3.1 Internet of Things Vision

Internet of Things (IoT) is a concept and a paradigm that considers pervasive presence in the environment of a variety of things/objects that through wireless and wired connections and unique addressing schemes are able to interact with each other and cooperate with other things/objects to create new applications/services and reach common goals. In this context the research and development challenges to create a smart world are enormous. A world where the real, digital and the virtual are converging to create smart environments that make energy, transport, cities and many other areas more intelligent. The goal of the Internet of Things is to enable things to be connected anytime, anyplace, with anything and anyone ideally using any path/network and any service. Internet of Things is a new revolution of the Internet. Objects make themselves recognizable and they obtain intelligence by making or enabling context related decisions thanks to the fact that they can communicate information about themselves and they can access information that has been aggregated by other things, or they can be components of complex services [69].

The Internet of Things is the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment and the confluence of efficient wireless protocols, improved sensors, cheaper processors, and a bevy of start-ups and established companies developing the necessary management and application software has finally made the concept of the Internet of Things mainstream. The number of Internet-connected devices surpassed the number of human beings on the planet in 2011, and by 2020, Internet-connected devices are expected to number between 26 billion and 50 billion. For every Internet-connected PC or handset there will be 5–10 other types of devices sold with native Internet connectivity [43].

According to industry analyst firm IDC, the installed base for the Internet of Things will grow to approximately 212 billion devices by 2020, a number that includes 30 billion connected devices. IDC sees this growth driven largely by intelligent systems that will be installed and collecting data - across both consumer and enterprise applications [44].

These types of applications can involve the electric vehicle and the smart house, in which appliances and services that provide notifications, security, energy-saving, automation, telecommunication, computers and entertainment will be integrated into a single ecosystem with a shared user interface. IoT is providing access to information, media and services, through wired and

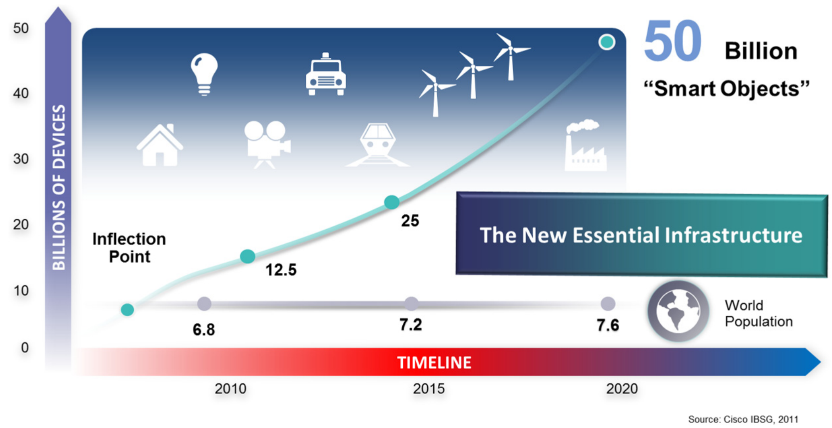

Figure 3.1 Internet-connected devices and the future evolution (Source: Cisco, 2011)

wireless broadband connections. The Internet of Things makes use of synergies that are generated by the convergence of Consumer, Business and Industrial Internet Consumer, Business and Industrial Internet. The convergence creates the open, global network connecting people, data, and things. This convergence leverages the cloud to connect intelligent things that sense and transmit a broad array of data, helping creating services that would not be obvious without this level of connectivity and analytical intelligence. The use of platforms is being driven by transformative technologies such as cloud, things, and mobile. The Internet of Things and Services makes it possible to create networks incorporating the entire manufacturing process that convert factories into a smart environment. The cloud enables a global infrastructure to generate new services, allowing anyone to create content and applications for global users. Networks of things connect things globally and maintain their identity online. Mobile allows connection to this global infrastructure anytime, anywhere. The result is a globally accessible network of things, users, and consumers, who are available to create businesses, contribute content, generate and purchase new services.

Platforms also rely on the power of network effects, as they allow more things, they become more valuable to the other things and to users that make use of the services generated. The success of a platform strategy for IoT can be determined by connection, attractiveness and knowledge/information/data flow.

The European Commission while recognizing the potential of Converging Sciences and Technologies Converging Sciences and Technologies to advance

Figure 3.2 Future Communication Challenges – 5G scenarios [2]

the Lisbon Agenda, proposes a bottom-up approach to prioritize the setting of a particular goal for convergence of science and technology research; meet challenges and opportunities for research and governance and allow for integration of technological potential as well as recognition of limits, European needs, economic opportunities, and scientific interests.

Enabling technologies for the Internet of Things considered in [36] can be grouped into three categories: *i*) technologies that enable "things" to acquire contextual information, *ii*) technologies that enable "things" to process contextual information, and *iii*) technologies to improve security and privacy. The first two categories can be jointly understood as functional building blocks required building "intelligence" into "things", which are indeed the features that differentiate the IoT from the usual Internet. The third category is not a *functional* but rather a *de facto* requirement, without which the penetration of the IoT would be severely reduced. Internet of Things developments implies that the environments, cities, buildings, vehicles, clothing, portable devices and other objects have more and more information associated with them and/or the ability to sense, communicate, network and produce new information. In addition the network technologies have to cope with the new challenges such as very high data rates, dense crowds of users, low latency, low energy, low cost and a massive number of devices, The 5G scenarios that reflect the future challenges and will serve as guidance for further work are outlined by the EC funded METIS project [2].

