space (Figure 6-6). It divided building blocks into a number of layers: IP, Devices, Protocols, Storage, Servers, Embedded Software, Embedded MPU and SoCs.

Figure 6-6: IoT Ecosystem (Source: FirstMark Capital)

6.2 IoT Ecosystem by CB Insights

CB Insights has introduced an IoT ecosystem after taking account a substantial number of private companies, corporations, venture investors, angels, accelerators, and acquirers engaged in this space [45] (Figure 6-5).

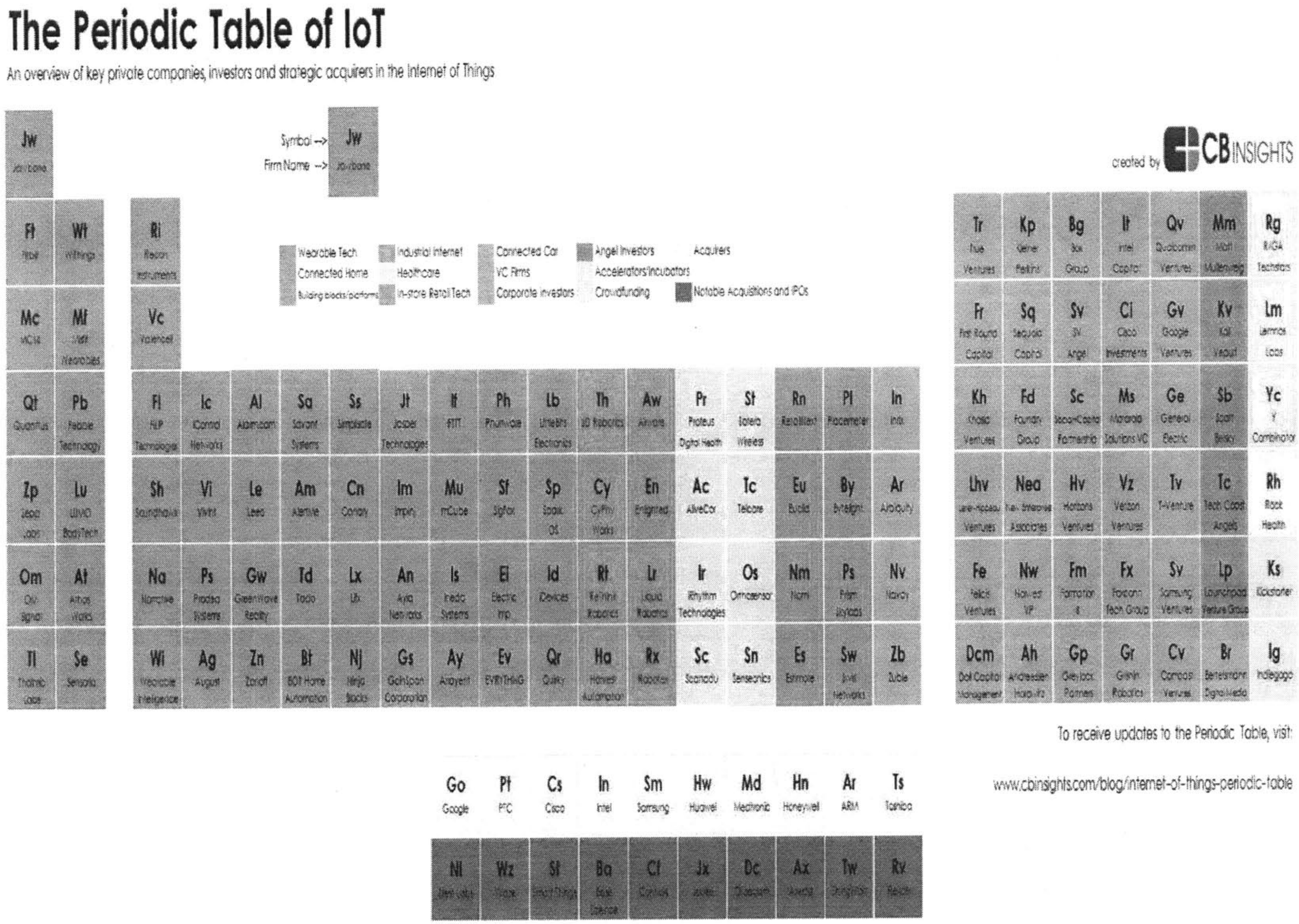

Figure 6-7: IoT Periodic Table (Source: CB Insights)

CB Insights calls this ecosystem as the "Periodic Table" of IoT. The table is divided into three parts:

6.2.1 The left side

The left side of the Periodic Table of IoT includes companies across several sub-verticals that comprise IoT. These sub-verticals are:

- **Wearable Tech**

Private wearable tech firms on the list include clothing or accessory companies that fuse sensor and other connected technologies in order to help track primarily health-related matters such calories burned, heart rate, steps taken, sleep and hearing but also more general use cases such as photos, email and GPS location.

- **Connected Home**

Private connected home companies on the list offer connected software platforms and hardware for your home in functional areas ranging from security, temperature management and lighting.

- **Building Blocks & Platforms**

This includes companies that help power, facilitate and/or create the IoT universe. This ranges from open-source IoT toolkits to embedded chip makers to DIY electronics.

- **Industrial Internet**

A term credited to GE, this includes a subset of companies working to extend the capabilities of connected devices to physical machinery, industrial processes and workplaces. Many of the firms listed primarily operate in the drone and/or robotics spaces.

- **Healthcare**

Healthcare companies on the table span key remote patient monitoring or machine-to-machine products for the healthcare industry, specifically for use by physicians or home healthcare providers.

- **In-store Retail**

This includes companies using sensor, beacon and WiFi technologies within the physical retail store in order to help better track and understand in-store customers.

- **Connected Car**

Connected car companies on the table provide wireless technology and/or hardware to help drivers be alerted of details including traffic, accidents, alerts and speeding.

6.2.2 The right side

On the far right, the table shifts to venture capital firms (both multi-stage and micro VCs), corporate investors, angels, accelerators/incubators and crowdfunding platforms selected based primarily on total recent portfolio investments into IoT.

- **Venture Capital Firms**

Venture capital firms included make venture equity investments across the stage spectrum and geographies focusing on IoT opportunities. The VC firm category spans both micro VCs and large multi-stage firms with LP commitments ranging from $25M to well over $1B+.

- **Corporate Investors**

Corporate investors in the Internet of Things include both corporations making direct investments and separately identifiable corporate venture units such as Intel Capital and Qualcomm Ventures.

Rank	Investor	Select 2014 Investments
1	Intel Capital	Enlighted, Appscomm, Avegant
2	Sequoia Capital	Lifx, Simplisafe, Airstrip
3	True Ventures	Ring, Narrative, Athos Works
4	Qualcomm Ventures	Ineda Systems, Airstrip, Streetline
4	Kleiner Perkins Caufield & Byers	Enlighted, Kinsa, mCube
4	Khosla Ventures	Thync, Misfit, Helium Systems
4	Andreessen Horowitz	IFTTT, Thync, Wearable Intelligence
8	Cisco Investments	Alya Networks, EVRYTHING, Ineda Systems
8	Norwest Venture Partners	IFTT, iRhythm, Misfit
8	The Social+Capital Partnership	BoomBotix, FiLiP Technologies, Athos Works

CB INSIGHTS

Table 6-1: Most Active Internet of Things Investors of 2014 (Source: CB Insights)

Table 6-1 shows the most active investments done in the Internet of Things space in 2014.

- **Angel Investors**

IoT angel investors span both angel groups that bridge the gap between angel investment and institutional VC, providing either a managed fund or direct investment from angel group members as well as individual angel investors who offer early-stage capital, advice and networks to startups in exchange for equity or convertible debt.

- **Crowdfunding**

Internet platforms for financing ventures or projects through contributions from the 'crowd', a larger group of people whose collective contributions help fund the project. See our prior report on Kickstarter-funded hardware projects.

- **Accelerators/Incubators**

Accelerators and startup incubators typically offer some combination of equity investment, mentorship and resources around company development. Those on the Internet of Things periodic table have either funded a number of IoT portfolio companies or have a specific focus on hardware i.e. *R/GA TechStars* and *Lemnos Labs*.

6.2.3 The bottom section

The bottom section includes the list of acquirers and notable IoT exits. Key IoT companies that have been acquired range from smart home companies (*Nest, Dropcam, SmartThings*) to wearable computing firms (*Basis*) to M2M application platforms (*ThingWorx*).

7 Semiconductors – The next IoT driver

According to a latest McKinsey research [46], the installed base for Internet of Things devices will grow from around 10 billion connected devices today to as many as 30 billion devices by 2020—an uptick of about 3 billion new devices per year (Figure 7-1). Each of these devices will require, at a minimum, a microcontroller to add intelligence to the device, one or more sensors to allow for data collection, one or more chips to allow for connectivity and data transmission, and a memory component. For semiconductor players, this represents a direct growth opportunity that goes beyond almost all other recent innovation.

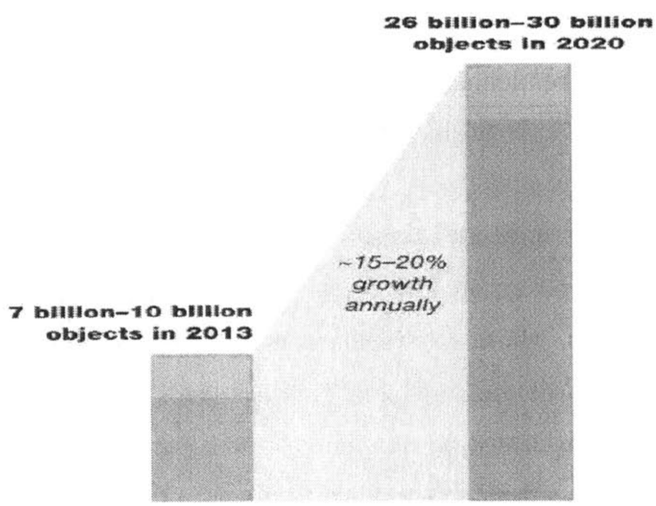

Figure 7-1: Internet of Things Devices Growth Estimate (Source: Forcasts from McKinsey, IDC, Gartner)

A new class of components will be required to address this opportunity: system on a chip–based devices produced specifically for the Internet of Things, with optimal power and connectivity features and with sensor integration. First-generation chips are already on the way, although it will probably be a few generations before chips can deliver all the functionality required. Intel, for instance, is releasing a low-power system on a chip designed for smaller products in automotive and industrial environments. This chip also can be used in fitness bands and other wearable devices. Additionally, sensors based on microelectro-mechanical-systems (MEMS) technology will continue to play a significant role in enabling Internet of Things applications.

