Internet of Things: The Foundational Infrastructure for a Smarter Planet

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Abstract. Every day, our world is getting more instrumented and interconnected. Streams of data are continuously being generated by mobile devices, personal computers, networks, sensors, RFID tags, web services, social media and the like. IBM's newest study reveals how new technologies support the development of the Internet of Things, and how the Internet of Things provides the foundational infrastructure for a smarter planet. Key trends that relate to the Internet of Things include Mobile, Big Data, Cloud Computing, and Smart Networks. The paper describes the latest developments in Mobile, Big Data (including cognitive systems capable to evaluate large amounts of both structured and unstructured data), Cloud Computing and Smarter networks (including software defined environments to cope with the ever increasing workloads in the networks).

Keywords: IoT, Mobile, Big Data, Cloud Computing, Software Defined Environment.

1 Introduction

The Internet of Things (IoT) is a technological revolution in the future of communication and computing that is based on the concept of any place, anytime connectivity for anything [1]. Even in these early stages, the IoT has transformed the way consumers and corporations interact with each other and the environment around them. IoT technologies have impacted solution domains, such as Smart Grid, Supply Chain Management, Smart Cities, and Smart Home. The IoT is a computing paradigm that will change business consumer experiences, models, technology investments, and everyday life.

The IoT also represents a network of Internet-enabled, real-world objects, such as consumer electronics, nanotechnology, home appliances, embedded systems, sensors of all kinds, and personal mobile devices. It includes enabling network and communication technologies, such as web services, RFID, IPv6, and 4G networks. We are already applying IoT solutions in practical ways by using mobile devices. For example, people can monitor their home security, lights, heating, and cooling from their smartphone. They can purchase a refrigerator that monitors its processes and sends reports to their smartphone.

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It is critical for us to consider the challenges and approaches in an IoT-centric ecosystem. The primary focus must be on critical operational considerations, such as scalability, availability, manageability, data management, and security.

- Scalability

An IoT environment contains two scalability issues, each of which poses unique challenges. The first scalability issue is based on the number of connected devices and include the number of concurrent connections, or throughput, that a system can support and the quality of service (QoS) level that can be guaranteed. Here, Internet scalability is a critical factor. Currently, most Internet-connected devices use IPv4, which does not provide sufficient unique addresses for the IoT, and optimum scalability would require migrating to IPv6 [2]. The second issue is based on the volume of generated data, and highlight performance issues that are associated with data collection, processing, storage, query, and display. IoT systems need to handle both device and data scalabilities.

- Availability

IoT availability involves reliability and recoverability. One architecture implication to availability is driven by the increased demand around cloud computing and *x*-as-a-service, such as software as a service. Corporations must closely look at the implications to the services and capabilities that are required in an IoT environment. An innovative solution addresses fault avoidance/intolerance in ways that will facilitate a business to meet enterprise needs and customer expectations.

- Manageability

Currently, only IT-related systems, such as computers, servers, and storage devices, are managed under a governance model. Most other IoT devices are not managed systematically as part of a larger ecosystem. Many devices operate remotely without direct human interaction, which requires management of such devices in the same way, that is, remotely and without human intervention. New approaches are required to develop an IoT architecture and to manage its lifecycle.

- Managing data

Big data and the IoT are computing paradigms that, together, fundamentally change the nature of how we work, and interact with our environment. Where big data is all about volume, velocity, verity, and veracity, the IoT is about using that data in meaningful ways to improve productivity and quality of life. For example, the IoT can collect temporospatial information, which is both temporal (time) and spatial (location) data. This information, when combined with analytic technology, provides new insight into when, where, and how devices and humans can or should interact. The key issue is how corporations handle storing, managing, and manipulating this data.

- Security

Traditional IT security establishes secure boundaries and firewalls around internal IT systems. But with the Internet of Things, the concept of *controlled access* has changed to one of *controlled trust* that offers the widest range of possible solutions. Security challenges require IoT implementations to effectively deal with authentication, authorization, access control, trust and privacy requirements without negatively impacting usability.

