Differences and Commonalities of Service-Oriented Device Architectures, Wireless Sensor Networks and Networks-On-Chip

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Abstract

Device centric Service-oriented Architectures have shown to be applicable in the automation industry for interconnecting manufacturing devices and enterprise systems, thus, establishing a comprehensive, heterogeneous service architecture. A similar scenario can also be found in the domain of integrated circuits where a growing number of components is being interconnected by a network inside a single chip. Thus, service-oriented concepts seem promising to be used for the abstract composition of on-chip components. However, tight constraints on power consumption and performance have to be considered when a compound service shall be executed. In this paper will be shown that the consideration of such constraints is profoundly beneficial. From this starting point, we argue that such an approach can also be useful in the context of wireless sensor networks with its large number of distributed, heterogeneous sensor nodes and limited energy sources.

1. Introduction

The introduction of Service-Oriented Architectures (SOA) and their related concepts has facilitated an enormous improvement in the domain of software engineering. Complex processes and functions are encapsulated by services whereas the services are more abstract and allow withdrawing from technical specifications and requirements. Though, these concepts for the simplification of software development are about to find their way into other application domains with diverse and additional requirements.

In different ITEA2 projects, like SIRENA [1] and LOMS [2], the theoretical and technical bases have been developed to enable device centric SOAs for transparent integration of software services and hardware devices in a given architecture (see figure 1a). Such so called **Service-Oriented Device Architectures (SODA)** [3] have high potential to solve the problems, associated with the increasing number of distributed systems, devices and services. SODAs are characterized by several advantages like independency of operating systems, programming languages and communication channels. Thus, a single physical device can host several services which can be accessed by different logical and physical interfaces. Moreover, complex services can appear as a single service where further calls to subservices ─ which can be located either on the same device or somewhere else in the network ─ are hidden from the user.

A very different adaptation of SOAs can be found in the domain of integrated circuits as such chips are becoming highly complex with plenty of different hardware components on a single chip. Figure 1b) depicts a small example with nine components that are interconnected by a so called **Network-On-Chip (NOC)**, to enable communication among each other [7]. Current chip designs comprise already up to 50 components and this number is about to increase further on. Thus, mapping a complex application with its numerous subtasks onto the given chip architecture represents a serious concern. However, as power consumption is a key limiter in mobile and high-performance computing [14], tight power and performance constraints have to be considered additionally during the application mapping (i.e. the service composition).

Besides the adaptation of primary SOA concepts for devices (SODA) and on-chip networks (NOC), another interesting application domain should also be considered. **Wireless Sensor Networks (WSN)** are

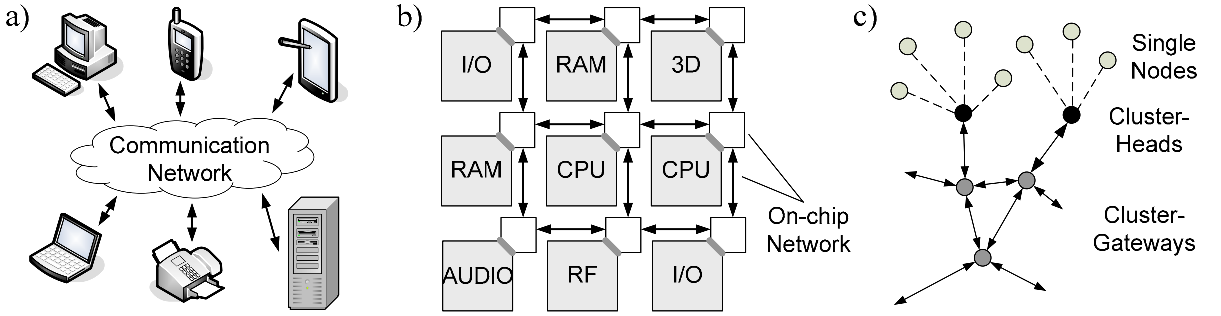

Figure 1. Examples of various service providers and service users in a) a typical SODA scenario b) in a Network-On-Chip and b) in a Wireless Sensor Network

