Journal of Universal Computer Science, vol. 16, no. 13 (2010), 1668-1693
submitted: 15/3/10, accepted: 6/5/10, appeared: 1/7/10 © *J.UCS*

Service Networks Modelling: An SOA & BPM Standpoint

Olha Danylevych
(Institute of Architecture of Application Systems
University of Stuttgart, Germany
olha.danylevych@iaas.uni-stuttgart.de)

Dimka Karastoyanova
(Institute of Architecture of Application Systems
University of Stuttgart, Germany
dimka.karastoyanova@iaas.uni-stuttgart.de)

Frank Leymann
(Institute of Architecture of Application Systems
University of Stuttgart, Germany
frank.leymann@iaas.uni-stuttgart.de)

Abstract: Services are quintessential in the current economical landscape. Enterprises and businesses at large rely on the consumption and providing of services to ensure their operations and to realize their business offers. That is, nowadays businesses all over the world are interconnected with each other by complex service-centric webs called *service networks*. The ubiquity and pervasiveness of service networks call for models, methods, mechanisms and tools to understand them and harness their potential.

This paper investigates the modelling of the service networks with a focus on business relationships and exchanges of software services among the involved parties. The contribution of this work is threefold. Firstly, we provide an overview of what service networks modelling can offer in combination with Business Process Management (BPM) and Service Oriented Architecture (SOA) technologies. Secondly, we propose a formalism to model service networks that depicts them as aggregations of participants – e.g. enterprises or individuals – that offer, request, consume and provide services to each other. With the goal of providing a foundation for the alignment between service network- and business process models, we finally map the constructs of our service networks modelling formalism to the ones of the Business Process Modelling Notation (BPMN).

Key Words: service networks, service oriented architecture, software services, business process management, business processes, BPMN

Category: D.2.9, H.1, H.3.5

1 Introduction

We live in "services times". Services are paramount in the global economy. In western societies like USA and Germany more than 60% of the work force is devoted to the delivery of services [Maglio 06]. The meaning of the term "service" itself is changing to keep up with the times. Originally, the economical meaning of service was (1) an intangible type of good or (2) a value-increasing addition to a good [Maglio 09]. Nowadays, however, it has evolved to "the process of doing something for another party, without reference to goods as the primary focus of the exchange activity" [Maglio 09].

Everyone taps into services every day by using Google, Facebook, Twitter, online banking facilities, webmail applications of choice, etc. But services are not only an Internet-related phenomenon. For example, education at large can be seen as a service system, as well as call centers, IT support [Maglio 06], and telecommunication [Buford 01].From business perspective, the importance of services for modern enterprises is such that it has led to the rise of the Service Oriented Computing (SOC) paradigm [Papazoglou 07a, Papazoglou 08] and its technological embodiment Service Oriented Architecture (SOA).

Enterprises rely on services provided to them by other parties for the realization of their own service offers. The interconnections in terms of services offered and required by enterprises shape complex webs called *service networks*. Furthermore, service networks are not phenomena occurring only among distinct businesses. In fact, service networks exist as well inside enterprises because of the interplay among business units, divisions, departments, etc. In the turmoil of nowadays globalized economy we need models, methods, mechanisms and tools to understand and deal with service networks.

Service networks are at the crossroad of many different and converging disciplines, each approaching the topics from a different point of view and focusing on different aspects [Maglio 09]. In the state of the art service networks come under many names such as service system [Maglio 06, Caswell 08], service ecosystems [Barros 06], and service value networks [Blau 09]. Approaches to service networks with an economy focus are mainly concerned with the creation of value [Gordijn 01, Biem 08, Allee 08, Caswell 08]. On the contrary, the business communities investigate the structure of organizations in service networks [Camarinha-Matos 06, Steen 02] and the related business models [And. 05, Osterwalder 04]. The SOA and Business Process Management (BPM) communities focus on the technology to realize and operate service networks and automate the business processes that take place inside them.

Our contribution comes under the SOA and BPM banner. We envision service networks modelling as the means to gain better alignment between the business and IT perspectives in enterprises. The enhanced alignment is achieved by (1) providing an overview of inter- and intra-enterprise business relationships in terms of service offerings and providings, (2) supporting decision making on service networks in terms of business relationships between participants, and (3) facilitating the propagation of changes from service networks to the underpinning software service infrastructures and vice versa.