The IoT represents the logical evolution in mobile, big data, cloud and smarter networks:

- *Mobile*: Mobile is becoming a part of everything we do
- *Big data*: The increasing number of ‘things’ will produce a tsunami of data, taxing our already complex information management systems
- *Clouds*: IoT systems require systems to scale quickly and autonomously
- *Smart Networks*: Networks must enable trillions of devices and objects to ‘talk’

Most of the elements in the IoT are *mobile* devices whether they are smart phones, tablets, automobiles or smart grids. They are connected wirelessly, and they each have an IP address. It is estimated that by 2015 we will have 1 trillion of such devices. These devices are not isolated instruments. The whole purpose of the device is to connect to networks, applications, data and people, that is to be interconnected. Mobile can be leveraged to gather information, often in real time, and push out insights for better, faster decision making.

Mobile extends to Machine-to-Machine (M2M) as well. Advances in technology are enabling M2M connections that are creating new operating models and opportunities to provide business value. We are able to identify things through tagging and sensing them. Advances in nanotechnology are helping us infuse intelligence and processing power into mobile objects to create thinking things. Advances in power technology allow us to power things more efficiently and for longer periods of time and in increasingly remote location. The ability to tag, sense, power and shrink things has extended mobility beyond people to nearly every type of object on the world. Mobile is right at the center of the IoT story.

In the following sections, we will focus on three other key trends that relate to the IoT: Big Data (analytics), Cloud computing and Smart networks.

2 Big Data Is Getting Bigger

Ten to fifteen years ago data was coming in from just a few sources, mainly customer transactions and supply chain transactions. Today, data is coming in from everywhere, ranging from the consumer space (personal devices like smartphones, gadgets, implants, etc.) to the service space (Internet services, local environment services, etc.). In addition, the huge growth of pictures, audio, video, social media and other unstructured data is taxing the storage systems and information databases of many data centers.

Our appetite for creating, gathering and storing data continues to grow and grow and grow. IDC forecasts 15 billion devices will be communicating over the network in 2015 [3]. Ericsson estimates 50 billion devices will be connected to the Web by the year 2020, producing enormous streams of data [4].

To more clearly understand how organizations – and in particular communications service providers (CSPs) – view big data in the Internet of Things, the IBM Institute for Business Value conducted a global big data study, surveying 1144 businesses and IT professionals in 95 countries [5]. The CSPs in this survey responded quite differently on a number of questions as compared to the other industries. For instance, more than any other industry we studied, CSP respondents define big data as the capabilities needed to perform ‘*real-time*’ information analysis (see Fig 1). In fact, 40% percent of CSPs defined big data as such, in contrast to only 15 percent in the total sample.

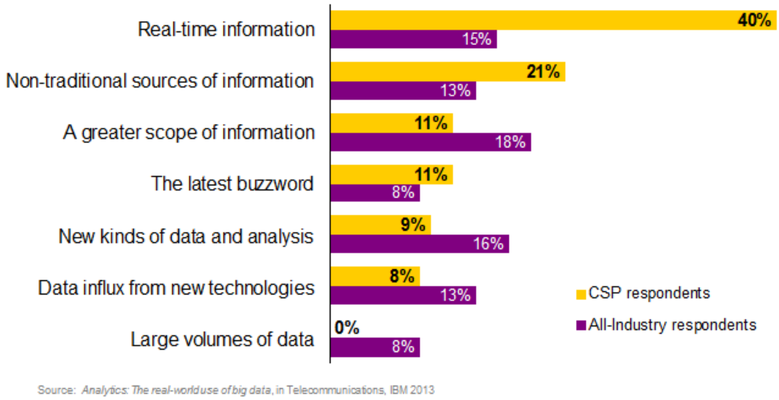

Fig. 1. For CSPs, big data is best described by the emerging requirements for real-time information

While large volumes of data are not new to CSPs – collecting millions of call detail records per day has become routine – the level of complexity of data today is a significant challenge. Analyzing the contextual data provided today by smartphones, tablets, personal computers, networks, sensors, RFID tags, web services, social media and the like, in near real-time is becoming increasingly complex yet crucial. Moreover, with the advent of smart phones, tablets and other devices that are application dependent, the volume of signaling data – i.e. non-message information about the device, its location and updates – has also increased significantly.