gaining in importance as another type of device architecture and could become a benchmark for mobile communication systems because of the enormous demands for low power consumption, low computing power, wireless range and data rates. However, the increasing number, from a handful to hundreds, of sensor nodes within a WSN can cause serious problems concerning the overall functionality and service composition. The increasing energy consumption ─ due to higher communication complexity at constant limited battery capacities ─ affects single nodes and the overall lifetime of the complete network. To reduce the arising traffic owing to routing of messages through the network between individual sources and sinks, cluster structures [8] can be established (see figure 1c). Thereby, several approaches have been proposed to organize such clusters and to determine cluster-heads and cluster-gateways. Thus, similar to a compound service, cluster-heads and cluster-gateways are able to encapsulate the whole cluster from the remaining network. However, besides the main functionalities (i.e. the services), additional constraints concerning the energy consumption of the affected nodes are always considered in the published approaches [6]. Therefore, it seems promising to examine SOA concepts due to similar numbers of devices in the network and the additional power considerations that are derived from NOCs, to solve the arising problems in wireless sensor networks.

Hence, this paper discusses the differences and commonalities of SOA concepts in the three different application domains. Thereto, section 2 introduces related work in connection with Service-oriented Device Architectures, on-chip networks and wireless sensor networks. A discussion of properties and possible advantages follows in section 3 together with a motivating example, before section 4 concludes the paper.

2. Related Work

Within the three diverse domains ─ SODAs, WSNs and NOCs ─ numerous efforts have been made to optimize concepts and architectures under consideration of the specific requirements. In this section, the paper presents related work and state of the art of the three different domains with regard to constrained implementations.

2.1. Service-Oriented Device Architectures

Service-oriented Architectures are often mentioned in the same breath as Web services (WS) [4]. Certainly, WS standards often require too many resources for being implemented on devices with limitations on computing power, memory and energy. Therefore, a group leaded by Microsoft, specified the Devices Profile for Web Services (DPWS) [11]. This specification combines a set of Web service standards and adds several supplements to enable Web service functionalities on resource constrained devices. DPWS uses XML for data representation and HTTP on top of TCP/IP for transmission. Because Web services were originally designed for resource-rich devices, the data representation in XML represents a slight drawback on performance.

In the SOCRADES project [9], efforts have been made to implement DPWS on embedded devices which can grant access to the physical tier of automation systems. There, a single device is designed for dedicated functions which are encapsulated by services. Furthermore, the integration of these devices into the IT-landscape provides a high-level abstraction of the whole manufacturing process. Hence, enterprise systems and applications can be coupled with low-level embedded devices via a single integrated technology and communication architecture.

In [12, 13] a different approach has been presented to be implemented even on deeply embedded devices

(devices with small controllers and few kB of RAM and memory). Such devices are omnipresent because of their combination of price, power and integrated hardware components. The recommended table driven approach embeds all associated messages of possible scenarios for the dedicated devices at compile time. Hence, only minor adoptions of messages have to be done at runtime. The messages are parsed with an elementary string compare, which is available on deeply embedded devices like wireless sensor nodes also.

2.2. Networks-On-Chip

Over the past decades, scaling of transistor dimensions has enabled the exponential increase in computing power of integrated circuits. However, the number of functional components per chip has grown similarly and previous bus-based communication systems cannot cope with today's on-chip requirements. Thus, Networks-On-Chip (NOC) have been proposed as a new design methodology to overcome the large number of issues whereas power dissipation is the primary concern [7, 14]. A NOC consists of numerous independent components ─ e.g. general purpose processors, memory, decoders or I/O ─ that are connected to an on-chip network (see figure 1b) whereas the network itself is composed of routers and links. Lastly, interfaces encapsulate the individual components and the network from another and enable the communication among the various components.