As the Internet of Things becomes established in smart factories, both the volume and the level of detail of the corporate data generated will increase. Moreover, business models will no longer involve just one company, but will instead comprise highly dynamic networks of companies and completely new value chains. Data will be generated and transmitted autonomously by smart machines and these data will inevitably cross company boundaries. A number of specific dangers are associated with this new context – for example, data that were initially generated and exchanged in order to coordinate manufacturing and logistics activities between different companies could, if read in conjunction with other data, suddenly provide third parties with highly sensitive information about one of the partner companies that might, for example, give them an insight into its business strategies. New instruments will be required if companies wish to pursue the conventional strategy of keeping such knowledge secret in order to protect their competitive advantage. New, regulated business models will also be necessary – the raw data that are generated may contain information that is valuable to third parties and companies may therefore wish to make a charge for sharing them. Innovative business models like this will also require legal safeguards (predominantly in the shape of contracts) in order to ensure that the value added created is shared out fairly, e.g. through the use of dynamic pricing models [55].

3.1.1 Internet of Things Common Definition

Ten "critical" trends and technologies impacting IT for the next five years were laid out by Gartner and among them the Internet of Things. All of these things have an IP address and can be tracked. The Internet is expanding into enterprise assets and consumer items such as cars and televisions. The problem is that most enterprises and technology vendors have yet to explore the possibilities of an expanded Internet and are not operationally or organizationally ready. Gartner [54] identifies four basic usage models that are emerging:

- Manage
- Monetize
- Operate
- Extend.

These can be applied to people, things, information, and places, and therefore the so called "Internet of Things" will be succeeded by the "Internet of Everything."

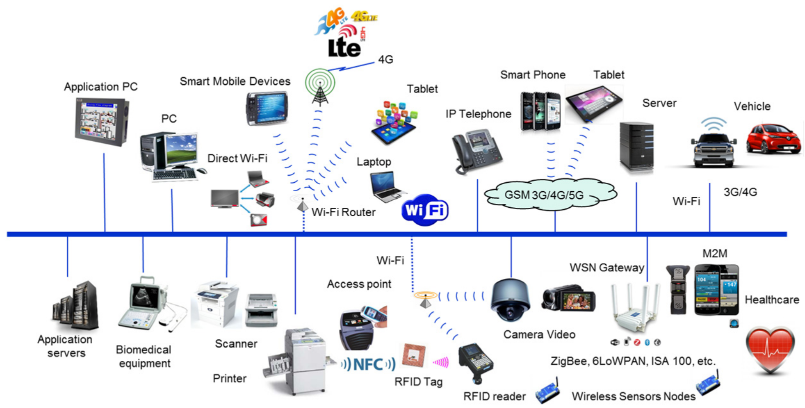

Figure 3.3 IP Convergence

In this context the notion of network convergence using IP is fundamental and relies on the use of a common multi-service IP network supporting a wide range of applications and services.

The use of IP to communicate with and control small devices and sensors opens the way for the convergence of large, IT-oriented networks with real time and specialized networked applications.

The fundamental characteristics of the IoT are as follows [65]:

- Interconnectivity: With regard to the IoT, anything can be interconnected with the global information and communication infrastructure.
- Things-related services: The IoT is capable of providing thing-related services within the constraints of things, such as privacy protection and semantic consistency between physical things and their associated virtual things. In order to provide thing-related services within the constraints of things, both the technologies in physical world and information world will change.
- Heterogeneity: The devices in the IoT are heterogeneous as based on different hardware platforms and networks. They can interact with other devices or service platforms through different networks.
- Dynamic changes: The state of devices change dynamically, e.g., sleeping and waking up, connected and/or disconnected as well as the context of devices including location and speed. Moreover, the number of devices can change dynamically.
- Enormous scale: The number of devices that need to be managed and that communicate with each other will be at least an order of magnitude

> larger than the devices connected to the current Internet. The ratio of communication triggered by devices as compared to communication triggered by humans will noticeably shift towards device-triggered communication. Even more critical will be the management of the data generated and their interpretation for application purposes. This relates to semantics of data, as well as efficient data handling.

The Internet of Things is not a single technology, it's a concept in which most new things are connected and enabled such as street lights being networked and things like embedded sensors, image recognition functionality, augmented reality, near field communication are integrated into situational decision support, asset management and new services. These bring many business opportunities and add to the complexity of IT [52].

To accommodate the diversity of the IoT, there is a heterogeneous mix of communication technologies, which need to be adapted in order to address the needs of IoT applications such as energy efficiency, security, and reliability. In this context, it is possible that the level of diversity will be scaled to a number a manageable connectivity technologies that address the needs of the IoT applications, are adopted by the market, they have already proved to be serviceable, supported by a strong technology alliance. Examples of standards in these categories include wired and wireless technologies like Ethernet, Wi-Fi, Bluetooth, ZigBee, and Z-Wave.

Distribution, transportation, logistics, reverse logistics, field service, etc. are areas where the coupling of information and "things" may create new business processes or may make the existing ones highly efficient and more profitable.

The Internet of Things provides solutions based on the integration of information technology, which refers to hardware and software used to store, retrieve, and process data and communications technology which includes electronic systems used for communication between individuals or groups. The rapid convergence of information and communications technology is taking place at three layers of technology innovation: the cloud, data and communication pipes/networks and device [46].

The synergy of the access and potential data exchange opens huge new possibilities for IoT applications. Already over 50% of Internet connections are between or with things. In 2011 there were over 15 billion things on the Web, with 50 billion+ intermittent connections.