It's worth noting that semiconductor players may also be able to profit indirectly from the Internet of Things, since the data generated from billions of connected devices will need to be processed—all those "little" data must be turned into big data—and users will require greater storage capacity, spurring new demand for more servers and more memory. Building on an existing market, semiconductor companies can continue to provide the critical devices and components that are at the heart of these products.

7.1 Overview of Semiconductor Industry

The semiconductor industry is the aggregate collection of companies engaged in the design and fabrication of semiconductor devices. It formed around 1960, once the fabrication of semiconductors became a viable business. It has since grown to be a $336 billion industry [48].

Traditionally, semiconductor companies controlled the entire production process, from design to manufacture. Yet many chip makers are now delegating more and more production to others in the industry. Foundry companies, whose sole business is manufacturing, have recently come to the fore, providing attractive outsourcing options. This has led to the emergence of *Fabless Chip Makers* in recent years. These are the semiconductor companies that carry out design and marketing, but choose to outsource some or all of the manufacturing. These companies have high growth potential because they are not burdened by the overhead associated with manufacture, or "fabrication". In addition to foundries, the ranks of increasingly specialized designers and chip testers are starting to swell. Chip companies are emerging leaner and more efficient. Chip production now resembles a gourmet restaurant kitchen, where chefs line up to add just the right spice to the mix.

Broadly speaking, the semiconductor industry is made up of 10 business sectors:

1. **Memory.** Memory chips serve as temporary storehouses of data and pass information to and from computer devices' brains. The consolidation of the memory market continues, driving

memory prices so low that only a few giants like Toshiba, Samsung and SanDisk can afford to stay in the game and continue to innovate.

2. **Microprocessors.** These are central processing units in the semiconductor devices that contain the basic logic to perform tasks. In last decade or so, Intel's domination of the microprocessor segment has forced nearly every other competitor, with the exception of Advanced Micro Devices, out of the mainstream market and into smaller niches or different segments altogether. However, the evolution of mobile business has led to the emergence of another player – ARM - in the market. Today almost every mobile platform, except the ones produced by Intel, has a processor based on ARM architecture.
3. **Fab and Foundries.** These are the factories where devices such as integrated circuits and chips are manufactured. Though there are several semiconductor companies which design as well as manufacture, a number of firms have started outsourcing manufacturing activities to reduce the fixed costs and overheads associated with fabrication. Today there are fabs and foundries such as TSMC that are solely fabricating the designs of other companies.
4. **Radio Frequency Integrated Circuits.** These are usually less than one square millimeter in area and are used in the wireless industry for such purposes as amplification, mixing and/or sending and receiving radio signals. They usually consume low power and require several dozen high frequency connections to printed circuit board.
5. **Mixed Signal.** These are the chips which have both analog and digital circuits on a single semiconductor die. The most common applications of these circuits are to convert analog signals to digital, and vice-versa, in a typical mobile phone, DVD player, etc. They are more difficult to design and manufacture than analog-only and digital-only circuits.
6. **Discrete components.** These include resistors, capacitors, diodes and transistors which are used to build on electronic circuit, typically on a printed circuit board, instead of a single integrated circuit.
7. **Programmable Devices.** These are the components whose functions are not static, but can be modified by changing its configuration. They offer customer a wide range of advantages by meeting its requirements for time to market, logic capacity, speed and voltage.
8. **Power Integrated circuits.** These are the circuits which are used for the managing power requirements, typically in battery operated devices such as mobile phones, tablets and media

players. Their functions include power source selection, voltage regulation, battery charging, etc.

9. **System-on-chips and platforms.** "System on a Chip" is essentially all about the creation of an integrated circuit chip with an entire system's capability on it. The market revolves around growing demand for consumer products that combine new features and lower prices. With the doors to the memory, microprocessor and commodity integrated circuit markets tightly shut, the SOC segment is arguably the only one left with enough opportunity to attract a wide range of companies.
10. **Electronic Design Automation.** It is a category of software tools used for designing electronic systems such as printed circuit boards and integrated circuits. The tools work together in a design flow that chip designers use to design and analyze entire semiconductor chips.

7.2 Selection of Semiconductor players for study

The thesis studies major semiconductor players in the Internet of Things space and identifies both significant breakthroughs and crucial gaps by exploring their current states and latest strategies. It uses three criteria to compile a list of companies that are at the forefront in global semiconductor industry : a) revenue, b) growth rate, and c) product line.

Table 7-1 shows the top 20 worldwide sales ranking for global semiconductor companies. A number of geographical regions are represented in this ranking. Eight companies are headquartered in the U.S., three in Europe, three in Taiwan, two in South Korea and one in Singapore.

2014F Top 20 Semiconductor Sales Leaders ($M)

2014F Rank	2013 Rank	Company	Headquarters	2013 Total	2014 Total	2014/2013 % Change
1	1	Intel	U.S.	48,321	51,368	6%
2	2	Samsung	South Korea	34,378	37,259	8%
3	3	TSMC*	Taiwan	19,935	25,088	26%
4	4	Qualcomm**	U.S.	17,211	19,100	11%
5	5	Micron + Elpida	U.S.	14,294	16,614	16%
6	6	SK Hynix	South Korea	12,970	15,838	22%
7	8	TI	U.S.	11,474	12,179	6%
8	7	Toshiba	Japan	11,958	11,216	-6%
9	9	Broadcom**	U.S.	8,219	8,360	2%
10	10	ST	Europe	8,014	7,374	-8%
11	11	Renesas	Japan	7,975	7,372	-8%
12	12	MediaTek + MStar**	Taiwan	5,723	7,142	25%
13	14	Infineon	Europe	5,260	6,151	17%
14	16	NXP	Europe	4,815	5,625	17%
15	13	AMD**	U.S.	5,299	5,512	4%
16	17	Sony	Japan	4,739	5,192	10%
17	15	Avago + LSI**	Singapore	4,979	5,087	2%
18	19	Freescale	U.S.	3,977	4,548	14%
19	20	UMC*	Taiwan	3,940	4,300	9%
20	21	Nvidia**	U.S.	3,898	4,237	9%
Top 20 Suppliers				237,379	259,562	9%
Top 20 Suppliers Excluding Foundries				213,504	230,174	8%

*Foundry **Fabless

Source: IC Insights' Strategic Reviews Database

Table 7-1: Top 20 semiconductor companies in 2014 (Source: IC Insights)

It is clear from above table that **Intel** and **Samsung** are giants in terms of revenue and are going strong in terms of growth. In addition, they have been making significant efforts in their product lines to make a solid presence in the Internet of Things space. So they are selected for study in this thesis.

Another set of companies considered in the thesis for study are **ARM**, **Qualcomm**, **Texas Instruments** (TI) and **STMicroelectronics** (ST). Qualcomm is a big player in terms of revenue and has been posting two digit growth rates since long. In addition, it holds 50% market share in mobile phone platform market and thus expected to play a big role in the IoT space. The other two companies - TI and ST – are considered because they deliver solutions across the spectrum. Though ST revenues declined during 2014, it is still a well-regarded company and thus important for study. It is interesting to note that, though ARM does not find a place in the top 20 list, it is chosen for the study. The reason is that ARM has 95% in smartphone processor market share and today every smartphone, except the ones produced by Intel, has an ARM chip. So it is highly likely that ARM will play an important role the Internet of Things space.

MediaTek and **Freescale** are also considered for the study. Both of them are among the top 20 list of semiconductor firms, as shown in the table 7-1, and are experiencing huge growth. Their product lines are well-suited for mobile and Internt of Things markets, and they are making planned efforts to get a considrable pie in the Internt of Things maket.

7.3 Case Studies

This section aims at understanding the progress that major semiconductor companies have made in the Internet of Things. It mainly focuses on finding the answers to following questions for each of the companies choosen for the study:

- Who are the major customers?
- Which applications and industries are being targeted?
- What are the product and services being offered?
- Are there any complements?
- What is the business model being followed or planned for the Internet of Things market?
    - What is the scope and focus of work company is doing? Which partnerships are being targeted and on what basis?
- Which consortiums and alliances are being targeted and on what basis?
- Which acquisitions company has done in the recent times?

7.3.1 Intel

7.3.1.1 Major Customers

- Apple
- Dell
- Hewlett-Packard
- IBM
- Lenovo

- Google
- Facebook
- Amazon

7.3.1.2 Applications and Industries

- Personal computers and devices
- Enterprise servers
- Storage
- Networking and communications components
- Wireless connectivity
- Internet of Things Platform
    - Automotive and transportation
    - Energy
    - Healthcare and fitness
    - Industrial
    - Retail
    - Smart manufacturing
    - Smart cities and buildings

7.3.1.3 Products

- Processors and CPUs
    - Quark (energy efficient), Atom, Core, Xeon (high performance)
- Boards and chipsets
- Servers
- Solid State Drives
- Chalk Talk – IoT platform
- Curie platform for wearables
- Security solutions
    - Intel Identity Protection Technology
- Network connectivity platforms
    - Ethernet Controller L210

- XMM platform for LTE
- Chipsets for I/O interfaces (Ethernet, USB, PCI, SPI, CAN, Bluetooth, ZigBee, WiFi456+ etc.)

- Gateways

7.3.1.4 Complements

- Operating system
- Embedded software
- Security software

7.3.1.5 IoT Business Model

Intel business model for Internet of Things is focused on mainly three areas: a) leveraging Intel expertise to develop IoT building blocks, b) building partnerships, and c) focusing on inorganic model to acquire products and talent out of its expertise that are crucial for IoT market

The major areas Intel is focusing in the IoT market are: Things, Gatways, Network & Cloud, and application layer APIs (Figure 7-2). These are summarized below.