Though, lots of effort has been put into the design of NOCs it is still under consideration how to efficiently manage the plenty of services provided by the components. Unfortunately, to simply adapt current system software is not appropriate due to the distributed and heterogeneous nature of NOCs. Nonetheless, most NOC specific approaches assume a central instance with global system awareness [23, 24]. There, compound services are composed by the use of Remote Method Invocation (RMI) so that local function calls are wrapped with their parameters into messages that are sent over the network to the remote components. However, to achieve global awareness of the system software, control messages have to be permanently exchanged (with parameters on bandwidth constraints in the network, temperature hotspots, service unavailabilities etc.).

As the exchange of control messages is inappropriate and power consuming in large networks, a distributed and modular approach was discussed by Benini et al. [25]. They integrate system software into the network interfaces which represents a simple, modular and scalable solution. The price is the loss in global awareness which can be overcome by the use of SOA concepts [10] when additional hardware parameters are submitted along with the service announcement. This allows choosing the best services, not just functionally but also under power or latency considerations. An appropriate example demonstrating the advantages is described in section 3.

2.3. Wireless Sensor Networks

It requires lightweight communication stacks and SOA implementations that consider the additional power constraints in wireless sensor networks. Existing approaches to provide a middleware for sensor networks are not built on standards such as DPWS due to given energy constraints. For instance, the independence of XML from binary representation and character set determines an unacceptable overhead for transmission of messages and for payload filtering. This is because transmission and reception of data are the most significant factors in power consumption for a sensor node.

The entering of addressing, routing and further protocol concepts from existing networks (like IP, TCP, UDP and HTTP) into WSNs is an ongoing process to handle the enormous number of sensor. Dunkels et al. have developed uIP and lwIP, two standard compliant TCP/IP stacks for 8 bit controller architectures [15, 16, 17]. Their work focuses on minimal code size as well as minimal usage of memory and computing power on the controller ─ without losing standard conformance. Both implementations are designed to run on 8 bit architectures with and without an operating system.

With respect to power consumption, the IEEE 802.15.4 standard [18] for wireless personal area networks is gaining in importance. In accordance to the IPv6 specification, the IETF has established the 6LoWPAN Working group [19] which aims at finding possibilities to compress IPv6 headers [21] so that they can be sent on top of 802.15.4. Thus, 6LoWPAN establishes the basis for TCP and UDP data transmissions [20] in WSNs. The main advantage of 6LoWPAN in comparison to nanoIP and other protocols is the compliance to IPv6 and the possibility to establish further protocols or middleware on top (like DPWS). Figure 2 depicts a protocol stack where it can be seen that other proprietary protocols (like ZigBee [22]) cannot compete with these benefits.

The proposed technologies and architectures (IEEE 802.15.4, 6LoWPAN and DPWS including XML optimized encodings) could become the basis for a lightweight SODA which can be applied in WSNs.

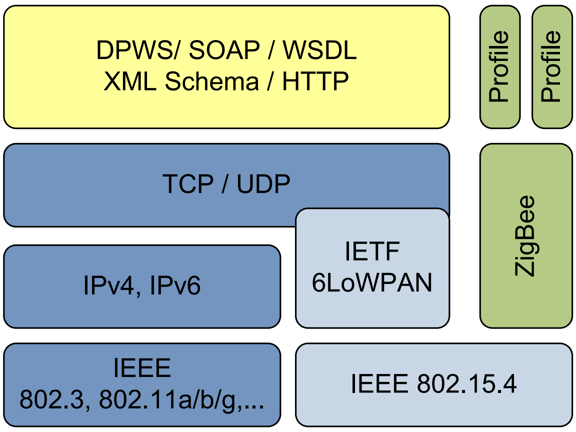

Figure 2. Protocol Stack

This will allow a much higher abstraction of devices and information flow inside the network as well as the interaction of WSNs with other networks. However, great efforts will have to be done to enable Programming In The Large (PITL) [5] for Wireless Sensor Networks and to consider the energy constraints within the SOA concepts.

