Cooperating Objects Design Space and Markets

Stamatis Karnouskos[1], Pedro José Marrón[2], and Daniel Minder[3]

[1] SAP Research, Germany, stamatis.karnouskos@sap.com
[2] Universität Duisburg-Essen, Germany, pjmarron@uni-due.de
[3] Universität Duisburg-Essen, Germany, daniel.minder@uni-due.de

Abstract. The area of Cooperating Objects is an emerging domain that builds upon (networked) embedded systems, ubiquitous computing and (wireless) sensor networks but stresses the cooperation between modular, autonomous and heterogeneous devices that try to achieve a common goal. We present a definition and explain the characteristics of Cooperating Objects. By looking at market predictions and our own survey we show that the impact of Cooperating Objects to the monitoring and control area can be very significant and has the potential to drastically affect future applications and services.

Keywords: Cooperating Objects, market, survey

1 Introduction

Networked embedded devices enable the timely integration of information from the real world to the virtual world where modern applications live. The core idea behind amalgamating the physical and virtual (business) world is to seamlessly gather useful information about objects of the physical world and use the information in various applications in order to provide some added value. In the last years we have witnessed a paradigm change, where the rapid advances in computational and communication capabilities of embedded systems are paving the way towards highly sophisticated networked devices that will be able to carry out a variety of tasks not in a standalone mode as usually done today, but taking into full account dynamic and context specific information, and following dynamic collaborative approaches.

These "objects" will be able to cooperate, share information, act as part of communities and generally be active elements of a more complex system. The close interaction of the business and real world will be achieved by auxiliary services provided in a timely fashion from networked embedded devices. These will be able to collaborate not only among them but also with on-line services that will enhance their own functionality.

As already defined [10], one can consider that:

> "*Cooperating Objects are modular systems of autonomous, heterogeneous devices pursuing a common goal by cooperation in computations and in sensing and/or actuating with the environment.*"

The domain of Cooperating Objects is a cross-section between (networked) embedded systems, ubiquitous computing and (wireless) sensor networks. There are, therefore, several flavours of Cooperating Objects depending on the degree in which they fulfil different features. Some of them can process the context of cooperation intentionally, act on it and intentionally extend it, change it or stop it. As such they may possess the necessary logic to understand semantics and build complex behaviours, thus allowing the Cooperating Object to be part of a dynamic complex ecosystem.

Currently there are several market "predictions" and studies that draw a promising future for several areas where Cooperating Objects play a pivotal role. We take a closer look on some of the claims and market predictions, complementing them with a survey carried out during the CONET project lifetime.

2 Design Space of Cooperating Objects

Cooperating Objects share common ground [10] with several domains such as software agents, Internet of Things, Cyber-Physical Systems, System of Systems, etc. Hence, it is natural that they share also a common design space. However, the distinguishing difference is that the collaboration is playing a pivotal role as well as the cross-layer interaction among different devices, systems, services and applications.

We have already identified several Cooperating Object characteristics which are depicted in more detail in [10]. More specifically we have:

- **Modularity:** A Cooperating Object is composed of several elements that need to exhibit certain features. Each of the elements contributes to the functionality of the overall Cooperating Object, but the modularisation helps to keep the single devices simple and maintainable. The modular design makes it possible to replace an element by a more powerful one or to add new ones that extend the functionality. Thus, the Cooperating Object can be developed in an evolutionary fashion and adapted to new needs.
- **Autonomy:** Each Cooperating Object element can decide on its own about its involvement in a Cooperating Object. If the element does not participate at all in the cooperation and coordination activities, it is not considered part of the Cooperating Object. Otherwise, it decides about the degree of participation. In general, an element can dedicate only a fraction of its resources or its functionality to the current Cooperating Object, thus leaving the possibility to serve multiple Cooperating Objects.
- **Heterogeneity:** In Cooperating Objects, heterogeneity is a crucial point since it is more than heterogeneity in terms of, e.g., processing power or memory. In fact, a Cooperating Object must combine devices of different system concepts, i.e. Wireless Sensor Networks, embedded systems, robotics, etc. Since these elements can have different hardware characteristics, heterogeneity is also exhibited as a consequence.
- **Computation:** Due to the different nature of the single elements in a Cooperating Object the computational capabilities can vary largely. However,

a device must at least be able to take an autonomous decision about its involvement in a Cooperating Object and to communicate with others, which usually requires also computation.

