The Internet of Things

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Objective: This paper provides a short introduction into the concept of the Internet of Things, suitable for students and practitioners in related areas of Computer Science. After studying this paper, and some further reading, the reader should be able to demonstrate an understanding of technologies enabling the Internet of Things; become familiar with typical terminology in the area; consider the suitability of software structures dependent on the addressed hardware requirements; analyse the maturity of the technology required for a particular problem, and explain current challenges and potential impact of the technology.

About the author: Tom Pfeifer holds a PhD (Dr.-Ing.) in Computer Science from TU Berlin, and a MSc (Dipl.-Ing.) from TU Dresden, Germany. He has been directing research in Ubiquitous and Pervasive Computing in Waterford, Ireland, for nine years, after working in Berlin, Germany, in a variety of senior research, industry consulting, project management and lecturing positions in the Fraunhofer Institute of Open Communication Systems (FOKUS), the GMD Computer Science research labs, and the Technical University. He has published numerous technical papers, is member of the editorial boards of the Journals *Computer Communications* and *Pervasive Computing and Communications*, and co-edited several books. In 3-4 IEEE conferences each recent year, he has been chairing in different roles, been TPC member of 9-10 events worldwide, and been invited to numerous scientific talks throughout Europe.

Introduction

The *Internet of Things* (IoT) is a recent development in the area of ubiquitous and pervasive computing. The term *Ubiquitous Computing* has been coined by Mark Weiser in the early 1990ies [Weiser 1991] as he foresaw computing moving from a bulky, fixed-location type device to computing as a service that could be accessed anywhere, embedded in everything and portable by users. *Pervasive Computing* is being used by some authors as a synonym, other consider it as a focus on computing technology penetrating everyday objects.

It took about a decade of underlying technologies to mature until the first realistic scenarios were tested in the labs at the dawn of the millennium. This first phase of Pervasive/Ubiquitous Computing was quite euphoric, with the idea to instrument everything, create massive wireless sensor networks, and computing devices shrinking to "smart dust" or being painted to the walls.

The next phase brought the reality shock: All these tiny devices would have to be managed, would need energy supply, and be accepted by the users. Thus currently we experience a revised approach, considering fewer devices, which would be wired or wireless based on requirements, and more intelligence programmed per device, requiring more sophisticated algorithms.

The *Internet of Things* – the term probably used first in 1999 [Ashton 2009] – focuses on the networked aspect of Pervasive Computing, with a large amount of communication happening between the devices, thus termed *Machine-to-Machine Communication (M2M)*.

The IoT is characterised by the objects being uniquely identifiable, an idea influenced by the enumeration scheme of the Auto-ID Centre promoting RFID-Identification of individual products.

Tens, hundreds or thousands of nodes per human being on the planet multiplies to billions of nodes in total, and beyond.

Enabling Technologies

The maturing of some enabling technologies has lead to the interdisciplinary proliferation of pervasive computing. Driving factors are, among others, RFID (in passports, animals, logistics, sports timing), location recognition, the disappearing computers (i.e. tiny, cheap, single-purpose processors in everyday objects) and the saturation with information processing capabilities.

Hardware miniaturisation

Moore's law, a self-fulfilling prophecy quoting the co-fonder or Intel about the doubling of computer power every 18 months, became reality as Intel actually aligned their technology roadmaps to the popular opinion, and was also applied to computer memory capacity.

While miniaturisation slows down eventually, the low price of those chips allows to use them massively in parallel. The embedded microcontrollers in devices become networked, initially in small proprietary networks, are now being connected to the Internet.

Sensors and Actuators

Nowadays it is possible to sense a wide variety of physical phenomena cheaply and efficiently, from acceleration, over chemical parameters to visual sensing where the image processing can be performed within the camera. .

Micro-Electro-Mechanical Systems (MEMS) are mechanical devices manufactured with similar technology than computer chips, allowing their mass-production for sensing and actuating. Examples span a wide range from accelerometers to arrays of micro-needles administering medication.