3. Differences and Commonalities

The first obvious common basis of SODAs, NOCs and WSNs is the large number of modules within their common network that can interact with each other by services that they provide (see table 1). However, the complexity of the infrastructures and the amount of acceptable protocol overhead differs significantly. Moreover, as mentioned in section 2, tight constraints exist for NOCs that have to be considered, particularly on power consumption. A simple example shall demonstrate the impact of different service compositions in a NOC, when power constraints are not taken into account. Figure 3 shows an example of a chip with 25 components offering diverse services that are interconnected via an on-chip network. There, service calls can use either Remote Method Invocation (RMI) which equals the service orchestration as known in SODAs or a distributed approach which corresponds to the decentralized choreography in SODAs. In the given example, two different applications are mapped onto the given components (illustrated by the directed graphs on the left side). The first one represents a standard communication scheme between CPU and memory. The second one is a streaming application that uses five components and runs in two concurrent data streams (e.g. MPEG decoder). The overall power consumption of such a scenario is shown on the right side (with red meaning a lot and blue meaning only little power consumption). It can be observed that the power consumption is obviously higher at those components that perform the services and the communication.

A second example is shown in figure 4 for the same applications. However, the positions of the individual services are different and the overall power consumption is higher (dark red areas). The simplified explanation is that the communication distance is longer which consumes already more power. This in turn means that the execution takes longer and the components cannot return into a power saving idle state as early as in the previous example. Lastly, higher power consumption has further negative impact on system performance and reliability. Concluding, even though a service-oriented approach can provide the requested functionality, it cannot provide an efficient composition of services if additional parameters are not taken into account.

At first glance, WSNs are quite similar compared to NOCs. That is, individual sensor nodes are interconnected via a wireless communication network and energy is a limited. In case of higher power consumption in a NOC, failures are caused by rising temperature. Higher power in WSNs in turn causes a reduced lifetime of a sensor node due to limited battery capacities. Furthermore, sensor nodes also provide a

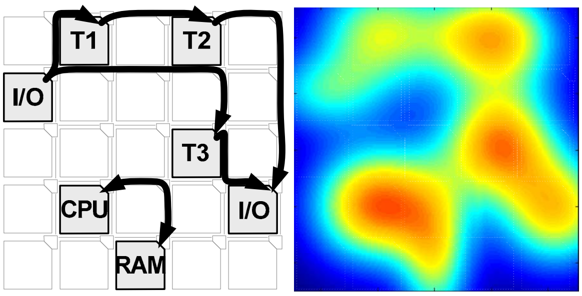

Figure 3. Optimized composition of distributed services and components

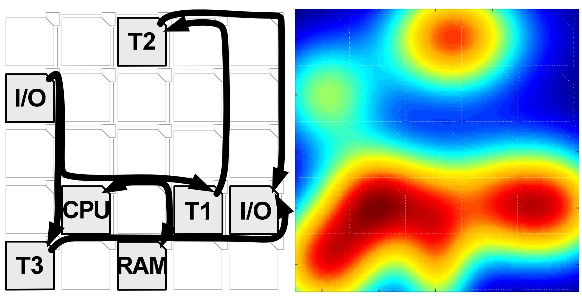

Figure 4. Non-optimized composition of distributed services and components

sleep mode during their idle time that helps to preserve energy significantly. Hence, the longer the distance to used remote services is (e.g. measured in hops), the longer the device has to remain in a power consuming state to await the response (just as in NOCs). However, in contrast to NOCs where the network and the communication distances are mostly static and given at design time, WSNs exhibit a dynamic characteristic. For instance, sensor nodes might disappear due to exhausted batteries or communication paths and distances might change due to the mobility of the devices. And lastly, service distribution has to be balanced over the network so that certain areas (those of higher usage) do not disappear and interrupt the functionality of the complete network. Therefore, a combined approach of SODA concepts to cope with the large number of sensor nodes and considerations on power consumption from NOCs is to be aspired.