The real-time aspect of big data is extremely important for the IoT. For consumers, IoT and Contextual Services will make their lives fully connected. Today, mass production is no longer good enough; smarter consumers expect unique products and services customized for themselves. Interconnected devices are enabling mass personalization through contextual-awareness by utilizing continuous processing to make meaningful inferences that can benefit the end user.

For businesses and government organizations the real-time aspect is very important in cases that require quick decision-making, such as logistic problems or spread of infectious diseases. Big data approaches can help cities to leverage near-real time city information, anticipate incidents and coordinate resources to give support in the event of an emergency. The Operations Center implanted in Rio de Janeiro, for example, is using a forecasting system that synthesizes data from rivers, historical rainfall logs and radar feeds in order to anticipate heavy rains, flash floods, landslides, power outages and traffic hazards [6].

Big data itself does not create value in the IoT, until it is put to use to solve important issues or challenges. This requires access to more - and different kinds of - data, as well as adequate analytics capabilities.

Examining the responses in our global big data survey, more than 75 percent of all types of organizations reported to have started with a strong core of analytics capabilities - such as data mining - to analyze big data to support key decision processes. This can transform data into insight by delivering relevant, integrated, timely and actionable information. Two-thirds reported using predictive modeling, enabling them to start the transition to an optimized, 'outcomes-focused' environment. Predictive capabilities can create foreknowledge and deep awareness of consumer, operations and network behaviors [7].

Big data increasingly creates the need to analyze multiple data types, including location data, social media, data from sensors and natural language text. In more than half of the active big data efforts, respondents reported using advanced capabilities designed to analyze text in its natural state. These analytics include the ability to interpret and understand the nuances of language, such as sentiment, slang and intentions.

Intelligent analytics and 'autonomics' can help create a highly dynamic and efficient information-centric environment. A system that is automated and aware of real-time events can provide input to promote solutions for immediate execution. As contextual information from the IoT and all other types of environments – including data produced by social platforms – becomes more important to support effective decision making, organizations should increasingly focus on acquiring the capabilities needed to wield prescriptive analytics designed to automate actions.

New powerful technologies – including cognitive systems [8] – are capable of evaluating large amounts of both structured and unstructured data in or near real-time. Whereas in today's programmable era, computers essentially process a series of "if then what" equations, cognitive systems learn, adapt, and ultimately hypothesize and suggest answers.