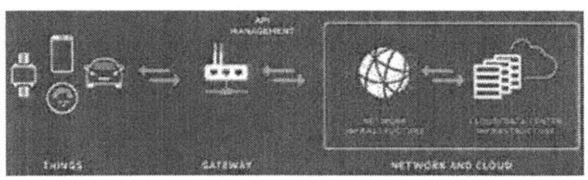

Figure 7-2: Intel's IoT Solutions

- **Things and Devices**. Intel Quark, Intel Atom and Intel Core processors each support a wide range of performance and power efficiency points to build IoT devices. In addition, the company is a world leader in building connectivity platforms and networking chipsets.

  For wearables, Intel has partnered with eyewear companies Luxxotica and Oakley, watch company Fossil Group, and fashion brand Opening Cermony (Figure 7-3).

Figure 7-3: Intel's partners for wearable solutions

- **IoT Gateways**. Intel® IoT Gateways are the result of Intel's collaboration with *McAfee* and *Wind River* (Figure 7-4). It offers customers a key ingredient for enabling the connectivity of legacy industrial devices and other systems to the IoT. It integrates technologies and protocols for networking, embedded control, enterprise-grade security, and easy manageability on which application-specific software can run.

Figure 7-4: Intel's major partners for gateways

Intel is also collaborating with a number of companies to develop complete end-to-end solutions for connected home solutions (Figure 7-5).

Figure 7-5: Intel's partners for connected home solutions

- **Network and Cloud**. Intel Xeon processors enables data center performance through its multi-core performance and hardware based security, virtualization and power management. Also, Intel has put forward an Open Network Platform (Figure 7-6) to speed up the development of network platforms that support advanced networking concepts such virtual machines (VMs), software defined networking (SDN) and Network Fucntion Virtualization (NFV).

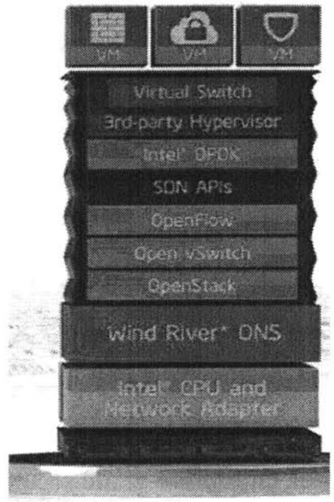

Figure 7-6: Intel's Open Network Platform

- **Services creation and application layers**. Intel provides a API management portfolio for a number of verticals: Automotive, Energy, Healthcare and Industrial (Figure 7-7).

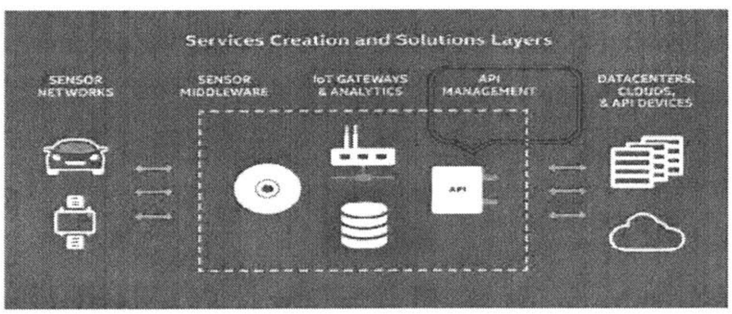

Figure 7-7: Intel's API management Portfolio

7.3.1.6 Consortiums

- Intel, along with IBM, Cisco, GE and AT&T, co-founded *Industrial Internet Consortium* (IIC) to support open standards and common architectures for IoT industrial applications. It has now over 150 members (Figure 7-8).

Figure 7-8: Industrial Internet Consortium

- Intel, along with Samsung, Dell and Broadcom, launched *Open Interconnect Consortium* (OIC) to set open standards for connecting household gadgets and appliances (Figure 7-9).

Figure 7-9: Open Interconnect Consortium

- Intel is a member of the *Alliance for Internet of Things Innovation* (AIOTI) launched by Europen Commision that aims at strengthening links and build new relationships between the different IoT players (industries, SMEs, startups) and sectors. It will also be used to promote interoperability and convergence between standards, facilitate policy debates and prepare an initiative for large scale testing and experimentation.

7.3.1.7 Recent Acquisitions

- **Lantiq**. Intel acquired Lantiq, a German home networking and chip maker, to extend its existing home gateway business into the telecom [30].
- **Basis Science**. To follow wearables in healthcare segment more aggresively, it has acquired Basis Science, the creator of Basis band.

7.3.1.8 Executive Summary

Intel is trying to be successful in the IoT business through partnerships and inorganic growth (acquisitions). Given the fact that IoT market is broad and diverse, it seems to be right strategy at the moment. Though it does not have enough expertise in healthcare and it does not develop end-to-end solutions on its own, the partnerships and acquistions seem to play a positive role in ensuring Intel's success in the IoT market.

The downside of Intel's startegy of partnerships and acquistions is that Intel is playing its cards everywhere. It does have any strategic vision of where it wants to do in the IoT space in the long run or where it wants to see the IoT space going. It has been following what its partners and acquired companies had been doing. However, through its strategy, Intel has definitely moved up in the value chain and is focussing on end-to-end IoT solutions, rather just harware.

7.3.2 Samsung

7.3.2.1 Major Customers

- Apple
- Hewlett-Packard
- Asus
- Acer
- Mio

7.3.2.2 Applications and Industries

- Personal Devices
- TVs and home appliances
- Memory and Storage – SSDs and memory cards

- Wearable Technology
- Digital cameras and comcorders
- Security and monitoring solutions

7.3.2.3 Products and Services

- Fabrication services
- TV panel components
- SoC components
- Cell phones and tablets
- Computing products - Laptops, PC, Printers, Chromebooks, Monitors
- Plasma, LED and UHD TVs
- Solid State Drives and memory cards
- Gear watches
- Washers, Dryers, Vacuums, Microwaves, Dishwashers
- Blu-ray media players, home theater, audio, digital cameras and camcorders
- Application processor platforms

7.3.2.4 Complements

- Operating system
- On-demand Internet streaming media
- Internet TV and set-top box
- Video game consoles
- Mobile security and encryption technologies

7.3.2.5 IoT Business Model

Samsung business model for Internet of Things revolves around devices, popularly known as "things" in the IoT business. In order to execute this model, Samsung has a broad portfolio of devices from smartphones and tablets to watches and UHD TVs to light bulbs, refrigerators and thermostats. The company has claimed that 90% of its devices would connect to Internet by 2017, that they would all be smart by 2019 and that every single product it sells will be connected to IoT in 2020. However, the company has not yet disclosed its strategy yet.

Samsung CEO Boo Keun Yoon recently promised $100M in funding for developers to create an open ecosystem for Internet of Things [52]. To win against the major rivals such as Apple which is famous for creating "walls" around its products, Samsung is placing its bet on open ecosystem.

It has been working for some time to develop an open IoT platform and SDK using which any device will be able to communicate with every other device (Figure 7-10). These are summarized below.

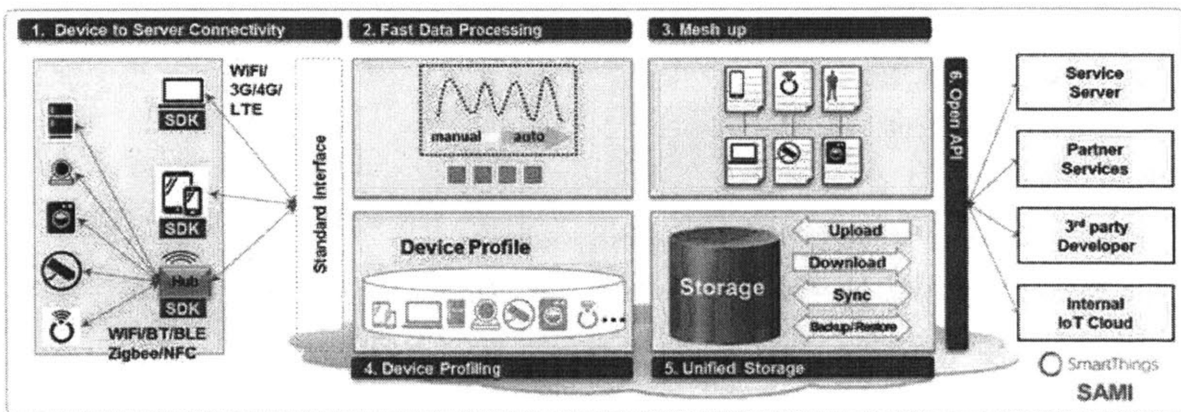

Figure 7-10: Samsung IoT Platform

- **Samsung IoT Platform**. It provides standardized connections between various devices on smart device or hub. It simplifies new service development for developers and partners by collecting and processing all kinds of data (service data, sensor data, etc) from users' IoT related services.
- **Samsung IoT SDK.** It also provide SDK for developing a service application for android using Samsung IoT Platform (Figure 7-11). The SDK includes key features such as messaging between devices under the pub/sub architecture using real time connectivity, fast data processing for real time processing of event data and storage management for user data storage.

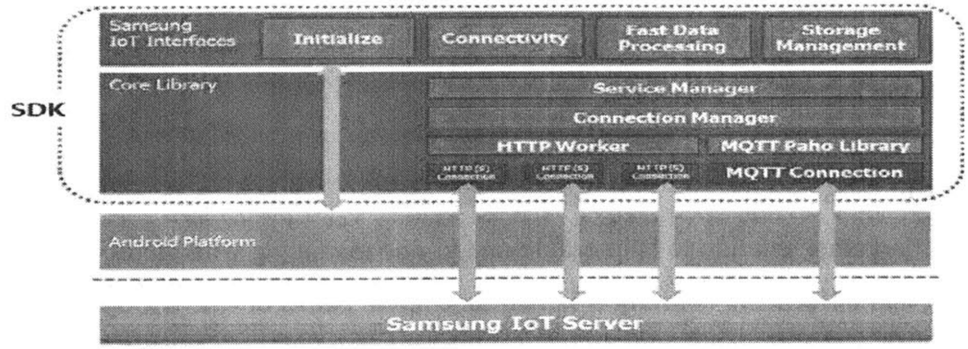

Figure 7-11: Samsung IoT SDK

In the connected home vertical, Samsung is placing its major bet. It has introduced what it calls its *Smart Home Service* to control connected appliances and eventually help consumers build out automatic scenarios that could make their lives easier. Using Android apps, the service allows consumers to program their home appliances. For example, saying "Good Night" to the TV remote control will automatically turn off connected devices within the home such as the recently launched Smart Bulb and configure air conditioners for night mode.