By 2020, over 30 billion connected things, with over 200 billion with intermittent connections are forecast. Key technologies here include

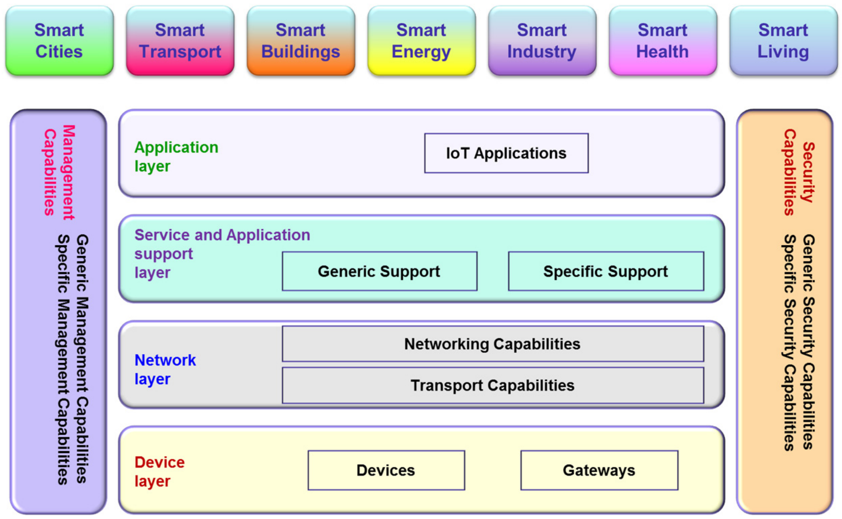

Figure 3.4 IoT Layered Architecture (Source: ITU-T)

embedded sensors, image recognition and NFC. By 2015, in more than 70% of enterprises, a single executable will oversee all Internet connected things. This becomes the Internet of Everything [53].

As a result of this convergence, the IoT applications require that classical industries are adapting and the technology will create opportunities for new industries to emerge and to deliver enriched and new user experiences and services.

In addition, to be able to handle the sheer number of things and objects that will be connected in the IoT, cognitive technologies and contextual intelligence are crucial. This also applies for the development of context aware applications that need to be reaching to the edges of the network through smart devices that are incorporated into our everyday life.

The Internet is not only a network of computers, but it has evolved into a network of devices of all types and sizes, vehicles, smartphones, home appliances, toys, cameras, medical instruments and industrial systems, all connected, all communicating and sharing information all the time.

The Internet of Things had until recently different means at different levels of abstractions through the value chain, from lower level semiconductor through the service providers.

The Internet of Things is a "global concept" and requires a common definition. Considering the wide background and required technologies,

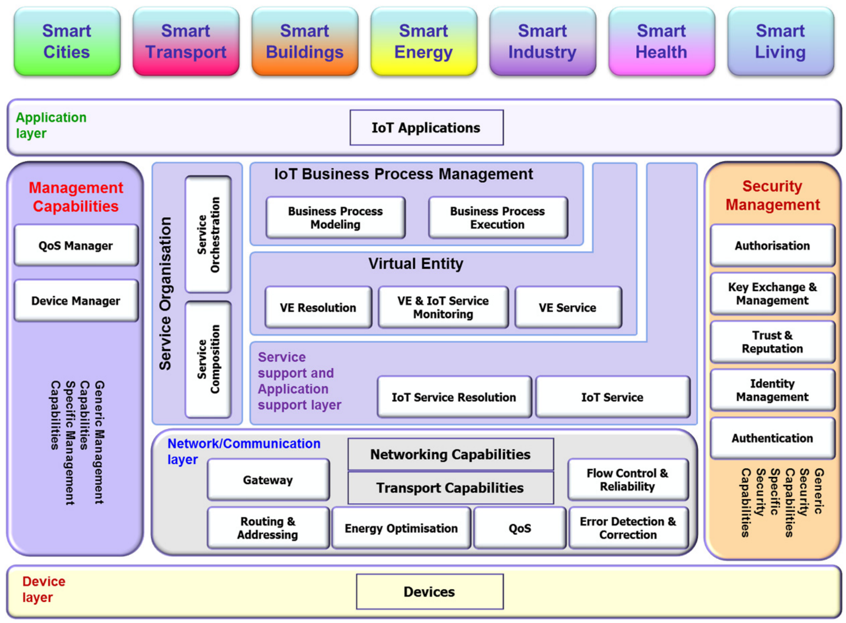

Figure 3.5 Detailed IoT Layered Architecture (Source: IERC)

from sensing device, communication subsystem, data aggregation and pre-processing to the object instantiation and finally service provision, generating an unambiguous definition of the "Internet of Things" is non-trivial.

The IERC is actively involved in ITU-T Study Group 13, which leads the work of the International Telecommunications Union (ITU) on standards for next generation networks (NGN) and future networks and has been part of the team which has formulated the following definition [65]: *"**Internet of things (IoT)**: A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies. NOTE 1 – Through the exploitation of identification, data capture, processing and communication capabilities, the IoT makes full use of things to offer services to all kinds of applications, whilst ensuring that security and privacy requirements are fulfilled. NOTE 2 – From a broader perspective, the IoT can be perceived as a vision with technological and societal implications."*

The IERC definition [67] states that IoT is "*A dynamic global network infrastructure with self-configuring capabilities based on standard and inter-operable communication protocols where physical and virtual "things" have*