This work focuses on service networks built around *software services*, i.e. services that are provided over a software infrastructure and that do not involve the exchange of physical goods between parties. We propose a formalism to model service networks as aggregations of participants (organizations, individuals, etc.) that provide services to and consume services from each other. Moreover, we lay the foundations for aligning service networks with the technologies that undergird them. This is accomplished by establishing correlations between the service networks modelled with our formalism and the business processes modelled with the Business Process Modelling Notation (BPMN) version 1.2, the de-facto standard for modelling the operational aspects of business processes at BPM level.

The paper is structured as follows. Section 2 introduces the running example that is used throughout the paper to exemplify the proposed concepts. Section 3 outlines the role of service networks modelling with respect to BPM and SOA, and shapes the overarching scope of our research. Section 4 presents the formalism to model service networks. In Section 5 we investigate the alignment of service network- and business process models. The related work is treated in Section 6. Finally, Section 7 concludes the paper by presenting the closing remarks.

2 The Running Example: The SomeTunes Media Store

The running example of this paper is a fictional service network centred on the online Media Store “SomeTunes” and encompassing SomeTunes’ customers and the service providers it relies on.

The SomeTunes D, subordinated to Mango Inc, runs an online media store offering services that sell music, movies and applications for mobile devices (smartphones, tablets, handheld music players) running the Anthropoid mobile operative system. Each of the service offerings of SomeTunes can be accessed separately by its customers. For the sake of brevity, in this scenario we restrict ourselves to four customers: Alice, Bob, Carl and John. The customers are individuals, and consume different combinations of SomeTunes’ service offerings. Alice buys Athropoid applications, Bob buys some music, Carl buys movies and their soundtracks, and John buys movies and unrelated music.

SomeTunes relies on external payment services for handling customers’ online payments. Customers of SomeTunes can currently choose between the payment services offered by the PayDude and OverlordCard companies. From the point of view of SomeTunes, the particular payment service provider adopted in a given transaction with a customer is of marginal importance because both of them implement a common interface and apply equivalent commission fees.

SomeTunes does not develop the Anthropoid applications it sells. Instead, it offers a platform for enabling application publishers to sell their products. The platform has just been launched, and the only publisher currently using it is

Snowstorm Publisher. Customers who buy Snowstorm Publisher's applications on SomeTunes are required to activate them by contacting a software service provided by Snowstorm Publisher.

3 The Scope of Service Networks

This section discusses the scope of our research on service networks and their application to the practice of BPM and SOA. Section 3.1 covers the modelling of service networks. The analysis of service network models is treated in Section 3.2. Section 3.3 describes how service network models can be used to depict either actual or hypothetical service networks. Finally, Section 3.4 discusses the change management of service network models.

3.1 Modelling Service Networks

Service networks modelling aims at providing an overview of the interplay among service consumers and providers while abstracting from the technical details of business process- and service composition modelling. Service networks modelling is applicable to both inter- and intra-organization scenarios, which respectively describe the interactions among organizations and, inside a business, among divisions, departments, units, etc.

The description of a service network is a combination of several elements, namely (1) ***participants***, (2) the ***service requests*** and ***service offerings*** that populate the network, and (3) the *relationships between participants*, e.g. ***business relationships*** or ***service providings***. The consumption of services is implied by the service providings, i.e. providing and consuming a service are the same relation from different points of view.

Our approach to service networks modelling adopts an *instance* point of view. That is, our goal is to enable the modelling of *concrete* service networks, i.e. real service networks that are made of actual participants (e.g. the SomeTunes Division in the running example) in contrast with the roles they play (e.g. Music Reseller or Application Store). We wish to underline that role and instance perspectives on service networks modelling must ultimately reconcile. For example, practitioners should be able to relate participants of instance service networks to the more abstract roles they play. Bringing together instance and role points of view of service networks modelling is in the overarching scope of our research. However, in this paper we restrict ourselves to the modelling of instance service networks because we believe that the instance point of view is the one on the basis of which business decisions are taken. For example, when a business has to decide which providers to rely on for the provisioning of some services, the roles alone do not convey enough information about the available options, i.e. the actual providers. Instead, business analysts need to visualize the concrete contracts, service offerings, etc., that are input to the business decisions and that are available only from the instance perspective.