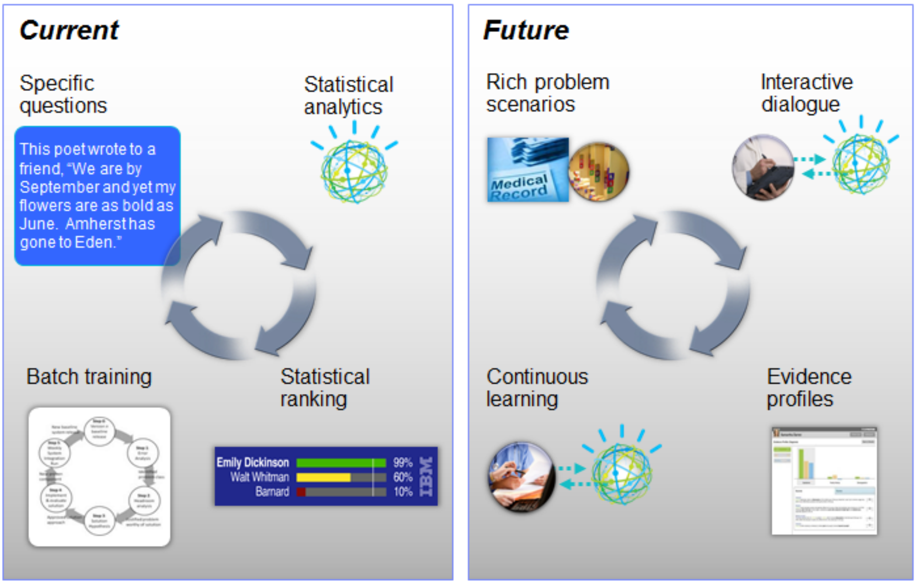

Fig. 2. Cognitive systems

Cognitive computing aims to break the conventional programmable machine paradigm and to evolve to entirely new computing architectures and programming paradigms. The end goal: ubiquitously deployed computers imbued with a new intelligence that can integrate information from a variety of sensors and sources, deal with ambiguity, respond in a context-dependent way, learn over time and carry out pattern recognition to solve difficult problems based on perception, action and cognition in complex, real-world environments (Fig 2).

Watson technology, for example, applies advanced natural language processing, information retrieval, knowledge representation and reasoning, and machine learning technologies to answering questions. It can sift through an equivalent of about 1 million books or roughly 200 million pages of data, and analyze this information and provide precise answers in less than three seconds [9].

Cognitive computers are expected to learn through experiences, find correlations, create hypotheses, and remember - and learn from - the outcomes, mimicking the brains structural and synaptic plasticity. Next steps to more advanced cognitive computing includes:

- development of chips that enable brain's abilities to perception, action and cognition
- computer simulation of the human brain
- exascale computing that will be more than 80% faster than today's fastest computers while consuming just a trickle of energy through designs inspired by human brains

3 Clouds That Scale

For the full power of the IoT to be realized, the utilization of cloud computing is fundamental. The 'things' in the IoT - such as sensors in cars, cameras, food packages, refrigerators and the like - are generally very small, primary doing M2M communications and constrained in capacity. Cloud computing on the other hand has unlimited capabilities in terms of storage and processing power. Where sensors act as the digital *nerves* for connected devices, the cloud can be seen as the *brain* to improve decision-making and optimization for internet-connected actions related to these devices.

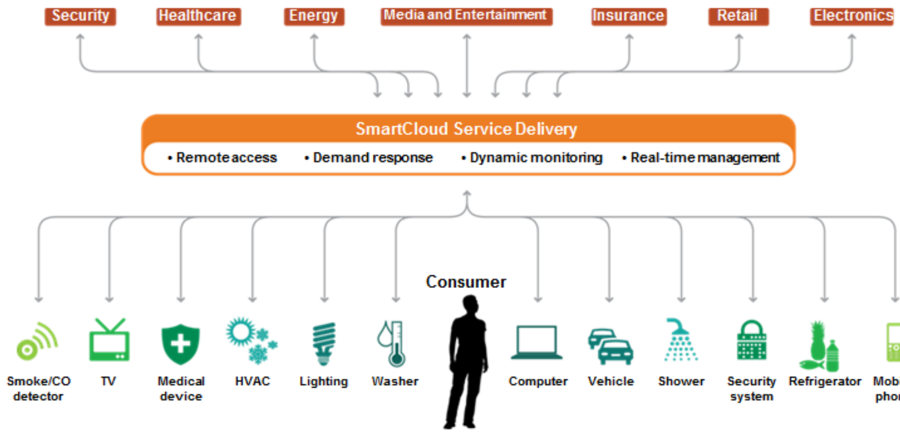

Fig. 3. Devices connect to the Cloud, reducing complexity and further empowering the consumer

Cloud-based M2M technology is becoming increasingly important in smarter healthcare, smarter utilities, smarter cities and smarter homes, to mention a view (see Fig 3). The next wave of Internet applications promise to have a massive impact on the society as a whole, and cloud computing – though IoT may change the overall architecture of the cloud – will provide the virtual infrastructure for all these applications.