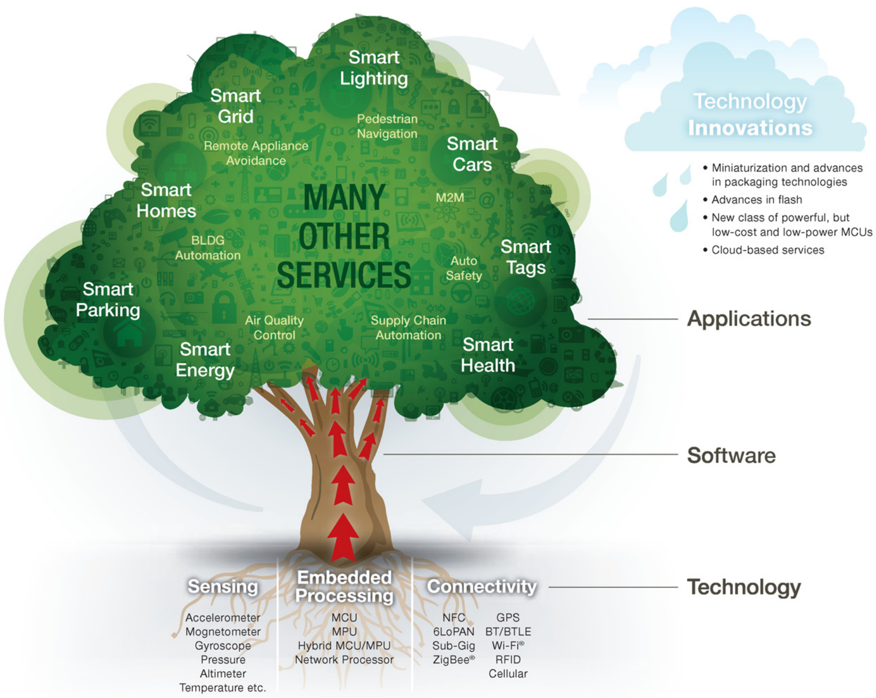

Figure 3.6 The IoT: Different Services, Technologies, Meanings for Everyone [77]

identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network.".

3.2 IoT Strategic Research and Innovation Directions

The development of enabling technologies such as nanoelectronics, communications, sensors, smart phones, embedded systems, cloud networking, network virtualization and software will be essential to provide to things the capability to be connected all the time everywhere. This will also support important future IoT product innovations affecting many different industrial sectors. Some of these technologies such as embedded or cyber-physical systems form the edges of the Internet of Things bridging the gap between cyber space and the physical world of real things, and are crucial in enabling the Internet of Things to deliver on its vision and become part of bigger systems in a world of "systems of systems".

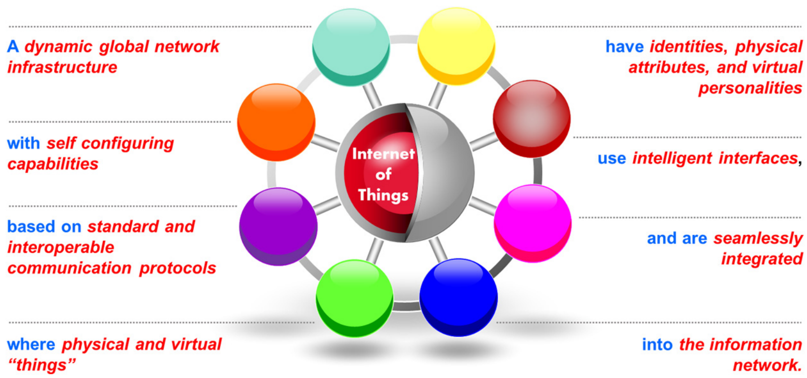

Figure 3.7 IoT Definition [68]

The final report of the Key Enabling Technologies (KET), of the High-Level Expert Group [47] identified the enabling technologies, crucial to many of the existing and future value chains of the European economy:

- Nanotechnologies.
- Micro and Nano electronics
- Photonics
- Biotechnology
- Advanced Materials
- Advanced Manufacturing Systems.

As such, IoT creates intelligent applications that are based on the supporting KETs identified, as IoT applications address smart environments either physical or at cyber-space level, and in real time.

To this list of key enablers, we can add the global deployment of IPv6 across the World enabling a global and ubiquitous addressing of any communicating smart thing.

From a technology perspective, the continuous increase in the integration density proposed by Moore's Law was made possible by a dimensional scaling: in reducing the critical dimensions while keeping the electrical field constant, one obtained at the same time a higher speed and a reduced power consumption of a digital MOS circuit: these two parameters became driving forces of the microelectronics industry along with the integration density.

The International Technology Roadmap for Semiconductors has emphasized in its early editions the "miniaturization" and its associated benefits in terms of performances, the traditional parameters in Moore's Law. This trend for increased performances will continue, while performance can always be traded against power depending on the individual application, sustained by the incorporation into devices of new materials, and the application of new transistor concepts. This direction for further progress is labelled “More Moore”.

The second trend is characterized by functional diversification of semiconductor-based devices. These non-digital functionalities do contribute to the miniaturization of electronic systems, although they do not necessarily scale at the same rate as the one that describes the development of digital functionality. Consequently, in view of added functionality, this trend may be designated “More-than-Moore” [50].

Mobile data traffic is projected to double each year between now and 2015 and mobile operators will find it increasingly difficult to provide the bandwidth requested by customers. In many countries there is no additional spectrum that can be assigned and the spectral efficiency of mobile networks is reaching its physical limits. Proposed solutions are the seamless integration of existing Wi-Fi networks into the mobile ecosystem. This will have a direct impact on Internet of Things ecosystems.

The chips designed to accomplish this integration are known as “multi-com” chips. Wi-Fi and baseband communications are expected to converge and the architecture of mobile devices is likely to change and the baseband chip is expected to take control of the routing so the connectivity components are connected to the baseband or integrated in a single silicon package. As a result of this architecture change, an increasing share of the integration work is likely done by baseband manufacturers (ultra -low power solutions) rather than by handset producers.