The participants in a service network are of two types: individuals, i.e. natural persons (humans), and business entities, e.g. organizations and consortia. Participants can establish relationships among each other, which can be grouped into business- and structural relationships. Business relationships describe for example strategic alliances between organizations, and have implications on how service networks operate and change over time.

Structural relationships model how the business entities and individuals relate to other participants in terms of organizational structures. One business entity can be subordinated to another, e.g. the subordination of the SomeTunes Division to Mango Inc. Another structural relationship is the affiliation of an individual to a business entity, e.g. Steve Works (Mango Inc.'s CEO) is affiliated to Mango Inc. Structural relationships are relevant to the change management of service network models, because they may impose constraints to which changes can actually be applied.

Participants in a service network can be both consumers and providers at the same time. Consumers are participants that need services, and they issue service requests to advertise their needs. Service requests state the characteristics of the required services, e.g. in terms of functionalities and Quality of Service, and the conditions under which they should be provided, e.g. acceptable price ranges. Providers make their services available to other participants through service offerings. A service offering is the description of a service plus information on the conditions under which the service is made available, for example pricing schemes and contractual obligations.

The consumption of services takes place over service providings. A service providing is a particular type of relationship that occur between a provider and a consumer and that consists of the actual delivering of one or more provider's services to the consumer. Service providings are regulated by contracts that specify the terms and obligations that regulate the exchange.

3.2 Analysis of Service Networks

Service networks modelling aims at facilitating the management of service offerings, requests and providings between and inside organizations. To reach this goal we need analysis methods that support the decision making concerning change and optimization of service networks.

The state of the art of service network analysis is still limited and currently centered on the economical perspective (see Section 6). For example, in our previous work we have investigated the optimization of value in service networks [Bitsaki 08a]. Other analysis methods focus on profitability and sensitivity [Gordijn 01] and value flows [Allee 08]. Future research will need to develop analysis methods that bridge the economical, operational and technological aspects of service networks. For instance, we envision methods for analyzing long-term collaborations among partners to discover and prioritize which underlying business processes and service compositions should be optimized. Another interesting research direction is the analysis of service network for discovering patterns of interactions among participants. Through the mapping to the underlying business process models (see Section 5), this would results in the discovery of reference models and reusable fragments of business processes and service compositions that will simplify the creation and management of value-adding constellations.

Both local (one or more participants) and the global (the whole service network) perspectives should be supported by the next generation of analysis methods for service networks. In general, the perspectives employed by the analyses will depend on the scenarios depicted by the analyzed service networks. In service networks that model inter-organizational business relationships, the analysis will mainly aim at optimizing the situation of single participants or participant groups, i.e. local optimization. On the contrary, the analysis of intra-organizational service networks could be performed from a global perspective with the goal of optimizing the overall performance of the enterprise.

3.3 "As Is" and "To Be" Service Networks

Service network models either capture the state of existing interactions among participants – service networks "as is" – or depict planned service networks – service networks "to be". Service network models "as is" will be created bottom-up by extracting information from business process models, logs, service compositions, SLA agreements and contracts among parties. The analysis of "as is" service network models will support decision making for adapting and optimizing the behaviour of participants, e.g. in terms of services provided or consumed, explore possible optimizations, and detect underperforming participants on the basis of monitoring.

Service network models "to be" will be created either top-down or by modifying "as is" models. The analysis of "to be" service network models will employ simulation and predictions to outline "what if" scenarios. The service network models will then be used as starting points for implementing the business processes and service compositions that will operationalize the business relationships.

3.4 Change Management

Service network models change for a number of reasons. In "as is" service network models, changes are required to keep the alignment between the model and the reality of the service network.

Changes to service network models result from the application of change operators like the removal of a service offering, the addition a participant, or the modification of existing service requests. The change operators should be correlated with change operators for business process- and service composition models to streamline the implementation of the changes through the technology stack underpinning actual service networks.

In this paper we lay a foundation for the correlation of changes at the different levels by analyzing the correspondences between constructs of service network models and the ones of business process models in Section 5.2.

4 A Formalism for Modelling Service Networks

This section describes the formalism to model service networks based on hypergraphs, i.e. generalizations of graphs in which edges – in this case called hyperedges – connect two or more nodes. The constructs are exemplified on the basis of the "SomeTunes" running example proposed in Section 2. We have depicted the running example in Figure 1 using a simple graphical notation instead of showing hypergraphs for the sake of understandability.