A possible approach is the use of additional information sets which means that every service — hosted on a single node or being composed by subservices on distributed nodes — provides additional metadata. Such metadata is shared with other service users (in decentralized architectures) or the service repository (in centralized architectures) during service discovery and regularly during service runtime. Thereby, the service user or the service repository obtains additional information which can be used to minimize the power consumption for a required service and to maximize the overall lifetime of a WSN. Thus, if exchangeable services exist in the network, a power optimized composition can be realized considering the metadata.

Therefore, the metadata of a service may contain the following parameters to allow an efficient service selection or composition:

- **estimated duration for service completion**
- total number of services provided by the node
- number of service users
- frequency of usage of provided services
- power costs for the service (determined at runtime)
- remaining battery capacity of the node
- **estimated lifetime of the node**
- geographical and logical position in the network as this defines the distance or the number of hops required to communicate with this node

The exact number and definition of parameters is evidently dependent on the final implementation. However, from the perspective of the service user the duration for the service completion is the most important aspect as this defines when the node can return into sleep mode or how long the node can remain in sleep mode before the answer is about to arrive. Though, from a system perspective the estimated lifetime of the service provider and the logical position in the network are the most important aspects. These parameters impact how long the overall network can maintain its functionality. The former parameter influences the lifetime of the single node and the second indicates how many intermediate nodes (for a multihop communication) have to contribute to the service by sacrificing communication power.

In the context of SODAs, the power costs for transmission are often hard to calculate because of the complex network infrastructures with its different transmission technologies. This distinguishes between SODAs and WSNs where mostly homogeneous

Table 1. Comparison of SODA, NOC and WSN

	SODA	NOC	WSN
Interacting modules	Heterogeneous devices	Specialized hardware components	Highly resource constrained sensor nodes
Connection	Wired and wireless; Complex networks with different technologies	Wired; On-chip routers and links (static network)	Wireless (single and multi hop)
Number of modules	Few to many (known at runtime)	Few to medium (known at design time)	Medium to many (hard to determine even at runtime)
Coupling of modules	Lose coupling; Generic interfaces	Dynamic routing paths; Interfaces known at design time;	Lose coupling; Generic interfaces (should be)
Energy awareness	Not really concerned yet	Very important (e.g. sleep mode of idle components)	Highly important (e.g. sleep mode of idle components)
Energy aware routing	No (complex networks complicate energy aware routing	Yes (impacts performance and reliability)	Yes (location and distance most significant)

wireless radio technologies are used. Referring WSNs, such necessary information can be taken whether from the routing tables of the sensor nodes or by considering the metadata including the geographical and/or logical location in the network. In most scenarios, the number of hops is sufficient for the power estimation as the transmission itself is the dominating source for power consumption and because distance has rather small impact. Finally, table 1 briefly summarizes the discussed differences and commonalities.

4 Conclusion

Service-oriented Architecures have greatly improved software engineering by encapsulating complex functions and processes. Furthermore, device centric approaches (like SODA) have also allowed to seamlessly integrate hardware devices into such architectures. However, besides the functional service composition, additional aspects ─ like power consumption ─ are very rarely been accounted for.

This paper discussed the application of service-oriented concepts in the domain of networks-on-chip and Wireless Sensor Networks that are constrained by the power consumption. The need for considering power aspects was demonstrated by an example of a service composition inside an on-chip network. From there, we argued that the combination of SODA concepts and power constrained considerations from the NOC domain seem a promising approach for the implementation in Wireless Sensor Networks. Thus, the hundreds of sensor nodes and their dedicated functionalities can be handled efficiently, while preserving the robustness of the battery limited network and maximizing system lifetime.

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