- **Interaction with the Environment:** Cooperating Objects interact with the environment using sensors and/or actuators. The interaction with the environment should be substantial, especially with respect to actuators, i.e. actuation should have a changing effect on the environment. The involvement of sensors and actuators makes Cooperating Objects real-world objects, i.e. there are no pure virtual Cooperating Objects. The interaction with the environment must be a core functionality of the Cooperating Object and not just an optional side-effect.
- **Communication:** If a device communicates there are three techniques of information exchange [15]. The most common technique is explicit communication, which can be performed using various means, e.g., wires, radio, light, sound. The content of the communication is manifold and can range from just the state of the single element to a common planning. Besides explicit communication, there are two other techniques that work by observation using sensors. With passive action recognition the actions of other devices are observed, e.g., if an actuator moves. In contrast, the effects of actions of others can be sensed ("stigmergy"), e.g., the increase of temperature caused by a heater. Usually, these forms of communication show the lack of common interfaces for direct communication. Nevertheless, the inclusion of such devices allows for interesting applications.
- **Common Goal:** The ultimate reason for a Cooperating Object to exist is the common goal it tries to achieve. There should be a reason for pursuing the goal using Cooperating Objects: either the goal can only be achieved through Cooperating Objects or there is at least an improvement compared to a monolithic or centralised approach. Although the devices do not know the overall goal they execute a task to achieve it. Thus, each device has detailed knowledge only about its area of responsibility, but limited information about the whole Cooperating Object. However, the cooperation of the single devices makes it possible to achieve the overall goal, which needs the full picture. Thus, the intelligence of the system lies distributed in the network.
- **Cooperation:** In Cooperating Objects cooperation is always intentional and driven by a goal. Without a goal and, thus, no tasks, there is no need for cooperation at all. Although unintentional interaction might deliver the same results it does not happen in a controlled way which creates problems in case of errors. For example, reconfiguration is more difficult if the exact task that a device has performed is not known. The participation of all devices in a Cooperating Object is needed to achieve the common goal, i.e. a Cooperating Object is more than just the sum of the single devices. Nevertheless, the common goal does not imply benefits for all the cooperating devices. Some of them can be especially designed to help in cooperation; others can play a more active part in one cooperative task to profit more in another one. When autonomous and selfish objects decide autonomously if and how they

cooperate, the sum of the benefit must be positive. Otherwise, a device will eventually not agree to cooperate or not be asked to cooperate any more.

Within the CONET project(www.cooperating-objects.eu) several applications were designed and developed. A detailed overview is provided [5], mapping also the applications to the design space presented here. Examples of such areas with their respective applications include:

- *Deployment and Management of Cooperating Objects* e.g., Monitoring Railway Bridges, Cooperative Industrial Automation Systems, Light-weight Bird Tracking Sensor Nodes, Public Safety Scenarios, Road Tunnel Monitoring and Control
- *Mobility of Cooperating Objects* e.g., Mobility in Industrial Scenarios, Mobility in Air Traffic Management, Mobility in Ocean Scenarios, Person Assistance in Urban Scenarios, Mobility in Civil Security and Protection
- *Cooperating Objects in Healthcare Applications* e.g., Physical Activity Recognition, Real-time Physical Energy Expenditure, Emotional Stress Detection, Physical Rehabilitation, Energy Aware Fall detection, Distributed Digital Signal Processing, Model Predictive Control

3 Markets

Modern enterprises need to be agile and to dynamically support decision making processes at several levels. In order to be able to take efficient decisions and manage the resources in an optimal way, a direct link to the timely provision of information residing in all layers between the enterprise services and the resources needs to be established. This increases visibility at a very discrete level and can provide insights on how specific problems can be avoided or tackled. However monitoring is not enough, as controlling and adapting the behaviour of the resources needs to take place in order to close the loop [4].

Existing business processes may become more accurate since information taken directly from the point of action can be used to manage processes and related decision-making procedures. The continuous evolution of embedded and ubiquitous computing technologies, in terms of decreasing costs and increasing capabilities, may even lead to the distribution of existing business processes to the "network edges" and can overcome many limitations of existing centralized approaches. Cooperating Objects offer these capabilities by introducing cooperation as the key principle that may enhance future devices, systems and applications.