The market for wireless communications is one of the fastest-growing segments in the integrated circuit industry. Breath takingly fast innovation, rapid changes in communications standards, the entry of new players, and the evolution of new market sub segments will lead to disruptions across the industry. LTE and multicom solutions increase the pressure for industry consolidation, while the choice between the ARM and x86 architectures forces players to make big bets that may or may not pay off [63].

Integrated networking, information processing, sensing and actuation capabilities allow physical devices to operate in changing environments. Tightly coupled cyber and physical systems that exhibit high level of integrated intelligence are referred to as cyber-physical systems. These systems are part of the enabling technologies for Internet of Things applications where computational and physical processes of such systems are tightly interconnected and coordinated to work together effectively, with or without the humans in the

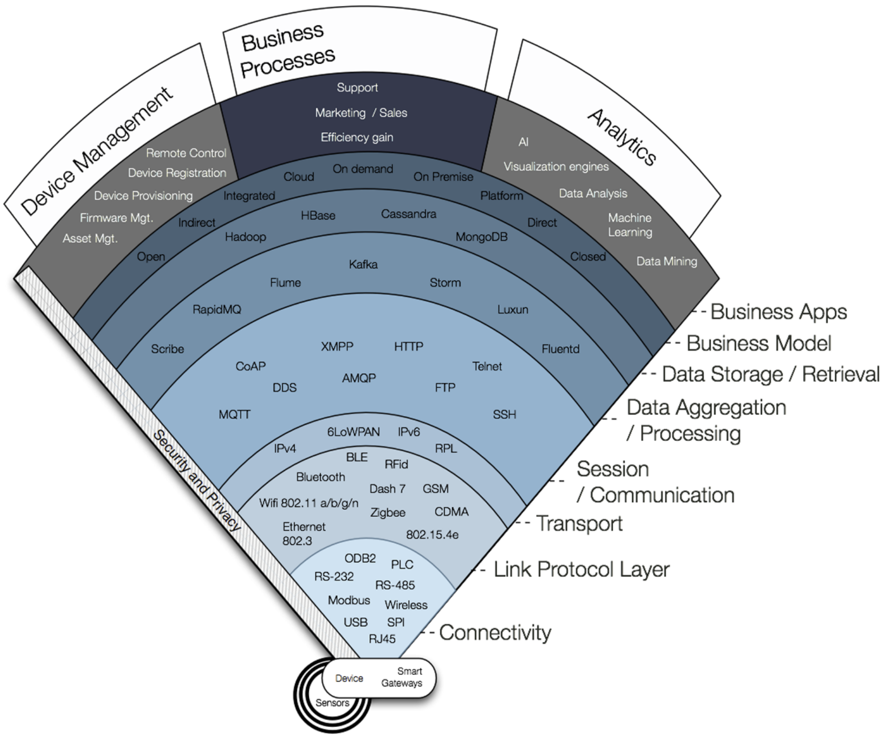

Figure 3.8 IoT landscape [21]

loop. Robots, intelligent buildings, implantable medical devices, vehicles that drive themselves or planes that automatically fly in a controlled airspace, are examples of cyber-physical systems that could be part of Internet of Things ecosystems.

Today many European projects and initiatives address Internet of Things technologies and knowledge. Given the fact that these topics can be highly diverse and specialized, there is a strong need for integration of the individual results. Knowledge integration, in this context is conceptualized as the process through which disparate, specialized knowledge located in multiple projects across Europe is combined, applied and assimilated.

The Strategic Research and Innovation Agenda (SRIA) is the result of a discussion involving the projects and stakeholders involved in the IERC activities, which gather the major players of the European ICT landscape addressing IoT technology priorities that are crucial for the competitiveness of European industry:

Figure 3.9 Internet of Things — Enabling Technologies

IERC Strategic Research and Innovation Agenda covers the important issues and challenges for the Internet of Things technology. It provides the vision and the roadmap for coordinating and rationalizing current and future research and development efforts in this field, by addressing the different enabling technologies covered by the Internet of Things concept and paradigm.

Many other technologies are converging to support and enable IoT applications. These technologies are summarised as:

- IoT architecture
- Identification
- Communication
- Networks technology
- Network discovery
- Software and algorithms
- Hardware technology
- Data and signal processing
- Discovery and search engine
- Network management
- Power and energy storage
- Security, trust, dependability and privacy

- Interoperability
- Standardization

The Strategic Research and Innovation Agenda is developed with the support of a European-led community of interrelated projects and their stakeholders, dedicated to the innovation, creation, development and use of the Internet of Things technology.

Since the release of the first version of the Strategic Research and Innovation Agenda, we have witnessed active research on several IoT topics. On the one hand this research filled several of the gaps originally identified in the Strategic Research and Innovation Agenda, whilst on the other it created new challenges and research questions. Recent advances in areas such as cloud computing, cyber-physical systems, autonomic computing, and social networks have changed the scope of the Internet of Thing's convergence even more so. The Cluster has a goal to provide an updated document each year that records the relevant changes and illustrates emerging challenges. The updated release of this Strategic Research and Innovation Agenda builds incrementally on previous versions [68], [69], [84], [85], [85] and highlights the main research topics that are associated with the development of IoT enabling technologies, infrastructures and applications with an outlook towards 2020 [73].

The research items introduced will pave the way for innovative applications and services that address the major economic and societal challenges underlined in the EU 2020 Digital Agenda [74].

Figure 3.10 Internet of Things - Smart Environments and Smart Spaces Creation

The IERC Strategic Research and Innovation Agenda is developed incrementally based on its previous versions and focus on the new challenges being identified in the last period.