Though Samsung has not entered into any partnership in the name of Internet of Things, there are several of its partnerships which will help it win the IoT market. Some that are worth considering are given below.

- **Samsung with SAP.** This partnership is focussed on delivering enterprice mobility solutions for a number of industries. The collaboration will enable developers to build solutions that can leverage the integrated offering on mobile devices and wearables—as well as leverage joint cloud solutions based on the SAP HANA Cloud Platform mobile services.

  SAP and Samsung will focus on key scenarios in vertical markets where the shift towards mobility coupled with emerging IoT user scenarios in the workplace present opportunities to bring value to customers. Such verticals include:

  Retail: New solutions will be designed to enable innovative shopping experiences by helping provide retail store operators with more immediate access to inventory and product availability data adapted for Samsung's portfolio of connected devices—including mobile devices, wearables and large format displays.

Also, retail sales employees will be able to access customer data and use the SAP PrecisionMarketing solution to help enable one-to-one marketing with their consumers while informing and influencing consumers in real time at the points of sale (POS). Business tasks like accessing customer data, looking up product information and implementing mobile payments are planned to be made available on Samsung mobile devices and wearables for the sales representative while on the retail floor.

Oil & Gas: The SAP Work Manager and SAP Field Service mobile apps are available on the Samsung GALAXY Tab Active, for completing work on site, in the field. Extending SAP software integration to Samsung wearables will create a hands-free user experience that allows field workers in heavy industries to receive information and respond more quickly and safely to urgent issues with minimal disruption to their work.

Finance: SAP and Samsung intend to co-develop mobile banking solutions to enable a secure and user-friendly experience for banking and insurance customers. They also plan to create solutions to deliver smarter banking services and enhance the onsite banking experience for visitors with mobile solutions,printers and large format displays.

Healthcare: With goals of bringing the power of analytics from the SAP HANA Cloud Platform to Samsung mobile devices with customized applications for the healthcare industry, both companies will collaborate to enhance personalized healthcare management with solutions designed to provide secure connections to personal health information stored in the cloud—as well as personalized management service options. They also intend to launch a pilot project aimed at managing chronic disease based on the SAP HANA Cloud Platform.

- **Samsung with Technicolor, Netflix, Amazon, Comcast and DirecTV.** By entering into partnerships with these companies, Samsung has speed up widespread adoption of its *Smart*

Hub which let consumers stream UHD content from providers via applications on its smart device. This is going to play a big role in IoT's Connected Home application domain.

- **Samsung with BlackBerry, VMWare, Citrix Systems and Mobile Iron.** These partnerships are helping Samsung accelerate its efforts to expand in the enterprise market by leveraging its partners' expertise in mobile security and device management space.

- **Samsung with Evrything.** Evrythng handles identity and authentication for smart devices, to make it easier for people and systems to interact with them and analyze their output – it's keen on calling itself the "Facebook for things". It also intends to create the operating system for smart conencted lighting. This partnership is very valuable for Samsung to gain IoT market.

- **Samsung with AT&T**. Samsung and AT&T are creating a TiZen device library for the M2X Data Service so developers can easily store and use time-series data collected from applications on the Samsung Gear S Watch and other TiZen based wearables. The M2X services allow businesses to manage and better utilize the data they collect from connected devices.

- **Samsung with Nike, Aetna, Stanford University, and the University of California San Francisco medical center**. The company is trying to develop a digital health platform that includes an SDK, an API, algorithms, analytics, devices and sensors optimized for both commercial and research purpoes.

7.3.2.6 Consortiums

- Samsung, along with Intel, Dell and Broadcom, launched *Open Interconnect Consortium* (OIC) to set open standards for connecting household gadgets and appliances. As part of this consortium, the first version of the Internet of Things (IoT) source code standard called *IoTivity* was launched recently. It will allow connected devices from different manufacturers to communicate.

IoTivity project is hosted by the Linux Foundation, which ensures its access to anyone, especially through RESTful API-based architecture. The open source project combined with the ICO standardization efforts is essential to provide true interoperability with billions of objects that will connect online over the next few years.

- Samsung is also a member of the *Industrial Internet Consortium* (IIC) to support open standards and common architectures for IoT industrial applications. The group was founded by several key players such as Cisco, GE, IBM, Intel and AT&T.

- Samsung Founded *Thread Group* with ARM Holdings and Google's thermostat-and-smoke-alarm acquisition, Nest Labs. The group is promoting a mesh networking protocol for low-power devices around homes

- Samsung is a member of the *Alliance for Internet of Things Innovation* (AIOTI) launched by Europen Commision that aims at strengthening links and build new relationships between the different IoT players (industries, SMEs, startups) and sectors. It will also be used to promote interoperability and convergence between standards, facilitate policy debates and prepare an initiative for large scale testing and experimentation.

7.3.2.7 Recent Acquisitions

- **SmartThings**. Last year Samsung bought SmartThings whichmakes software and mobile app to connect and control household objects. The deal is expected to give Samsugn a strong foothold in the burgeoning IoT market.

7.3.2.8 Executive Summary

Unlike Intel which is poking its head in every vertical within the IoT market, Samsung is clearly putting focus on a handful of verticals: smart home, digital health and wearables. With a broad and diversified portfolio of home applicances and connected devices, the strategy to focus on smart home seems logical. In addition, now that it has Gear watches in its kitty and recently launched smart home services, the company has already closed the loop between wearables and smart home. Since healthcare applications assume a big chunk of wearable market, the move to focus on healtcare seems perfect.

Though the compamy has shown its interrest in the IoT domain, it seems slow in executing its plans. For example, its digital health and open IoT platforms are still in infancy stage and need to be expedited. In addition, the company has not yet integrated SmartThings, an acqusition made last year, in its worldwide business settings.

7.3.3 ARM

7.3.3.1 Major Customers

- Apple
- Samsung
- Qualcomm
- Nvidia
- TSMC
- TI
- NEC
- STMicroelectronics
- Broadcom
- Freescale
- Lenovo
- ZTE
- Fujistsu
- AMD
- Intel

7.3.3.2 Applications and Industries

- Mobile devices
- Enterprise servers
- Graphics and multimedia
- Wearables

7.3.3.3 Products

- Application and embedded processors
    - Cortex A, R and M series
- Graphics Mali processors
- Server processor
- Networking and interconnect IPs

7.3.3.4 Complements

- Operating system
- Embedded software
- Computing Peripherals
- Security software
- System-on-Chips (SoCs)
- Original Equipment Manufacturers (OEMs)

7.3.3.5 IoT Business Model

ARM business model for Internet of Things is focused on licensing its core processor technology to different partners. ARM is following "one size fits all" strategy and believe its microcontrollers will enable several different IoT applications. It is putting its bet on smart homes, smart cities and smart health verticals (Figures 7-12, 7-13, 7-14).

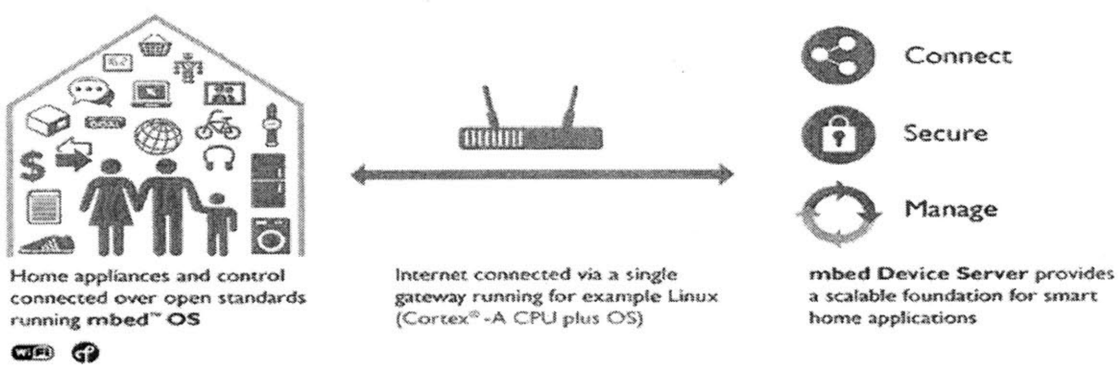

Figure 7-12: ARM Smart Home Scenario

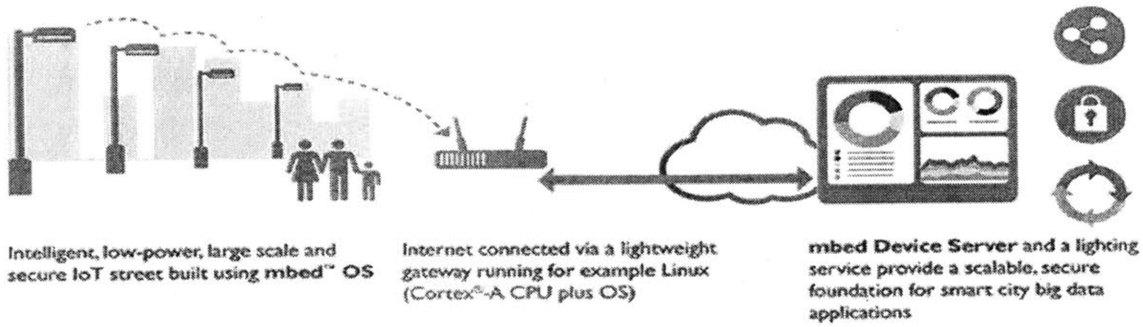

Figure 7-13: ARM Smart City Scenario

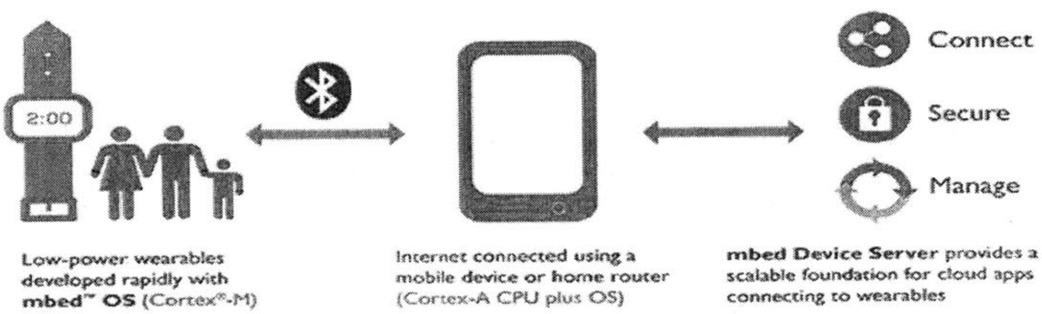

Figure 7-14: ARM Smart Health Scenario

To enable this, the company has developed an IoT device platform called *mbed* (Figure 7-15).