Nodes for Wireless Sensor Networks (WSN) that sense, compute and communicate, have shrunk in the last 5 years from a cubical inch to a cubical centimeter, the vision of the cubical millimeter not too far ahead. Their massive deployment allows and requires the fusion of many such data to generate more precise information about its surroundings.

Communication and co-operation of smart objects

Wired communication technology converge from proprietary infrastructure networks (LON (Local Operation Network), EIB (European Installation Bus), CAN (Controller Area Network); field buses in industry automation, etc.) to IP (Internet Protocol) based networks.

Wireless and mobile communication technology has matured and is available off-the-shelf for a variety of spacial ranges and utilisation cycles (WLAN, Bluetooth, wireless control networks (ZigBee), sensor communication, etc.), there are numerous protocols for Ad hoc networking and spontaneous interaction.

Communication between smart objects is a very energy-intensive operation, so approaches for devices on a tight energy budget are to reduce it as much as possible, and to shut them down in between cycles.

Energy supply

For devices that are supposed to operate away from mains electricity over a sustained period of time, the energy supply is one of the major challenge. The average capacity of batteries increases only 5% per year, thus much slower than the development in processing and communication. They also provide a maintenance problem for devices that are difficult to access.

Approaches are to scavenge energy from the environment, which is easy with solar cells for devices exposed to light. More sophisticated approaches range from exploiting environmental vibration, temperature differences, human motion, or even the glucose molecules in the blood for implanted devices.

Crucial are efficient processing algorithms and communication protocols – allowing a sleep mode most of the time. Such protocols need to consider the Nanowatt per Bit transmitted, and find a trade-off between computing and communication. On the receiver side the received energy per Bit competes with noise and therefore the error rate.

A classic challenge in the battle of duty cycles vs. communication is to construct a very low-power, but highly precise clock.

Location, Context and Ambient Awareness

The proliferation of positioning technology is another driving factor. GPS being the most prominent outdoors, followed by cell-based location of mobile phones; plenty other technologies are based on a variety of physical principles (infrared, ultrasonic, radio-based, visual, dead reckoning, hybrid) that allow to tailor systems for recognising the location of a person or a thing indoors and outdoors.

Location is a major ingredient of *Context*, considered as any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves. Primary context types are location, identity, time and activity.

With the complexity of context information rising, some elements of this contextual information must be *inferred* from a variety of simpler sources of input data.

Ambient awareness is the process of a computing device in acquiring, processing and – in the background, possibly unattended by the user – acting upon application specific contextual information, taking the current user's preferences and state of mind into account.

Some services will not only adapt to the current context, but also couple digital information to the environment. Depending on the user's perspective this can be viewed as digital data augmenting reality, or *Contextual Augmentation*.

Hardware Platforms

Hardware platforms can be as manifold and heterogeneous as the application examples discussed later. They can range from cars, which today are already sensor/actuator networks on wheels, over plenty small controllers in a building infrastructure, wireless 'motes' to tiny body-worn or even implanted devices monitoring and influencing functions of the human body.

While this paper is too short to give a comparison of hardware to start experimenting with, the open-platform Arduino board [http://www.arduino.cc] should be mentioned as a networked controller board with gaining popularity.

Software Architectures and Protocols

Traditional remote operation was based on processing remotely sensed information in a central hub with the action re-routed to the remote actuator. The IoT allows the sensors and actuators communicate more directly, which is referred to as Machine-to-Machine (M2M).

Approaches as the Session Initiation Protocol (SIP) allow the discovery of services, to initiate sessions, from voice, video to games and virtual reality, and may be used for control purposes

A number of communication platforms emerge for M2M communication. An example is the modular OpenMTC, providing a telecommunication-standard compliant middleware platform for M2M oriented applications and services, with added value for both telecom operators and equipment manufacturers and integrators. [OpenMTC 2012]

The IoT is closely linked to the concept of the Semantic Web, bringing meaning and logical reasoning to the networked devices.

Application Examples

"Smart" homes and offices were among the first environments where IoT technology was tested and deployed to provide Ambient Intelligence.