The timeline of the Internet of Things Strategic Research and Innovation Agenda covers the current decade with respect to research and the following years with respect to implementation of the research results. Of course, as the Internet and its current key applications show, we anticipate unexpected trends will emerge leading to unforeseen and unexpected development paths.

The Cluster has involved experts working in industry, research and academia to provide their vision on IoT research challenges, enabling technologies and the key applications, which are expected to arise from the current vision of the Internet of Things.

The IoT Strategic Research and Innovation Agenda covers in a logical manner the vision, the technological trends, the applications, the technology enablers, the research agenda, timelines, priorities, and finally summarises in two tables the future technological developments and research needs.

Advances in embedded sensors, processing and wireless connectivity are bringing the power of the digital world to objects and places in the physical world. IoT Strategic Research and Innovation Agenda is aligned with the findings of the 2011 Hype Cycle developed by Gartner [76], which includes the broad trend of the Internet of Things, called the "real-world Web" in earlier Gartner research.

The field of the Internet of Things is based on the paradigm of supporting the IP protocol to all edges of the Internet and on the fact that at the edge of the network many (very) small devices are still unable to support IP protocol stacks. This means that solutions centred on minimum Internet of Things devices are considered as an additional Internet of Things paradigm *without IP to all access edges*, due to their importance for the development of the field.

3.2.1 IoT Applications and Use Case Scenarios

The IERC vision is that "the major objectives for IoT are the creation of smart environments/spaces and self-aware things (for example: smart transport, products, cities, buildings, rural areas, energy, health, living, etc.) for climate, food, energy, mobility, digital society and health applications"[68].

The outlook for the future is the emerging of a network of interconnected uniquely identifiable objects and their virtual representations in an Internet alike structure that is positioned over a network of interconnected computers allowing for the creation of a new platform for economic growth.

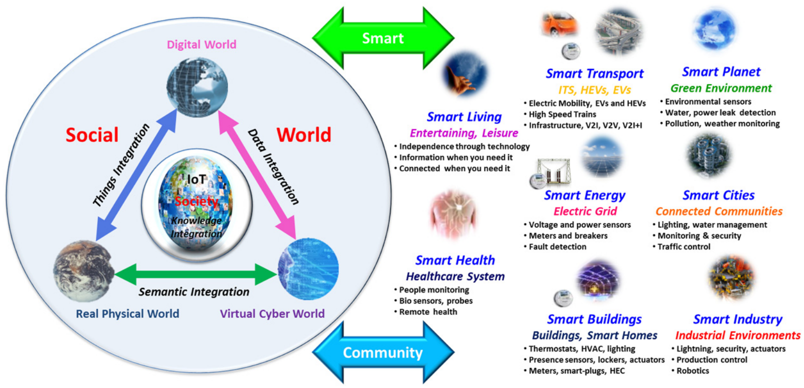

Figure 3.11 Internet of Things in the context of Smart Environments and Applications [84]

Smart is the new green as defined by Frost & Sullivan [51] and the green products and services will be replaced by smart products and services. Smart products have a real business case, can typically provide energy and efficiency savings of up to 30 per cent, and generally deliver a two- to three-year return on investment. This trend will help the deployment of Internet of Things applications and the creation of smart environments and spaces.

At the city level, the integration of technology and quicker data analysis will lead to a more coordinated and effective civil response to security and safety (law enforcement and blue light services); higher demand for outsourcing security capabilities.

At the building level, security technology will be integrated into systems and deliver a return on investment to the end-user through leveraging the technology in multiple applications (HR and time and attendance, customer behaviour in retail applications etc.).

There will be an increase in the development of "Smart" vehicles which have low (and possibly zero) emissions. They will also be connected to infrastructure. Additionally, auto manufacturers will adopt more use of "Smart" materials.

The key focus will be to make the city smarter by optimizing resources, feeding its inhabitants by urban farming, reducing traffic congestion, providing more services to allow for faster travel between home and various destinations, and increasing accessibility for essential services. It will become essential to have intelligent security systems to be implemented at key junctions in the city. Various types of sensors will have to be used to make this a reality. Sensors are moving from "smart" to "intelligent". Biometrics is already integrated in the smart mobile phones and is expected to be used together with CCTV at highly sensitive locations around the city. National identification cards will also become an essential tool for the identification of an individual. In addition, smart cities in 2020 will require real time auto identification security systems.

The IoT brings about a paradigm were everything is connected and will redefine the way humans and machines interface and the way they interact with the world around them.

Fleet Management is used to track vehicle location, hard stops, rapid acceleration, and sudden turns using sophisticated analysis of the data in order to implement new policies (e.g., no right/left turns) that result in cost savings for the business.

Today there are billions of connected sensors already deployed with smart phones and many other sensors are connected to these smart mobile network using different communication protocols.

The challenges is in getting the data from them in an interoperable format and in creating systems that break vertical silos and harvest the data across domains, thus unleashing truly useful IoT applications that are user centred, context aware and create new services by communication across the verticals.

Wastewater treatment plants will evolve into bio-refineries. New, innovative wastewater treatment processes will enable water recovery to help close the growing gap between water supply and demand.

Self-sensing controls and devices will mark new innovations in the Building Technologies space. Customers will demand more automated, self-controlled solutions with built in fault detection and diagnostic capabilities.

Development of smart implantable chips that can monitor and report individual health status periodically will see rapid growth.

Smart pumps and smart appliances/devices are expected to be significant contributors towards efficiency improvement. Process equipment with in built "smartness" to self-assess and generate reports on their performance, enabling efficient asset management, will be adopted.