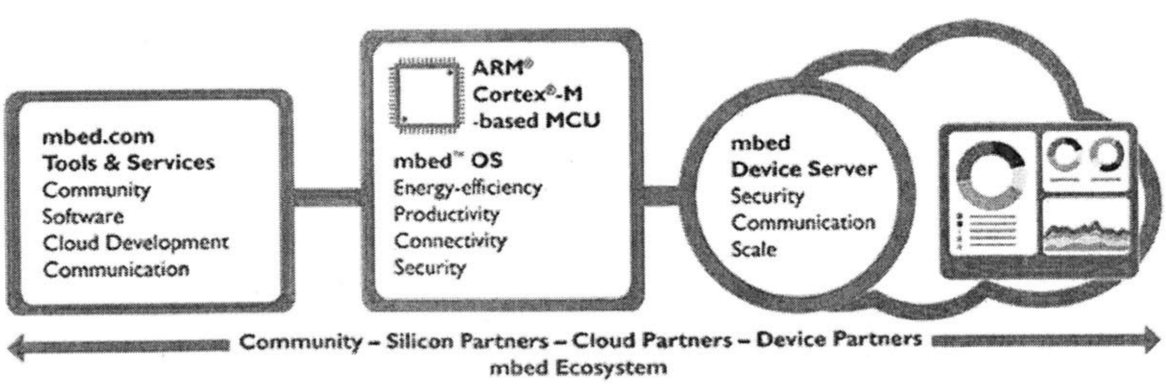

Figure 7-15: ARM mbed Ecosystem

To enable the faster development of applications over mbed, the company has developed an operating system, an SDK and an HDK (Figure 7-16).

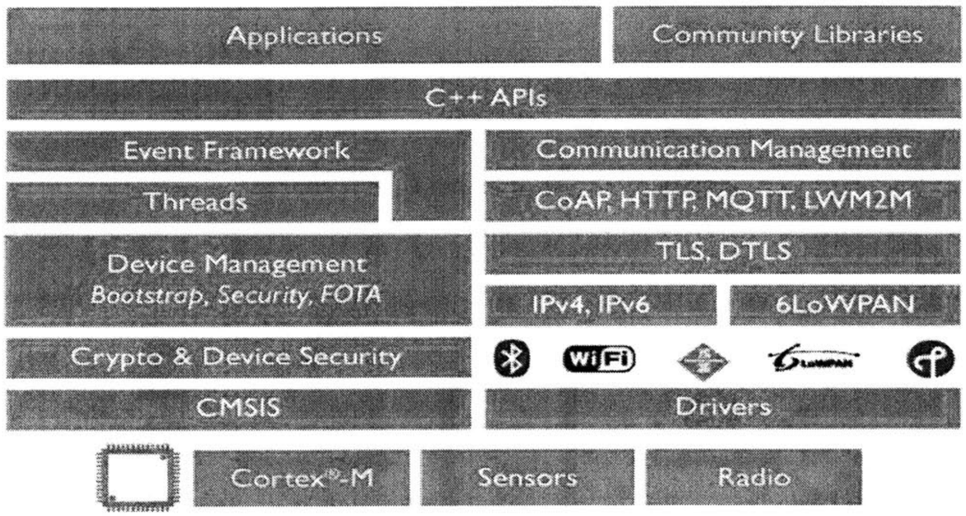

Figure 7-16: ARM mbed stack

ARM has entered into partnership with all the major semiconductor suppliers to increase the widespread adoption of its mbed platform (Figure 7-17).

Figure 7-17: ARM mbed partnerships

Algorithmic sensor software company Sensor Platforms and ARM introduced Open Sensor Platform (OSP), as open source software for sensor hub applications. OSP will simplify the integration of sensors across multiple applications, and provide a flexible framework for more sophisticated interpretation and analysis of sensor data.

7.3.3.6 Consortiums

- ARM is a member of *HyperCat Consortium* which is paving the way with over 40 other firms, including BT and IBM, for a new standard that drives interoperable Internet of Things
- ARM, along with Atmel, Ericcson and Google, founded *IPSO Alliance* to encourage innovation around Internet Protocol (IP) enabled smart objects for the Internet of Things
- ARM is also a member of *Open Interconnect Consortium* (OIC) which is driving open standards for connecting household gadgets and appliances. The group was founded by Intel, Samsung and Broadcom, and includes other key players such as Cisco, GE software, HP, Dell and Siemens.
- ARM founded *Thread Group* with Samsung and Nest. The group is promoting a mesh networking protocol for low-power devices around homes
- ARM is a co-founder of the *Linaro Group* which aims at developing open source software for the ARM® architecture

7.3.3.7 Recent Acquisitions

- **Offspark.** Offspark specializes in IoT communications security and its PolarSSL technology is already deployed in a wide variety of devices including sensor modules, communication modules and smartphones. As security is a requirement for all IoT deployments, this will help developers using the ARM® mbed™ platform to design and build IoT products with world-class communication security and software cryptography.

7.3.3.8 Executive Summary

ARM is approaching the IoT market as an enable rather than doer. Given its product portfolio, this seems to the right startegy. It has followed the same startegy in the mobile processor market where it supplies its processor archiotectures to several semiconductor companies that can modify and exploit it at their own will. Also, it works with other companies such as IBM to increase its outreach. It might be too early to comment on whether ARM will be successful in the IoT market. Its existing market share in the mobile space will definitely play huge role in the future.

In order to increases its chances of success of success in the IOT market, ARM is taking lead role in developing the next generation short-range communication standards such as 6LOWPAN for low power devices.

However, ARM is following "one size fits all" strategy and believe its microcontrollers will enable all the IoT applications. While this might be true in the short run, this might not be the best startegy to go in the long run. It should focus on developing different product lines for different domains such as travel, healthcare and connected home within the IoT market. To follow this strategy and move up in the value chain like Intel, it might want to collaborate with application service providers (ASPs) to understand the kind of services and requirements of different domains.

7.3.4 Texas Instruments

7.3.4.1 Major Customers

- Google
- Lenovo
- Intel
- Huawei
- Arrow Electronics
- Avnet

7.3.4.2 Applications and Industries

- Smart cities
- Wearables
- Building and home automation
- Smart manufacturing
- Healthcare
- Automotive

7.3.4.3 Products

- Analog components
- Baseband components
- Microcontrollers
- Processors
- Wireless connectivity solutions
- Sensors
- Storage solutions

7.3.4.4 Complements

- Operating system
- Embedded software
- Security software
- Cloud solutions
- Smartphone platforms
- Original Equipment Manufacturers (OEMs)

7.3.4.5 IoT Business Model

Texas Instrument's strategy for Internet of Things is focused on helping Original Equipment Manufacturers (OEMs) with its broad portfolio of hardware, software and tools. The company is focused on the IoT to deliver embedded wireless connectivity technologies, microcontrollers, processors and analog solutions to meet the wide variety of end applications being connected to the Internet and each other.

In order to beat stiff competition, the company has moved out of the SoC business and strategically shifted its focus from the digital space to become a primarily analog- and embedded processing-based company.

The company has built an extensive partnership program for the Internet of Things to help manufacturers link together devices and services from different companies. Participants in TI's ecosystem include 2lemetry, ARM, Arrayent, Exosite, IBM, LogMeIn (Xively), Spark, and

Thingsquare (Figure 7-18). If a company buys TI chips, it can work with software, hardware or cloud offerings from these partners.

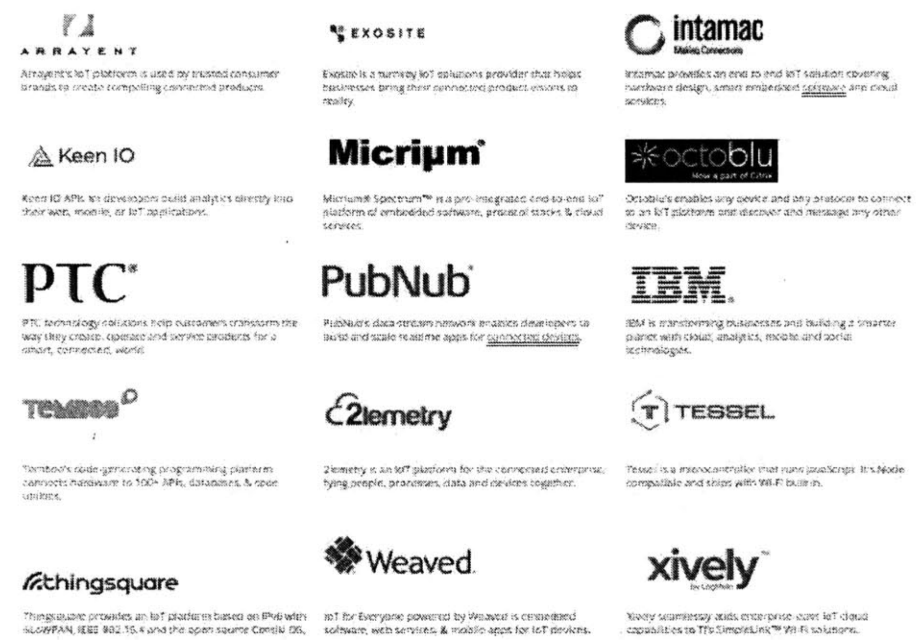

Figure 7-18: TI's cloud ecosystem for Internet of Things

In order to help customers easily and rapidly connect to its and its partners' IoT technology, Texas Instruments has developed Ian oT cloud ecosystem. Open to cloud service providers with a differentiated service offering and value-added services running on one of TI's IoT solutions, the TI cloud ecosystem provides options to meet individual manufacturer needs.