The domain of Cooperating Objects is still at its dawn; however its impact is estimated to be so broad and significant that could drastically change the future application and services. Numerous market analyses also seem to point towards this direction. It is important to understand that Cooperating Objects is a huge domain with applications in several fields [10], and therefore it is very difficult to set the limits and estimate its total value. As such we indicatively refer only to some markets that fall in the category of the Cooperating Objects such as the (wireless) sensors, networked embedded systems etc.

Cooperating Objects are an integral part of the future Internet of Things. The latter is expected to enable unprecedented interconnection of networked embedded devices and further blur the line between the real and virtual world. If we take a closer look at individual domains, we will see a tremendous growth on the network side, and information will be provided by networked embedded devices. Several predictions are made about the status of things connected to the Internet, which forms also a big part of the basis for Cooperating Object approaches to flourish. Similarly high expectations are made on the Cooperating Object domains that could be impacted such as the Smart Grid, smart cities, industrial automation, aviation, robotics etc.

According to Håkan Djuphammar, VP of systems architecture at Ericsson, "[In 10 years' time], everything has connectivity. We're talking about 50 billion connections, all devices will have connectivity ..." [7]. This was reinforced by the Ericsson President and CEO Hans Vestberg who mentioned that 50 billion devices will be connected to the web by 2020. Intel's John Woodget, global director, Telecom sector has a more moderate prediction, in the range of 20 billion connected devices by 2020 [7].

According to the Broadband Commission for Digital Development [2], "worldwide, mobile phone subscriptions exceeded already the 6 billion in early 2012", and "by 2020, the number of connected devices may potentially outnumber connected people by six to one". In the same report the total networked devices is expected to reach the 25 billion by 2020.

According to Gartner's "Top 10 Strategic Technology Trends for 2013" [14] already "... over 50% of Internet connections are things. In 2011, 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. Key technologies here include embedded sensors, image recognition and NFC."

Getting down to the smart grid specific statements, Marie Hattar, vice president of marketing in Cisco's network systems solutions group, estimated in 2009 that the smart grid network will be "100 or 1000 times larger than the Internet" [6]. Similarly Vishal Sikka, CTO of SAP, stated in 2009 that "The next billion SAP users will be smart meters" [11]. Only for installing smart meters in homes an estimated $4.8 billion will be spent according to ABI Research [1].

According to Pike Research the market for energy management systems (including Wireless Sensor Networks, lighting controls, heating and cooling management in buildings) will turn into a $6.8 billion a year market by 2020 and will generate investment of $67.6 billion between 2010 and 2020 [12]. They also note that a total of $4.3 billion will be spent on the installation, maintenance, and management services for smart grids by 2015 [13].

These are just some examples, depicting the fact that we are still at the dawn of a new era. A $4.5 trillion impact is estimated [8] by 2020 on people and businesses stemming from the sale of connected devices and services. There is a clear trend where networked embedded devices will blend with the everyday lives and directly or indirectly affect them. Cooperation among Cooperating Objects at local and system-wide level may create new business opportunities in the future.

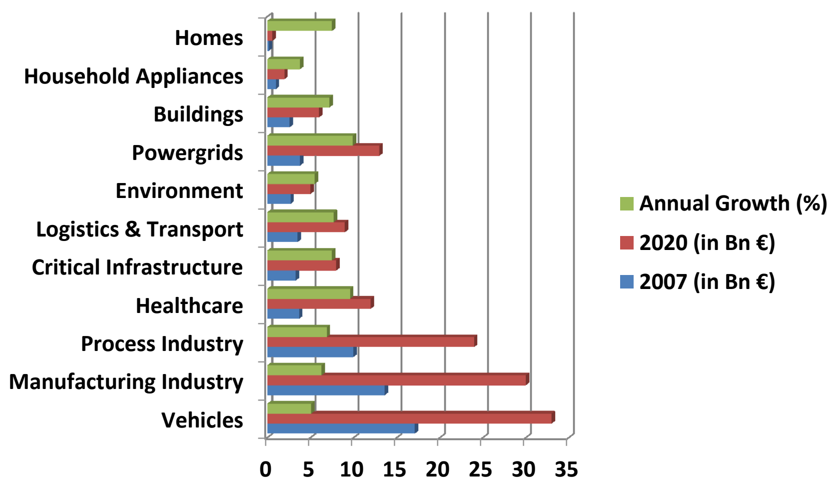

Fig. 1. Monitoring and Control Market 2007-2020 [3]