Test and measurement equipment is expected to become smarter in the future in response to the demand for modular instruments having lower power consumption. Furthermore, electronics manufacturing factories will become more sustainable with renewable energy and sell unused energy back to the grid, improved water conservation with rain harvesting and implement other smart building technologies, thus making their sites "Intelligent Manufacturing Facilities".

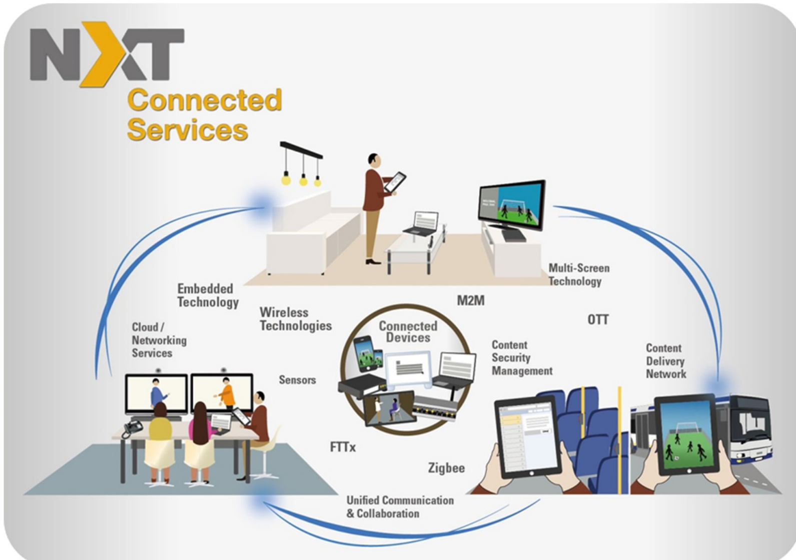

Figure 3.12 Connected Devices Illustration [62]

General Electric Co. considers that this is taking place through the convergence of the global industrial system with the power of advanced computing, analytics, low-cost sensing and new levels of connectivity permitted by the Internet. The deeper meshing of the digital world with the world of machines holds the potential to bring about profound transformation to global industry, and in turn to many aspects of daily life [58].

The Industrial Internet starts with embedding sensors and other advanced instrumentation in an array of machines from the simple to the highly complex. This allows the collection and analysis of an enormous amount of data, which can be used to improve machine performance, and inevitably the efficiency of the systems and networks that link them. Even the data itself can become “intelligent,” instantly knowing which users it needs to reach.

Consumer IoT is essentially wireless, while the industrial IoT has to deal with an installed base of millions of devices that could potentially become part of this network (many legacy systems installed before IP deployment). These industrial objects are linked by wires that provides the reliable communications needed. The industrial IoT has to consider the legacy using specialised protocols, including Lonworks, DeviceNet, Profibus and CAN and they will be connected into this new netwoek of networks through gateways.

The automation and management of asset-intensive enterprises will be transformed by the rise of the IoT, Industry 4.0, or simply Industrial Internet. Compared with the Internet revolution, many product and asset management solutions have labored under high costs and poor connectivity and performance. This is now changing. New high-performance systems that can support both Internet and Cloud connectivity as well as predictive asset management are reaching the market. New cloud computing models, analytics, and aggregation technologies enable broader and low cost application of analytics across these much more transparent assets. These developments have the potential to radically transform products, channels, and company business models. This will create disruptions in the business and opportunities for all types of organizations - OEMs, technology suppliers, system integrators, and global consultancies. There may be the opportunity to overturn established business models, with a view toward answering customer pain points and also growing the market in segments that cannot be served economically with today's offerings. Mobility, local diagnostics, and remote asset monitoring are important components of these new solutions, as all market participants need ubiquitous access to their assets, applications, and customers. Real-time mobile applications support EAM, MRO, inventory management, inspections, workforce management, shop floor interactions, facilities management, field service automation, fleet management, sales and marketing, machine-to-machine (M2M), and many others [56]

In this context the new concept of Internet of Energy requires web based architectures to readily guarantee information delivery on demand and to change the traditional power system into a networked Smart Grid that is largely automated, by applying greater intelligence to operate, enforce policies, monitor and self-heal when necessary. This requires the integration and interfacing of the power grid to the network of data represented by the Internet, embracing energy generation, transmission, delivery, substations, distribution control, metering and billing, diagnostics, and information systems to work seamlessly and consistently.

This concept would enable the ability to produce, store and efficiently use energy, while balancing the supply/demand by using a cognitive Internet of Energy that harmonizes the energy grid by processing the data, information and knowledge via the Internet. The Internet of Energy concept as presented in Figure 3.14 [35] will leverage on the information highway provided by the Internet to link devices and services with the distributed smart energy grid that is the highway for renewable energy resources allowing stakeholders to

Figure 3.13 Industrial Internet of Things [56]

use green technologies and sell excess energy back to the utility. The concept has the energy management element in the centre of the communication and exchange of data and energy.

The Internet of Energy applications are connected through the Future Internet and "Internet of Things" enabling seamless and secure interactions and cooperation of intelligent embedded systems over heterogeneous communication infrastructures.

It is expected that this "development of smart entities will encourage development of the novel technologies needed to address the emerging challenges of public health, aging population, environmental protection and climate change, conservation of energy and scarce materials, enhancements to safety and security and the continuation and growth of economic prosperity." The IoT applications are further linked with Green ICT, as the IoT will drive energy-efficient applications such as smart grid, connected electric cars, energy-efficient buildings, thus eventually helping in building green intelligent cities.