Texas Instruments with IBM. TI and IBM are collaborating on cloud-hosted provisioning and life cycle management services for IoT devices by using a set of APIs that TI will share with its customers. IBM also plans to create a Secure Registry Service that will authenticate devices based on TI silicon. Beyond simply connecting a device to the cloud, IBM aims to provision, activate, register, and deregister and retire IoT assets via a Bluemix platform-as-a-service environment running on the IBM SoftLayer cloud.

7.3.4.6 Consortiums

- Texas Instruments is a member of *IPSO Alliance* to encourage innovation around Internet Protocol (IP) enabled smart objects for the Internet of Things. The group was founded by over two dozen companies including ARM, Atmel, Bosch, Intel, FreeScale and Oracle.

7.3.4.7 Recent Acquisitions

- **Chipcon**. With the acquisition of Chipcon, TI now provides ZigBee™-compliant solutions and a broad range of proprietary RF-ICs that enable innovative low-power wireless applications.

7.3.4.8 Executive Summary

Texas Instruments has lost its shine in last few years – it moved out of the digital and SoC business and announced a major shift in its business strategy, moving away from consumer electronics devices such as smartphones and tablets and towards embedded applications such as computer systems in cars. This has impacted its presence in the IoT market which revolves around smartphones for a number of applications. While it still offers solutions across a number of verticals from healthcare and automobiles to wearables and smart citiies, its products are limited to embedded and analog applications. The only positive line in its IoT startegy is its focus on building partnerships for cloud-to-cloud solutions. This will go long way in helping the company win considerable share in the market.

7.3.5 STMicroelectronics

7.3.5.1 Major Customers

- Apple
- Blackberry
- Cisco
- Bosch
- Hewlett Packard
- Microsoft
- Samsung
- Western Digital

- Conti

7.3.5.2 Applications and Industries

- Computer and Personal Multimedia
- Healthcare and Wellness
- Energy and Smart Grid
- Communications and Networking
- Lighting and LED
- Transportation
- Power Supplies
- Home Appliances
- Building and smart Cities

7.3.5.3 Products

- Microcontrollers
- Microprocessors
- Memories
- Digital Set-top Box ICs and Imaging ICs
- Display Controllers
- MEMS and Sensors
- Automotive and Audio ICs
- Wireless Conenctivity Solutions

7.3.5.4 Complements

- Operating system
- Embedded software
- Security software
- Fabrication
- Original Equipment Manufacturers (OEMs)
- System-on-chips (SoCs)

7.3.5.5 IoT Business Model

STMicroelecronics strategy for Internet of Things is focused on offering a rich portfolio of technologies and products that cover all the IoT scenarios. The main building blocks it is targeting are:

- **MEMs** and **sensors** that can monitor motion, the environment and sound
- Low-power 32-bit **microcontrollers** to analyze data and make decisions
- A range of **application processors** with a strong software ecosystem for gateways
- Wired and wireless **communications** technologies for connectivity
- Ultra-efficient **power** conversion, monitoring and control technologies
- **Digital security** technologies for microcontrollers and application processors in Pay TV, banking and mobile space

The company recently used the lead user method to foster innovation and learn from lead users [66]. It launched an Internet of Things Design Challenge in Europe last year. The challenge encouraged participants to create products that include ST products suited for IoT use and finalists were selected on the basis of the level of innovation of the proposed application as well as the number of ST components used to implement it.

Following are the important partnerships STMicroelectronics have sealed to gain Internet of Things markets share:

- **STMicroelectronics with Thingsquare.** Thingsquare is a leading provider of open-source software for Internet of Things application in the connected home, smart city and smart lighting verticals. The collaboration aims at bringing Thingsquare Mist Internet-connectivity software to ST's SPIRIT1 radio transceiver on the STM32L microcontroller platform.
- **STMicroelectronics with Microsemi.** Microsemi and STMicroelectronics have collaborated on an electric vehicle car charger solution using Microsemi's power line communications (PLC) line driver.
- **STMicroelectronics with ARM.** The two companies are working together on ARM's mbed project which aims at developing an open platform for Internet of Things.

- **STMicroelectronics with IBM and Shaspa.** The three companies are collaborating on cloud computing to bring Internet of Things solutions in the connected home space. In this project, ST's Home Gateway and Shaspa's embedded software acts as a bridge between the home and cloud services provided by the IBM SmartCloud Service Delivery Platform, which gives electronics manufacturers a cloud platform to manage smart devices and rapidly introduce new consumer services. Their "smart home" initiative brings networking functions together, creating a gateway that connects a television, computer or mobile device with smart meters, lights, appliances, plugs and sensors within the home as well as services from outside.

7.3.5.6 Consortiums

- STMicroelectronics is a member of *IPSO Alliance* to encourage innovation around Internet Protocol (IP) enabled smart objects for the Internet of Things. The group was founded by over two dozen companies including ARM, Atmel, Bosch, Intel, FreeScale and Oracle.
- STMicroelectronics is a member of the *Alliance for Internet of Things Innovation* (AIOTI) which aims at strengthening links and build new relationships between the different IoT players (industries, SMEs, startups) and sectors. It will also be used to promote interoperability and convergence between standards, facilitate policy debates and prepare an initiative for large scale testing and experimentation
- STMicroelectronics is a member of the *Linaro Group* which aims at developing open source software for the ARM® architecture. It includes a number of sub-groups and has several key players such as ARM, MediaTek, Texas Instruments, AMD, Facebook, Cisco and Broadcom.

7.3.5.7 Recent Acquisitions

STMicroelectronics has not acquired any company in recent past.

7.3.5.8 Executive Summary

Like Texas Instruments (TI), STMicroelectronics has a broad portfolio of products. However, it has surpassed TI in planning and executing its Internet of things strategy. It has not only joined a number of alliances to develop open platforms, but also announced strategic collaboration with several key players to supply software and cloud components. In this approach, it is slowly but consistently following Intel which has been trying to move up in the value chain. However, it is lagging much behind Intel in terms of acquistions – it has not bought a single company in the IoT domain in the recent past. ST needs to buy few players which are developing software for Internet of things space. In addition, it needs to select few verticals, rather than going all over, to effectively and efficiently execute its IoT plans.

7.3.6 MediaTek

7.3.6.1 Major Customers

- Alcatel
- ZTE
- Micromax
- Huawei
- TCL
- Xiaomi
- HTC
- Panasonic
- Lenovo
- Karbonn
- Intex
- Xolo
- Zopo
- Doogee
- Elephone

7.3.6.2 Applications and Industries

- Mobile devices
- Home Entertainment
- Wireline and Wireless Connectivity

7.3.6.3 Products

- Smartphone and tablet platforms
- Digital TV, DVD and Blu-ray platforms
- WiFi, xDSL, Bluetooth, NFC and GPS Solutions

7.3.6.4 Complements

- Operating system
- Embedded software
- Security software
- Fabrication
- Original Equipment Manufacturers (OEMs)
- System-on-chips (SoCs)

7.3.6.5 IoT Business Model

MediaTek's IoT strategy revolves around wearables and connected home verticals. Through new platforms like *LinkIt* and *CrossMount*, the company plans to make it easier for partners, and eventually the end customers, to create IoT solutions that can simply work. Unlike its smartphone SoCs, LinkIT and CrossMount are solutions for IoT and wearables that include a hardware development kit (HDK), software development kit (SDK) or both.

- ***LinkIt Platform***. This platform is based around the world's smallest commercial System-on-Chip (SoC) for Wearables, MediaTek Aster (MT2502) (Figure 7-19). This SoC works with MediaTek's energy efficient Wi-Fi and GNSS companion chipsets also, making it easy to create devices that connect to other smart devices or directly to cloud applications and services.

Figure 7-19: MediaTek's LinkIt Platform

The platform has the familiar Arduino form factor, and can be programmed from the Arduino IDE, so it feels like an Arduino bolted on to a mobile phone. It comes with antennae for cellular (SMS/GPRS), bluetooth/wifi and GPS. The platform protocol stack is shown below.

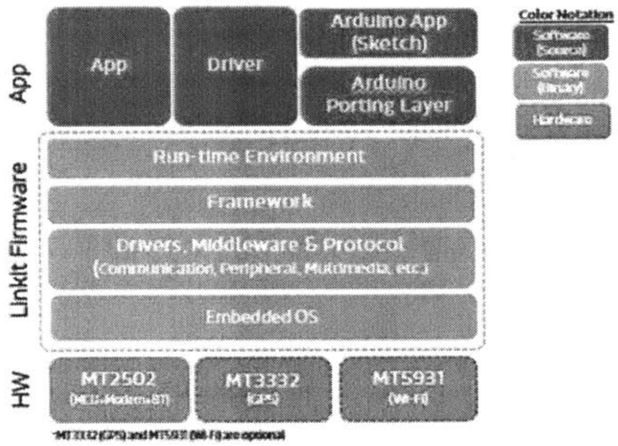

Figure 7-20: MediaTek's LinkIt Protocol Stack

- **Cloud Mount Platform.** CrossMount is an open and simple-to-implement technology for the wide ecosystem of MediaTek customers and partners that opens the possibilities for multiple devices effectively working as one or sharing applications and hardware resources. It a new technology that simplifies hardware and software resource sharing between different consumer devices. It ensures any compatible device can seamlessly use and share hardware or software resources authorized by the user.