Home automation is the "top of mind" application for many when discussing IoT. The market for cloud-based smarter home services is maturing in four key segments:

- *Entertainment and convenience:* create an open platform for new lines of televisions and devices that feature a portal which personalizes entertainment content from numerous content providers
- *Energy management*: automatically synchronize lighting, home appliances, climate control sensors and other electronics to minimize energy use based on changing exterior conditions and usage patterns in the home
- *Safety and security*: deploy home sensors that can instantly notify the homeowner, police and fire departments and selected neighbors – enhancing home security and providing peace of mind
- *Health and wellness*: continually monitor the health and fitness of patients using implanted or other at-home medical devices, avoiding the need to hospitalization or office visits.

Some CSPs are already exploring the potential to combine the pervasiveness of mobile technology with the ubiquity of the cloud platform. This milestone will pave the way for consumers to better control 'their' IoT, such as managing heating, lighting, laundry and the like via the CSP's mobile wireless network (see Fig 4).

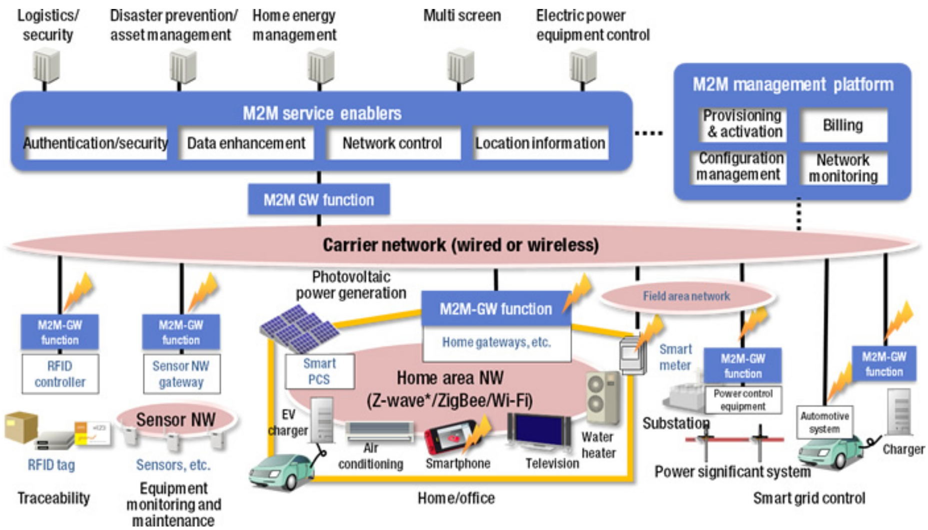

Fig. 4. In a M2M platform a variety of different devices are connected through fixed and wireless networks [10]

Vodafone, for example, combines mobile communications and cloud computing for the remote management of smart home appliances. The system combines Vodafone's Global M2M platform with a Smart Cloud platform to enable connected "smart" appliances to feed useful data to either service provider or vendor [11]. The system allows customers to control appliances through smartphones, with remote activities including the viewing of utility consumptions, security control, heating and lighting systems and the activation of appliances. It also provides vendors with a scaleable appliance management cloud-based platform, as well as the means to quickly introduce new consumer services.

This Vodafone smarter home initiative is a peek into a larger vision for mobile + Cloud-based innovation that extends into cities, buildings, banking, healthcare, government and more. Strong examples of how cloud can enable IoT connectivity exist in the healthcare industry. It includes a CSP's ability to offer health-specific solutions such as cloud-based remote monitoring to manage chronic diseases or sophisticated remote diagnostic capabilities. A&T, for instance, set up its ForHealth business unit in 2010, with a vision to accelerate the delivery of innovative, wireless, networked and cloud solutions specifically for the healthcare industry [12]

CSPs have a crucial role to play and they are well-suited to take a central position in the cloud-based IoT [13]. They fully control QoS at every point in the network. In addition, a cloud solution requires an infrastructure that is reliable and secure, and CSPs have a good reputation for managing large-scale infrastructures, dealing with personal and business-sensitive data in a confidential way.