Sensor and recording embedded in a parcel can already monitor that all transport conditions (cool chain, physical impact, atmospheric conditions) have been complied with. Further applications in logistics are plentyful.

Wearable artefacts, such as glasses with some face recognition and database access are currently brought to the market by Google and other companies.

Vehicular communication (communication with and within vehicles, communication between vehicles) leads to a new quality of assisting drivers, to increase safety not only within his own car but avoiding collisions between them, warning about upcoming hazards ahead (e.g. hidden behind a curve), and change plans in real time.

Health is another major application area, from tele-medicine with remotely and constantly monitored body functions, micro-dosed medication, to supporting ageing patients with loss of cognitive functions to allow a self-determined life as long as possible. Some data could be collected with "Body Area Networks" which are sometimes understood as networked wearables; sometimes even with the human body as the conductor.

Management of resources such as energy becomes possible with smart grids and smart metering, where devices with higher electricity-consumption can negotiate their duty cycles with providers of sustainable energy, such as on-demand heat/power cogeneration.

Sensor-saturated infrastructures and machinery monitoring themselves, e.g. buildings or bridges over their lifetime, can optimise maintenance cost and help recognising damages in disasters such as fire or earthquakes.

In agriculture, food is already administered to individual animals in livestock according to their needs, the cow is recognised before milking, and water can be dosed precisely to the needs of plants in dry areas.

The ad-hoc networking capabilities of some approaches are important in situations when infrastructure is lost, as in disasters.

New scenarios and further application areas emerge constantly.

Social, Privacy & Security Impact

With things and systems developing a life time memory and traceability we come towards a new quality of collectable data, that are increasingly difficult to keep private. Even with good intent, e.g. by a company, things change when they are sold at bankruptcy or getting attacked.

The concerns are not only the ‘Big Brother’ watching everyting, but also ‘little siblings’: curious neighbours and colleagues .

Networks and systems we increasingly rely on can fail, by malfunction or malicious action.

Beyond technological approaches to protect privacy, the society has to develop strategies to cope with the lack of.

As person-related data became a currency in the information economy, users need to understand the value of their electronic trails and being empowered to consider the tradeoff between protecting their privacy vs. improved services.

Visions need to be re-thought, whether a new approach will enhance people's life or might be exploited (by whomever) in a yet unforeseen way.

Challenges

Challenges, and need for further research, are plentyful, only a few examples can be given here.

Scalability becomes an issue in both directions: the miniaturisation of the devices, and the large scale deployment with interoperability in heterogeneous domains of application, with an immensely increasing volume of data.

Well-known algorithms, that work well on fully resourced computers, present particular challenges to resource-constrained IoT-environments. Particular research is required to provide intelligent solutions to keep processing feasible.

A particular issue that already looms in the Internet for a while – the running out of IPv4 addresses – becomes even more urgent when billions of small devices need to be numbered, making the deployment of IPv6 mandatory.

Manageability of such ubiquitous systems creates a new class of problems. With the goal of zero-configuration and low-maintenance, in reality systems still require substantial management overhead.

For testing the systems, new strategies have to be developed for predictability and acceptability of automated decisions, as well as for verification of adaptive system.

Conclusion

This short paper could only provide a first glance on a rapidly unfolding technological area with large impact on society as a whole, with benefits and threats. The IoT can contribute solutions to major problems such as ageing human populations and use of natural/energetic resources, but also creates new classes of problems on its own.

Appendices

Appendix 1 Terminology

Internet of Things; Ubiquitous/Pervasive Computing; Machine-to-Machine; Context; Ambient Awareness; Contextual Augmentation

Appendix 2 Acronyms

IoT	Internet of Things
GPS	Global Positioning System
Auto-ID	Auto-Identification
RFID	Radio Frequency Identification
IPv4/6	Internet Protocol Version 4 / 6

Proposed Activities

Identify some different influential factors that lead, at the beginning of the 21st century, into the disciple of Internet of Things within the area of Ubiquitous and Pervasive Computing.

Consider the pros and cons impact this technology might have on your own life, today and in future.

References and Further Reading

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