CrossMount defines its service mounting standard based on UPnP protocol, and can be implemented primarily in Android and Linux as well as other platforms. CrossMount works through simple discovery, pairing, authorization and use between devices of both hardware and software resources across smartphones, tablets and TVs. Communication between devices is achieved directly between devices via home gateways (Wireless LAN) or peer to peer (Wi-Fi Direct). Discovery and sharing are granted through an easy software implementation that allows all Wi-Fi capable devices to share resources without the need for cloud servers.

Though MediaTek has not developed any partnership in the name of Internet of Things, there are several of the partnerships it announced in recent past that will help it gain IoT market. The major ones are:

- **MediaTek with Google.** The collaboration between these two companies is going very strong and across several fronts. Aiming to reach the next billion people, MediaTek and Google are working together on Android One™, an initiative to provide a family of high-quality and affordably priced Android devices for consumers in emerging markets. MediaTek is also collaborating with Google on its new Google Cast for audio offering for music lovers globally to address consumer desire to connect with music quickly and easily. Recently MediaTek announced its MT2601 System on Chip (SoC) for wearable devices based on Google's Android Wear software.
- **MediaTek with Acer.** The two companies announced a memorandum of understanding in the cooperation of cloud and wearable technologies. They launched a kit, DevKit, targeted for IoT developers who want to collect and store mobile sensor data in a secure and convenient way.
- **MediaTek with Samsung.** The two companies are in discussion phase so Samsung can use MediaTek chipsets in Tizen-based devices, including HDTVs and smartphones
- **MediaTek with LG.** The two companies worked together to bring world's first triple-sim 3G smartphone
- **MediaTek with ARM.** The two companies have been collaborating since long to develop innovative mobile platforms
- **MediaTek with Telkomsel and IMO.** They have been working together to develop cheap smartphones for developing market
- **MediaTek with AMD.** The two companies are currently in discussion phase and are expected to collaborate on graphics solutions for mobile phone. This partnership will raise the performance of multimedia on MediaTek platforms and give AMD an entry to smartphone market

7.3.6.6 Consortiums

- MediaTek is a member of the *Open Interconnect Consortium* (OIC) which is working on creating an open specification for interoperability in the Internet of Things. The group was founded by Intel, Samsung and Broadcom, and includes other key players such as Cisco, GE software, HP, Dell and Siemens.

- MediaTek is a co-founding member of *internet.org* which aims at making interent available to next 5 billion people. Other founding members of this group are Facebook, Ericsson, MediaTek, Nokia, Opera, Qualcomm and Samsung.

7.3.6.7 Recent Acquisitions

MediaTek acquired its local rival in China, MStar, to gain semiconductor business, but IoT opportunities was not considered for this acqusition

7.3.6.8 Executive Summary

MediaTek has achieved new heights in last few years. Now it is betting big on the Internt of Things opportunity. Its IoT strategy revolves around capturing the wearable and connected home market with its LinkIt platform which uses its Aster SoC solution. The company has developed stretgic relationships with several big players such as Google, Facebook, Acer and ARM that will surely help it win a large chunk of the market. Unlike other semiconductor players and its rivals, it does not a broad portfolio of products, making it easier for the company to focus and strategize. Focusing on limited verticals such as wearables and connected home, and developing alliances with giants have proved to be a good strategy for the company in the past, and will work well for the Internet of Things market also, as IoT is a broad and fragmented market with huge number of applications and dominant players.

7.3.7 Qualcomm

7.3.7.1 Major Customers

- Samsung
- Apple
- Lenovo
- Alcatel
- Huawei
- Xiaomi
- HTC
- Vodafone

- LG
- ZTE
- Microsoft

7.3.7.2 Applications and Industries

- Mobile and personal devices
- Automotive
- Networking and Connectivity
- Healthcare
- Education

7.3.7.3 Products and Services

- Embedded and application processor platforms
- Wireless and wired conenctivity solutions
- Car safety and infotainment solutions
- Healtcare cloud platform and management portal
- IP Licensing

7.3.7.4 Complements

- Operating system
- Embedded software
- Security software
- Fabrication
- Original Equipment Manufacturers (OEMs)

7.3.7.5 IoT Business Model

Qualcomm's IoT business model is focussed on: a) delivering SoCs that can power smartphones and IoT applications, b) driving standards such as AllJoyn, and c) building an umbrella platform from base level to big data to applications layer.

- **Delivering SoCs.** Qualcomm still sees a pivotal role for its primary target market, the smartphone, in expanding the IoT and making it truly useful for the mass of consumers. About 8bn smartphones will ship between 2014 and 2018, according to Gartner, and those will remain the basis of most IoT applications - and of Qualcomm's roadmap for this space, from healthcare to cars. The company introduced low-power chipsets called the Qualcomm Internet Processor (IPQ) to turn networking devices like home gateways, routers and media servers into what it dubbed "smarthome" platforms.

  Its Snapdragon platform powers most of the high-end mobile devices. Also, Qualcomm chips can be found in smartwatches like the i.am Puls, the Timex Ironman and the LG G Watch R, and in virtual reality headsets like the Samsung Gear VR and the OGD R-7 glasses. Vehicles that use Snapdragon chips in their connected car features include the Maserati Quattroporte and the Cadillac XTS, providing advanced 3D navigation, HD video and streaming, gaming, device sharing and surround sound. The latest Qualcomm VIVE 802.11ac Wi-Fi solution on the Snapdragon 810 chip allows users to stream 4K video wirelessly, while also providing theater-quality surround sound audio.

- **Driving Standards.** Gathering industry support for AllJoyn, MU-MIMO and other important Qualcomm technologies - which it hopes to see embedded across the IoT - the firm is seeking to drive standards for IoT ecosystem. AllJoyn makes it easier to capitalize and create new and immersive experiences by enabling apps to connect, control and share resources with other nearby apps and connected smart things. Qualcomm also has come up with a smart watch platform, Toq SDK, which is based on AllJoyn (Figure 7-21).

Figure 7-21: Qualcomm Toq platform for smart watches

The Qualcomm® Toq™ SDK is designed to allow developers to enable interaction and communication between Android apps and the Qualcomm Toq smartwatch. When an Android app is on the same device as the Qualcomm Toq Android app, it can use the Toq app to interact with the Toq smartwatch. This allows developers to give consumers the ability to customize their Toq experience by adding their app as an on-watch display option. The Toq app processes incoming third-party API calls and communicates directly with the smartwatch.

- **Building partnerships.** In an effort to create a complex ecosystem of partnerships around itself, Qualcomm provided the Linux Foundation with the AllJoyn framework, paving the way for a major alliance in the IoT called *AllSeen Alliance.*

  Qualcomm is the star player in the alliance, but other leading members include Haier, LG Electronics, Panasonic, Sharp, Silicon Image and TP-LINK. Lower-level members include Canary, Cisco Systems, D-Link, doubleTwist, Fon, Harman, HTC, Letv, LIFX, Lite-on, Moxtreme, Musaic, Sears Brand Management Corporation, Sproutling, The Sprosty Network, Weaved and Wilocity. The alliance centers on several IoT segments, such as connected health, in which Qualcomm says it has signed up 500 partners. In this sector, it aims to provide the connectivity backbone for a wide range of devices, as well as contributing APIs to the cloud platforms which will manage the gadgets and the data they produce.

Qualcomm hopes that by handing over the AllJoyn code, companies will be able to create standards for things like lighting controls, thermostat controls and other protocols for a variety of connected devices. It has created a wide network of partnerships in the Internet of Things:

- **Qualcomm with LIFX**. The company has entered into smart lighting, where it announced a partnership with smart lightbulb company LIFX, adding WiFi and AllJoyn connectivity to a kit to create connected lamps.
- **Qualcomm with Dolby.** Qualcomm partnered with audio giant Dolby for audio centric IoT services, with Dolby's software implemented into and processed through Qualcomm's chip.

- **Qualcomm with 2lemetry**. Qualcomm entered into partnership with 2lemetry to provide cloud services to its partners. 2lemetry is an Internet of Things platform and solutions company that powers the connected enterprise, tying people, processes, data and devices together—transforming raw data into real-time actionable intelligence.
- **Qualcomm with FreeScale.** Freescale is a Qualcomm partner as a preferred silicon vendor to provide Qualcomm's customers embedded processing solutions from ICs and microcontrollers to connectivity and analog integrated circuits.

7.3.7.6 Consortiums

- Qualcomm, along with the Linux Foundation, formed the AllSeen Alliance, enlisting Cisco, Microsoft, LG, and HTC as members, among many others. It aims to create standards for things like lighting controls, thermostat controls and other protocols for a variety of connected devices, and uses AllJoyn platform developed by Qualcomm.

- Qualcomm is a co-founding member of *internet.org* which aims at making interent available to next 5 billion people. Other founding members of this group are Facebook, Ericsson, MediaTek, Nokia, Opera and Samsung.

7.3.7.7 Recent Acquisitions

Qterics. It is a spin-off from Silicon Image and allows Qualcomm to take on cloud-based device management in the smart home.

Cambridge Silicon Radio (CSR). CSR is a pioneer in bluetooth technology for machine-to-machine communication. Qualcomm believes that CSR's leadership in Bluetooth, Bluetooth Smart and audio processing will strengthen its position in providing critical solutions for the Internet-of-Things (IoT) market.

7.3.7.8 Executive Summary

Qualcomm holds a 51% revenue share in the cellular and smartphone market and it aims to use its leadership position in this market to develop a complex ecosystem and gain IoT market. It continues to assemble a broad ecosystem around AllJoyn device discovery framework, seeking to make that a standard in the internet of things (IoT). Having put the technology into open source and created a supporters' club, the AllSeen Alliance, it is looking for new partners to enrich the ecosystem. Though the company has been able to gain support from a number of players in the industry for its AllSeen Alliance, this step has bifurcated the industry in two sides and ignited IoT war. One side is being led by Qualcomm and its partners, while the other side being led by Intel and Samsung with a new IoT standard known as *Open Interconnect Consortium (OIC).* Given the ecosystem Qualcomm has gathered, it is expected to gain a considerable share of the market. However, OIC players will definitely provide a major hurdle to the company in its ambitions.