They also have access to a wealth of information about their customers' behavior, preferences and movements; applying analytics to produce the insights and context that are necessary to optimize decision making. And they are uniquely positioned to group and structure a wide variety of their own and third-party applications and services relevant in the IoT.

4 Networks That Are Smart

Ultra-fast broadband continue to be a high priority for CSPs, as they prepare to meet a considerable rise in demand for data capacity. Experimental fixed-broadband programs plans to offer 1000/1000 Mbit/s symmetrical connections directly to consumer homes. The race for ultra-fast broadband appears to have been decided in favor of LTE, in combination with WiFi mobile traffic offload and femtocells. LTE technology is to handle the tremendous surge in data traffic.

High speed broadband, as important it may be, doesn't make a network 'smart'. We need the network to be multidirectional instead of point-to-point. Smart networks must be infused with advanced analytics and intelligence, so they can identify connected instrumented things and collect relevant data from them. They'll have to be built on a foundation of standards and software that allows trillions of devices and objects to 'talk'.

The realization of the Internet of things have placed requirements upon mobile networks that the infrastructure was not originally designed to accommodate. Adding more intelligence at the *edge* of mobile networks is one of the options CSPs have to optimize their infrastructure to deal with unprecedented amounts of traffic, enhance latency-critical applications and to provide a distribution computing environment that can analyze massive amounts of information [14].

A more structural way of coping with the increasing workloads is the approach of Software Defined Environments (SDE) [15]. In the past (traditional) workload scenarios, there were few, stable and well known workloads (see Fig 5). The software was manually stood up on a fixed set of devices with minimum requirements for configuration. Often the hardware and software were tightly integrated.

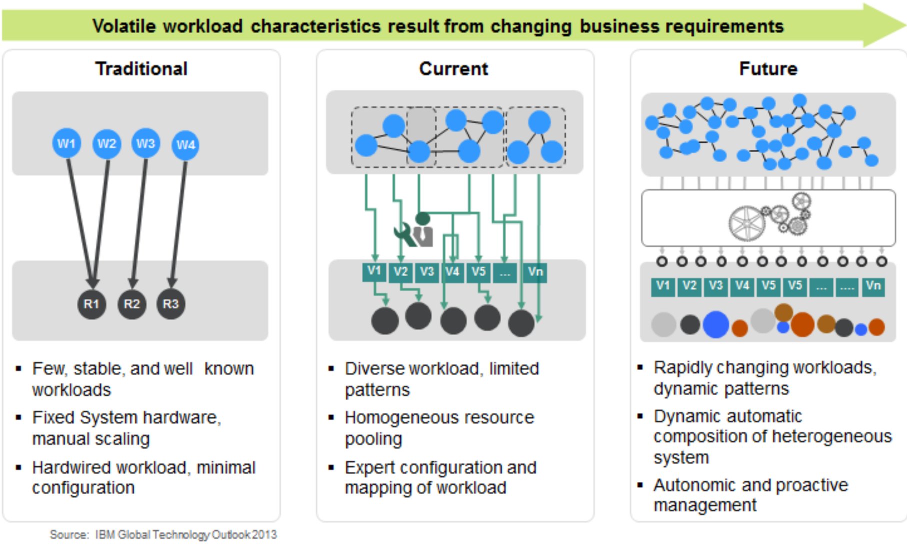

Fig. 5. Today's environment are making workloads (and Networks) more volatile

With the emergence of cloud, traditional workloads were virtualized and moved to the cloud, but at large, they were continued to be manually tuned and managed. In addition, new workloads started to emerge. Though limited workloads are available, expert configurations and mapping are still required. Cloud infrastructures are largely based on pooling of *homogeneous* resources.

Today's environment with mobile first, social technologies and scalable service ecosystems is making workloads (and networks) extremely volatile. The environment becomes dramatically *heterogeneous*. The exploding number and increased volatility of workloads and applications coupled with the heterogeneity leads to a situation where standing and tuning applications can no further be done in a manual fashion. A need to automate the deployment and to continuously and optimally manage these workloads is evident. This includes both the software and infrastructure of workload fit systems. This is what SDE is about.