The main focus of Cooperating Objects is in coupling the physical and virtual worlds; they do this via monitoring and control activities. The most important market sectors potentially affected by and from Cooperating Objects are depicted in Figure 1. As reported in the European Commission study [3], the world monitoring and control market is expected to grow from €188 billion in 2007 to €500 billion in 2020. With a share of €61.5 billion today, Europe represents 32% of this market. It is expected to grow at an annual rate of 5.7% between 2007 and 2020. Services, with more than 50% of the market value, have the biggest share. Together, three application markets — Vehicles, Manufacturing and Process industries — represent 60% of total monitoring & control market. Healthcare, critical infrastructures and logistic & transport follow closely. At the moment, the Home is still considered a small niche market.

Although the overall market where Cooperating Objects technologies are contributing is expected to grow significantly until 2020 (see Figure 1), hardware is expected to have a relative small growth due to decreasing prices; this does not hold true for network devices which will have an exponential growth in the next years. Services are expected to dominate the market i.e. next generation of products or components is included in service packages. This emergence of new services will create also the need for next generation products e.g., in environmental regulations, energy efficiency etc. The Total Cost of Ownership (TCO) is expected to be extended and include issues such as precision maintenance, asset management, production tools life extension with higher maintenance needs, more secure & safe installation & infrastructures.

Several innovations relevant to the Cooperating Object domain are expected. In Components, increasing computing power and integration, intelligent communicating local components, standardization and lower prices are foreseen. In networks, IP will be everywhere, networks will be transparent across application sectors, and service oriented approaches will be dominant. On the Services, it is expected that we will have a largely industrialized (e.g., standardized, widely used, sophisticated) version of them. As most of the technologies are already in place, what remains is the optimal exploitation of them. Many technologies still seem futuristic and with prohibitive cost for mass-application usage. As such the evolution of the domain will not be heavily based on the technology as such only but directly linked to different business models that are connected to it.

The majority of the market growth predictions are constantly modified to the current business climate, therefore the aforementioned numbers should be taken "*cum grano salis*" and only as an indicative trend depicting the underlying potential; the future will tell if and at what timeline they will be validated.

4 The CONET Survey

The vision of Cooperating Objects is quite new and needs to be understood in more detail and to be extended with inputs from the relevant individual communities that compose it. This will enable us to better understand the impact on the research landscape and to steer the available resources in a meaningful way. To achieve that, the European Commission co-funded project CONET (www.cooperating-objects.eu) was formed with leading academic and industry partners.

A survey was carried out by CONET among selected experts from within and outside of the consortium. We present selected results of this survey here; the full details can be found in the CONET research roadmap [9].

Several domains are expected to significantly benefit from Cooperating Objects. We have found out (depicted in Figure 2) that especially monitoring and management in automation, energy, health and environment followed closely by the transportation, logistics, and security domain will be the major beneficiaries. If we correlate Figure 2 and Figure 1 we can see that the emerging domains with the highest annual growth rate are the ones that may also benefit most from the success of Cooperating Objects.

For the wide-spread adoption of Cooperating Objects technologies in mass-market products, several roadblocks are also identified (depicted in Figure 3). Confidence in technology is the most critical issue to be solved, closely followed by the lack of standards and unclear business models. Furthermore social issues and no proven record of business benefit are seen as having a moderate effect on the success of Cooperating Objects. Especially the last one is typical in the technology domain as the advances and benefits cannot be fully envisioned nor