7.3.8 Freescale

7.3.8.1 Major Customers

- Continental Automotive
- Amazon
- Numera
- Fitbit
- OmniPod

7.3.8.2 Applications and Industries

- Automotive
- Consumer home appliances
- Wearables
- Industrial
- Networking and Connectivity
- Healthcare
- Energy

7.3.8.3 Products and Services

- Microcontrollers
- RF devices
- Sensors
- Embedded and Application Processors
- Connectivity Platforms

- Analog and Mixed Signal Components

7.3.8.4 Complements

- Operating system
- Embedded software
- Security software
- Fabrication
- Original Equipment Manufacturers (OEMs)

7.3.8.5 IoT Business Model

Freescale have been working actively to put together IoT business model for some time. The company's major steps in this direction include: a) moving from PowerPC architecture to adopt ARM architecture for its device platforms, b) focusing on security critical gateway applications, and c) building partnerships.

- **Adopting ARM architecture.** Freescale has aggresively begun incorporating ARM cores into all of its communications processors, the brains of everything from business wireless routers to gateways in the core of carrier networks. Recently the company has started collaboration with ARM on ARM's mbed platform for IoT and also implemented the Cortex-M7 processor in its Kinetics MCU family. This is crucial for Freescale in order to win IoT market where diversity of technical requirements and widening challenges such as battery life and cost sensitivity are driving complex SoC needs.

- **Focusing on gateway applications**. The company is create standards for gateways that can deal with a flood of data from devices associated with the "Internet of things." It foresees a flood of data coming from household devices as they collect data and pass it on. Freescale plans to make chips for home gateways that capture that data and pass it on so that it can be used to deliver internet of things services.

- **Building partnerships**. Freescale has entered into a number of partnerships to secure its place in the IoT market. The major ones are:

Freescale with Qualcomm. Freescale is Qualcomm's preferred silicon vendor for IoT applications

Freescale with Oracle. Freescale is working with Oracle to develop cloud platform for IoT applications

FreeScale with ARM. Freescale has adopted ARM's mbed platform for developing IoT applications

7.3.8.6 Consortiums

- Freescale founded Thread Group with ARM, Samsung and Google's Nest. The group aims at building support for future devices to connect to one another using a mesh network sending standard Internet packets over an existing low-power radio technology, a protocol known as 6LowPAN.
- Freescale is a member of *IPSO Alliance* founded by ARM, Atmel, Ericcson and Google to encourage innovation around Internet Protocol (IP) enabled smart objects for the Internet of Things

7.3.8.7 Recent Acquisitions

Freescale did not acquire in the recent past. Recently it got acquired by NXP Semiconductors.

7.3.8.8 Executive Summary

Freescale executed a number of plans to gain the IoT market, before it got acquired by NXP Semiconductos. The merger will strengthen its position in the market. NXP is a major supplier of chips to Apple which holds a critical share of mobile market. Though the company has already built a number of partnerships, it needs to step up its efforts to match its rivals. In addition, it needs to collaborate with more software firms to develop the whole ecosystem from bottom to the application layer.

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8 Summary and Recommendations

The question is no longer if the Internet of Things can provide substantial growth for semiconductor players; the real consideration is how best to capitalize on the trend. It is clear from the case studies that the semiconductor industry is currently facing potential challenges in two critical areas – technology and ecosystem development.

8.1 Technology challenges and mitigation

Major technical challenges are:

- **Chip design and development.** Semiconductor players may need to invest heavily to adapt their chip designs and development processes to account for specific Internet of Things system requirements. For instance, because many applications would require devices that are self-sustaining and rely on energy harvesting or long-life batteries, semiconductor companies must address the need for optimal power consumption and outstanding power management in their products.

- **Connectivity load.** Hundreds or even thousands of devices may need to be connected at the same time. The average smart home, for instance, may contain 50 to 100 connected appliances, lights, thermostats, and other devices, each with its own low-power requirements.

- **Power and network.** Existing connectivity solutions such as standard Bluetooth or Wi-Fi will probably not be able to meet smart-home requirements given their power and network limitations.

- **Form factors.** Manufacturers may also need to emphasize flexible form factors to a greater degree than they currently do. Components must be small enough to be embedded in today's smart watches and smart glasses but also amenable to further shrinking for incorporation into still-unidentified future products.

- **Security and privacy.** Internet of Things devices will not be used for critical tasks in, say, industrial or medical environments if connectivity protocols have not been established to prevent hacking, loss of intellectual property, or other potential breaches.

Semiconductor players are moving full steam ahead to address some of these challenges. Their efforts in two areas in particular are highly encouraging:

- ***Increased integration.*** Some semiconductor players are already considering investing in new integration capabilities—specifically, expertise in packaging, silicon manufacturing and software & firmware development. The emergence of more integrated system-in-package and system-on-a-chip devices is helping to overcome some of the challenges described earlier, in part by addressing power, cost, and size factors.

  The trend toward multidimensional chip stacking and packaging (2.5-D and 3-D integrated-circuit, or 2.5DIC and 3.0DIC, devices in particular) has resulted in integrated circuits that are one-third smaller than standard chips, with 50 percent lower power consumption and bandwidth that is up to eight times higher—at a cost that can be up to 50 percent lower when compared with traditional systems on a chip of the same functionality.

  Monolithic integration of MEMS sensor technologies with complementary metal-oxide semiconductors is considered unlikely for Internet of Things applications. In these instances, the integration of substrates with silicon requires making certain design trade-offs and optimizing both the sensor and the logic circuits. Instead, we expect to see 2.5DIC and 3.0DIC technologies being favored for Internet of Things–specific integrated circuits.

- ***Connectivity standards.*** The current cellular, Wi-Fi, Bluetooth, and Zigbee specifications and standards are sufficient to enable most Internet of Things applications on the market. Some applications, however, will require low-power, low-data-rate connectivity across a range of more than 20 meters—an area in which cellular technologies and Wi-Fi often fall short. New technologies that target this need are emerging from players such as those in the Bluetooth and Weightless interest groups. The latter is an industry group comprising technology companies that are exploring the use of free wireless spectrum to establish an open communications protocol. Such standardization efforts will enable Internet of Things applications that require broadly distributed sensors operating at low power over low-cost spectrum—for instance, temperature and moisture sensors used in agricultural applications.

8.2 Ecosystem challenges and mitigation

Joep van Beurden, the chief executive at CSR, points out that only about 10 percent of the financial value to be captured from the Internet of Things trend is likely to be in the "things"; the rest is likely to be in how these things are connected to the Internet [47]. Thus, the semiconductor players that focus primarily on the things themselves should therefore find ways to support the development of a broader ecosystem (beyond silicon) and find their niche as both enablers and creators of value for their customers and their customers' customers. Following are some of the strategies they can employ in this respect:

- **Partnerships for products and services.** This will mean developing partnerships with players further downstream, such as companies that are building and providing cloud-based products and services. It will be important for semiconductor companies to remember that different industries are at different levels of maturity and complexity with respect to the Internet of Things—so the roles that components manufacturers can play in application development in certain industries will vary, as will the timing of growth opportunities. The market for home-automation tools, for instance, has established some common APIs, but competing standards remain. A number of application developers have already started generating monitoring products for consumers, and once standardization issues can be addressed, the market may experience significant growth rather quickly. By contrast, the markets for monitoring and control systems in factories and for beacon technologies in retail are much more fragmented and will therefore take longer to develop. In retail, for instance, all the players in the value chain—the stores, the data aggregators, the Internet service providers, and other partners—must sort out their roles and standards of operation before beacon-technology providers can approach them with a clear customer value proposition and business model.

- **Alliances for standards development.** In these instances, semiconductor companies may want to test the waters by forming alliances with hardware companies, systems players, and customers or by finding ways to assist in developing standards. In the factory-monitoring-systems market, for instance, players are attempting to create common standards (through the Industrial Internet Consortium initiative, for example, and the Europe-only Industry 4.0 initiative), even though most of the hardware platforms are still proprietary, as are the data, which reside in legacy systems. Semiconductor players that pursue alliances and standard-setting activities may be able to play an enabling role in defining best practices in Internet of Things privacy, security, and authentication. These issues will be critical in markets that are dealing with sensitive consumer data, such as healthcare and wearables.

- **New approach to product development.** Given the potential 90 percent distribution of value to players that provide all the technologies "beyond" the silicon, there may never be a compelling enough business case for components manufacturers to develop individual chips and systems for hundreds of thousands of discrete Internet of Things industry applications. Semiconductor players should instead design a family of devices that are sufficiently flexible to cater to the needs of multiple industries—that can be used in industrial *and* consumer Internet of Things applications that boast similar characteristics. These devices will probably fall somewhere along a continuum of application requirements—at one extreme, high-power, high-performance, application-processing Internet of Things devices, such as those embedded in smart watches, and, at the other extreme, low-cost, ultralow-power integrated sensors that support sufficient (but not excessive) functionality and autonomous device operation. To achieve this level of design flexibility and to address the opportunity properly, semiconductor players may need to rethink their approach to product and application development.

8.3 Recommendations and Future Work

It is clear that challenges associated with the Internet of Things are many; semiconductor executives should consider ways to integrate new development models, process capabilities, and go-to-market strategies in their existing operations. Success will require bold moves, boards that are willing to bet on unfamiliar models and activities, and collaboration with those that are developing industry standards. But the semiconductor industry should embrace this era of innovation and reinvention. The opportunities for growth outweigh the challenges, as components manufacturers explore the creation of a new class of Internet of Things–enabled semiconductors that can cut across a wider swath of potential customers than existing components can. The sector may be on the cusp of unit growth similar to the surge it experienced with the smartphone—and perhaps an even greater jump.

This sort of enabling model can provide an opportunity for semiconductor players to have their say in standards development. It can also become a nice stepping stone toward larger application markets in industries where the value chain is not as well developed. In retail, for instance, many companies are just now exploring the use of beacon technology—a category of low-power, low-profile transmission devices that can help retailers provide personalized services to shoppers. The projected market value of the beacons themselves is $60 million a year—a nice figure but not one that will be game changing for the semiconductor industry. But because of the information the beacons can provide—what are people buying, and how much?—they will hold a value far greater than $60 million for the retailers that use them. The question is, how do semiconductor companies insert themselves into that value chain?

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