4.1 Service Networks

A service network model is a directed hypergraph formally defined as:

$$\mathcal{G}_{sn} = (\mathcal{V}, \mathcal{E})$$

In a service network there are three types of nodes: participants (denoted by $\mathcal{P}$), service requests ($\mathcal{R}$) and service offerings ($\mathcal{O}$). That is:

$$\mathcal{V} = \mathcal{P} \cup \mathcal{R} \cup \mathcal{O}$$

The hyperedges of a service network represent either business relationships ($\mathcal{L}$), ownership of service offerings ($\mathcal{E}_o$), ownership of service requests ($\mathcal{E}_r$), service providings ($\mathcal{E}_p$), service providing dependencies ($\mathcal{D}_{prov}$) or participant internal dependencies ($\mathcal{D}_i$).

$$\mathcal{E} = \mathcal{L} \cup \mathcal{E}_o \cup \mathcal{E}_r \cup \mathcal{E}_p \cup \mathcal{D}_{prov} \cup \mathcal{D}_i$$

In the reminder of the section we examine in detail the different types of nodes and edges. In particular, Section 4.2 treats participants and business relations. Section 4.3 covers service offerings and their ownership. Service requests and their ownerships are examined in Section 4.4. Section 4.5 treats service providings and service providing dependencies. Finally, Section 4.6 discusses participant internal dependencies.

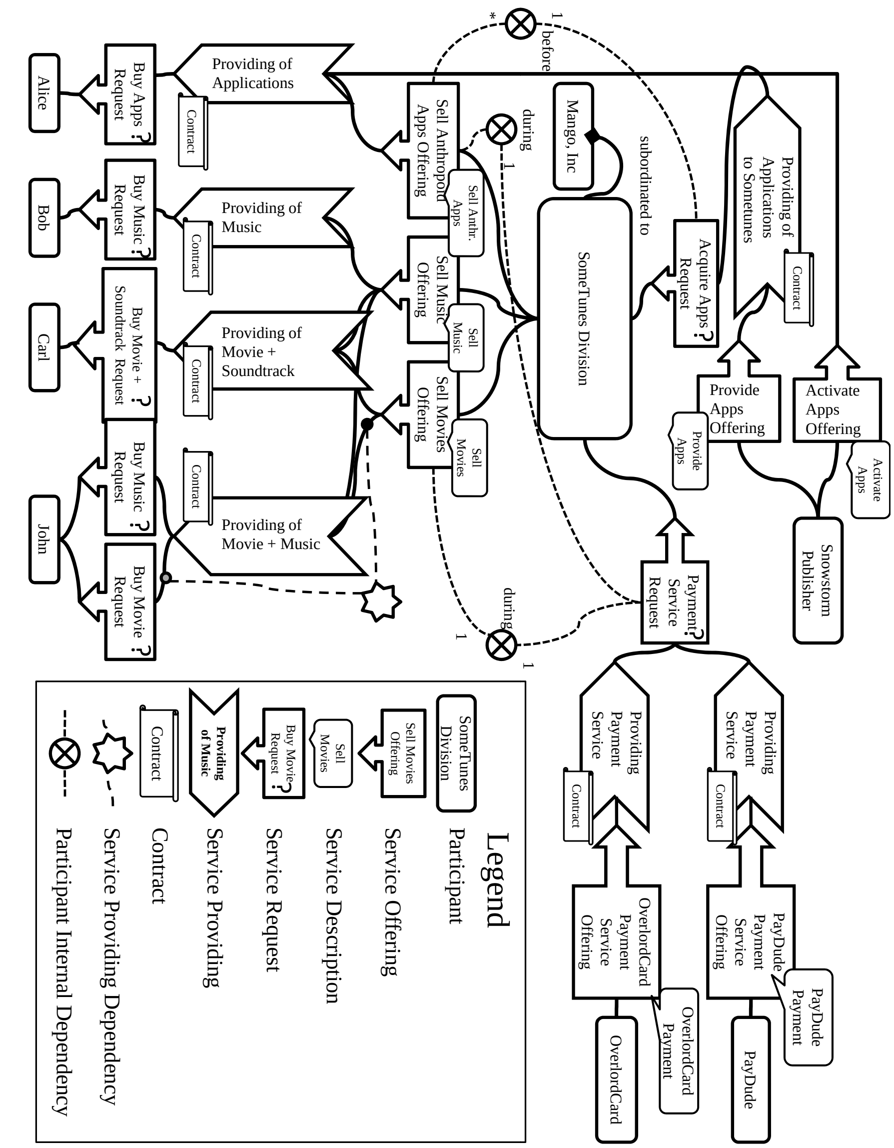

Figure 1: A graphical representation of the service network of the running example