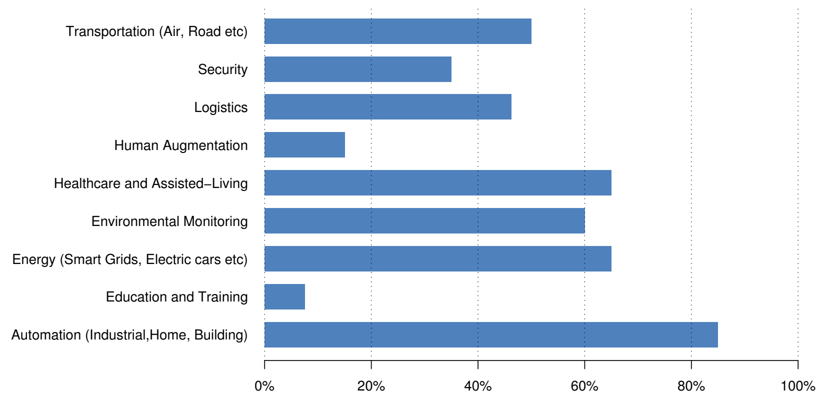

Fig. 2. Survey: Beneficiary Domains

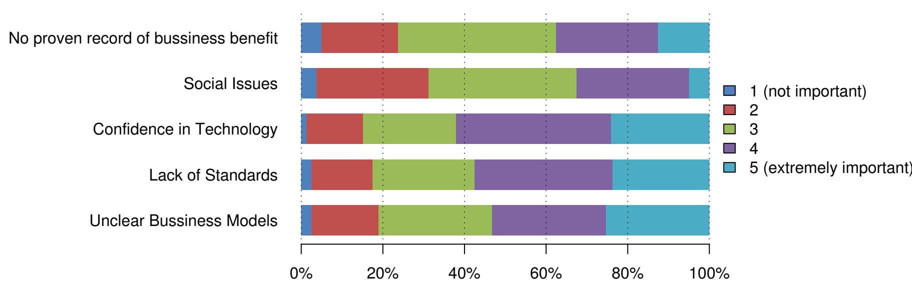

Fig. 3. Survey: Roadblock Impact

widely understood. Although market predictions for the deployment and use of Cooperating Object relevant technologies are promising, the identified roadblocks will need to be tackled effectively if Cooperating Objects are to succeed.

Nevertheless, it is clear that there is promising potential in versatile domains, which could greatly benefit with the introduction of Cooperating Object technologies, ranging from automation (home, industrial, building) to healthcare, energy etc. We estimate that we are still in the dawn of a new era, and in the early phases of Rogers' technology adoption lifecycle as depicted in Figure 4. We expect that the Cooperating Objects market will be cross-domain and strongly embedded in the fabric of success of other domains.

5 Conclusions

The emerging domain of Cooperating Objects envisions the widespread collaboration between devices, systems and applications in a fully networked world.

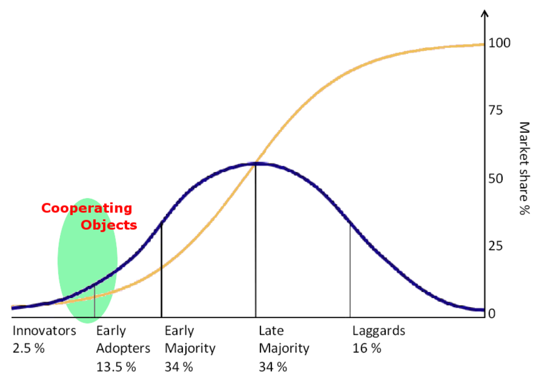

Fig. 4. Cooperating Objects in technology adoption lifecycle

As we are moving towards a Trillion Node Network Infrastructure, where devices will be interconnected and cooperate, providing and consuming information available, collaborative and emergent behaviours are expected to appear that empower new innovative approaches. The vision of Cooperating Objects is to tackle the emerging complexity by cooperation and modularity. Achieving enhanced system intelligence by cooperation of smart embedded devices pursuing common goals is relevant in many types of perception and system environments.

The impact of Cooperating Objects may affect many traditional industries and create significant business opportunities for companies across industries by opening up new markets and therefore may become an important factor of tomorrow's business environment and service-based economy. Its development holds the potential to provide market stakeholders with a competitive advantage in global markets, be it in terms of technologies or new services and applications. Finally, we consider that Cooperating Objects will act as an enabler for a wide range of applications and services, and hold the potential to empower sophisticated highly dynamic complex systems and applications in the long- term.

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