SDEs provide abstractions of workloads, services and infrastructure and end-to-end mappings (see Fig 6). Being able to abstract workloads and the infrastructure, the workloads, the network, the storage environment and the computing environment can be virtualized, as well as common services. As part of the deployment the abstract workload is mapped to the best suited sources at the time. The system is dynamically constructed and configured and the workload is mapped to this system. As a result SDE provides an end-to-end orchestration at the workload, services and system (resource) level.

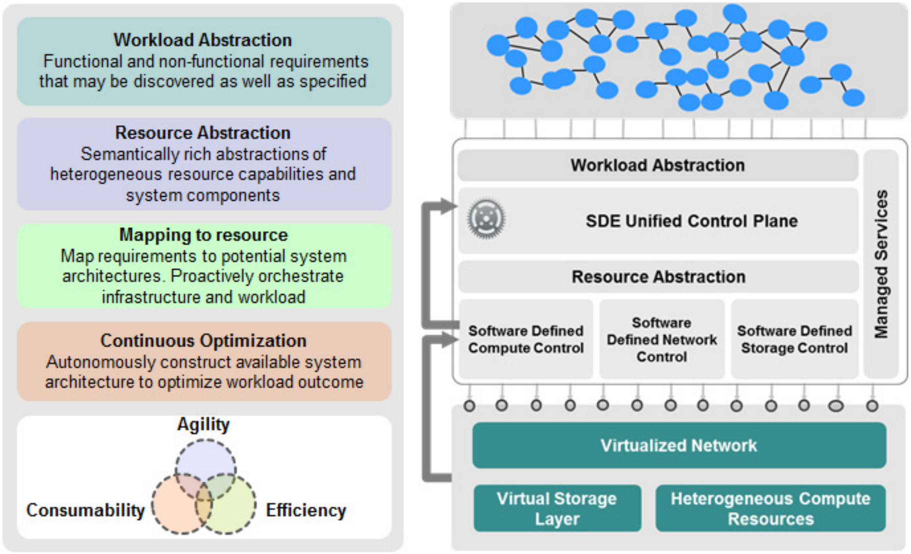

Fig. 6. Software Defined Environments provide abstractions of workloads, services and infrastructure and end-to-end mappings

The mapping/orchestration is autonomous, continuously monitoring and assessing the state of the system and if necessary reconfiguring hardware and software top optimize the outcome. SDEs bring together three key requirement of workload deployment in cloud environments: agility, efficiency and consumability. The vision of the SDE is one of an intelligent data-driven ecosystem that is easily managed and scaled to meet the requirements of the IoT.

5 Concluding Remarks

The IoT is a technological revolution in the future of computing and communications that is based on the concept of any time, any place connectivity for anything. The Internet of Things provides the foundational infrastructure for a smarter planet. It comprises billions of sensors and actuators embedded in physical objects, which are linked through fixed and wireless networks parallel to the hundreds of millions of people who have access to the Internet. When the objects in the IoT are able to interpret the continuous flow of data, to sense what is happening and to communicate with each other, the IoT will enable applications and uses in people's live that were previously unimaginable. The IoT vision is to provide a dynamic and global infrastructure which is characterized by intelligent and self-configuring capabilities.

A number of trends will be fundamental for realization of IoT. Communications and connectivity of IoT is enabled by IPv6, which is replacing IPv4. Sensors are getting smarter, smaller and cheaper, and there will be billions of them. Sensors and systems of sensors will be increasingly talking to each other and data centers via wireless communications. IoT will act as a nervous system, enabling an automated sense and respond system for any business process or application. All these 'things' will produce an ever-increasing amount of structured and unstructured data that requires advanced analytics to provide insights from all the 'things'. And IoT systems may have to scale quickly and autonomously. All these trends will result in new innovative and smart applications and services we only can dream of today. The IoT will impact every single industry and become a part of people's lives.

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