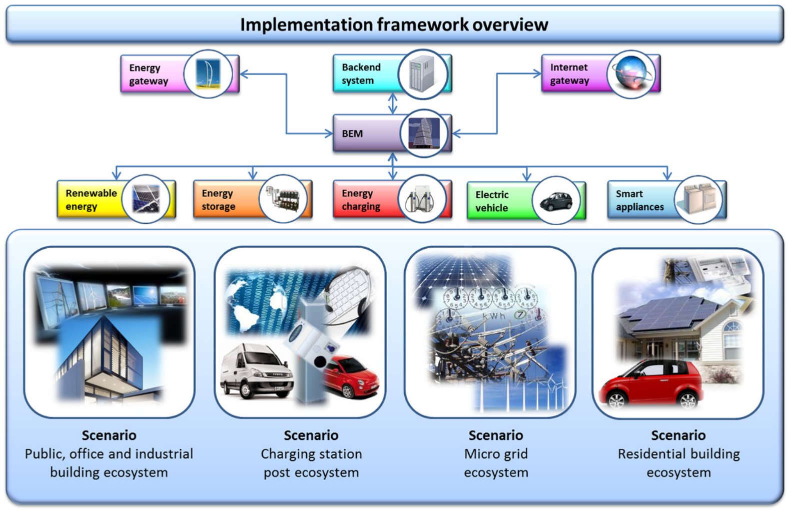

Figure 3.14 Internet of Energy Implementation Framework (Source:[35])

3.2.2 IoT Functional View

The Internet of Things concept refers to uniquely identifiable things with their virtual representations in an Internet-like structure and IoT solutions comprising a number of components such as:

- Module for interaction with local IoT devices (for example embedded in a mobile phone or located in the immediate vicinity of the user and thus contactable via a short range wireless interface). This module is responsible for acquisition of observations and their forwarding to remote servers for analysis and permanent storage.
- Module for local analysis and processing of observations acquired by IoT devices.
- Module for interaction with remote IoT devices, directly over the Internet or more likely via a proxy. This module is responsible for acquisition of observations and their forwarding to remote servers for analysis and permanent storage.
- Module for application specific data analysis and processing. This module is running on an application server serving all clients. It is taking requests from mobile and web clients and relevant IoT observations as input, executes appropriate data processing algorithms and generates output in terms of knowledge that is later presented to users.

- Module for integration of IoT-generated information into the business processes of an enterprise. This module will be gaining importance with the increased use of IoT data by enterprises as one of the important factors in day-to-day business or business strategy definition.
- User interface (web or mobile): visual representation of measurements in a given context (for example on a map) and interaction with the user, i.e. definition of user queries.

It is important to highlight that one of the crucial factors for the success of IoT is stepping away from vertically-oriented, closed systems towards open systems, based on open APIs and standardized protocols at various system levels.

In this context innovative architecture and platforms are needed to support highly complex and inter-connected IoT applications. A key consideration is how to enable development and application of comprehensive architectural frameworks that include both the physical and cyber elements based on enabling technologies. In addition considering the technology convergence trend new platforms will be needed for communication and to effectively extract actionable information from vast amounts of raw data, while providing a robust timing and systems framework to support the real-time control and synchronization requirements of complex, networked, engineered physical/cyber/virtual systems.

A large number of applications made available through application markets have significantly helped the success of the smart phone industry. The development of such a huge number of smart phone applications is primarily due to involvement of the developers' community at large. Developers leveraged smart phone open platforms and the corresponding development tools, to create a variety of applications and to easily offer them to a growing number of users through the application markets.

Similarly, an IoT ecosystem has to be established, defining open APIs for developers and offering appropriate channels for delivery of new applications. Such open APIs are of particular importance on the level of the module for application specific data analysis and processing, thus allowing application developers to leverage the underlying communication infrastructure and use and combine information generated by various IoT devices to produce new, added value.

Although this might be the most obvious level at which it is important to have open APIs, it is equally important to aim towards having such APIs defined on all levels in the system. At the same time one should have in mind the heterogeneity and diversity of the IoT application space. This will truly support the development of an IoT ecosystem that encourages development of new applications and new business models.

The complete system will have to include supporting tools providing security and business mechanisms to enable interaction between a numbers of different business entities that might exist [86].

Research challenges:

- Design of open APIs on all levels of the IoT ecosystem
- Design of standardized formats for description of data generated by IoT devices to allow mashups of data coming from different domains and/or providers.

3.2.3 Application Areas

In the last few years the evolution of markets and applications, and therefore their economic potential and their impact in addressing societal trends and challenges for the next decades has changed dramatically. Societal trends are grouped as: health and wellness, transport and mobility, security and safety, energy and environment, communication and e-society. These trends create significant opportunities in the markets of consumer electronics, automotive electronics, medical applications, communication, etc. The applications in in these areas benefit directly by the More-Moore and More-than-Moore semiconductor technologies, communications, networks and software developments.

Potential applications of the IoT are numerous and diverse, permeating into practically all areas of every-day life of individuals, enterprises, and society as a whole. The IERC [68–69], [84–85] has identified and described the main Internet of Things applications, which span numerous applications domains: smart energy, smart health, smart buildings, smart transport, smart industry and smart city. The vision of a pervasive IoT requires the integration of the various domains into a single, unified, domain and addresses the enabling technologies needed for these domains while taking into account the elements that form the third dimension like security, privacy, trust, safety.

The IoT application domains identified by IERC [68], [85] are based on inputs from experts, surveys [86] and reports [87]. The IoT application covers "smart" environments/spaces in domains such as: Transportation, Building, City, Lifestyle, Retail, Agriculture, Factory, Supply chain, Emergency, Health care, User interaction, Culture and tourism, Environment and Energy.

The applications areas include as well the domain of Industrial Internet [58] where intelligent devices, intelligent systems, and intelligent decision-making