4.2 Participants and Relations Among Them

The ***participants*** of a service network are either business entities (denoted by $\mathcal{B}$) or individuals (denoted by $\mathcal{I}$). That is:

$$\mathcal{P} = \mathcal{I} \cup \mathcal{B}$$

We wish to reiterate that participants in our service network models are actual, concrete participants, in contrast with mere roles. In our scenario, we have four business entities, namely Mango Inc, the SomeTunes Division, PayDude, and OverlordCard, Snowstorm Publisher, and four individuals, i.e. the consumers Alice, Bob, Carl and John.

We are aware of the fact that modelling each actual participant in a service network will lead in some cases to an explosion of the number of elements in the models, in particular when modelling customers in Business to Consumer (B2C) scenarios. However, this is not a disadvantage of our approach itself, as it is an issue that has been encountered for example in databases. And there are valuable lessons to be learned from the database community. In future research we will explore the possibility to support ***views*** in the modelling notation and the connected tooling. Views will enable the collapsing of multiple analogous participants (as well as service offerings, requests, etc.) in groups of manageable size.

Participants in a service network can be connected by *business relationships* that represent, for example, strategic alliances or partnerships. The role of contracts in service network modelling is to set constraints to how the networks (and the underpinning business processes) evolve. For example, the obligations specified in a contract signed by two participants might prevent one to offer in the future certain types of services due to a non-compete clause. In this work we refrain from providing a formalization of generic business relations, and instead focus on the structural ones (and the service providings later on). ***Structural relationships*** pertain to how participants are organized hierarchically. Individuals can be affiliated to business entities, e.g. organizations. Affiliations in a service network connect the individuals in the service network to the business entities they are affiliated to, and can be formalized as follows:

$$\mathcal{A} \subseteq \mathcal{I} \times \mathcal{B}$$

In our running example we have no affiliations. However, it is easy to envision scenarios in virtual networks and/or human-provided services in which the affiliation of individuals is an element to take into consideration in the modelling and management of service networks.

Business entities can be subordinated to one or more other business entities, e.g. divisions are subordinated to enterprises. Formally:

$$\mathcal{F} \subset \mathcal{B} \times \mathcal{B} \,:\, (b_1, b_2) \in \mathcal{F} \Rightarrow b_1 \neq b_2$$

As a convention, the first business unit in the relationship is subordinated to the second (b_1 subordinated to b_2 in the above formalization). In the running example the subordination relationship is exemplified by the fact that the SomeTunes Division is subordinated to Mango Inc. We do not impose restrictions to the subordination, for example we do not require the subordination of business entities to other to form a tree. This is because we wish to support the modelling of virtual organizations, i.e. the business entity resulting from the sharing of resources by independent organizations aiming at achieving some shared goals [Camarinha-Matos 04, Zirpins 09], alongside the more usual hierarchical, inter-enterprise organizational structures.

It should be noted that, in a sense, also service providings are relationships connecting the participants in service networks. However, they to not exactly connect the participants, but instead the service offerings and requests those participants provide. We treat service providings separately in Section 4.5.

4.3 Service Offerings

The services in a service network (i.e. the functionalities that are exposed by the participants) are represented as ***service offerings***. In the running example there are the "Sell Anthropoid Apps Offering", "Sell Music Offering" and "Sell Movies Offering" of SomeTunes Division, the two distinct "Payment Service Offerings" of PayDude and OverlordCard, and the "Activate Apps Offering" and "Provide Apps Offering" of Snowstorm Publisher.

Service offerings are aggregations of information that describe functional and non-functional properties of the services that are offered. The functional properties specify *what* the service does, e.g. in terms of the International Standard Industrial Classification of All Economic Activities (ISIC) revision 4 [1]. The non-functional properties specify how the functionalities are carried out, e.g. in terms of Quality of Service. The "Sell Music Offering" may contain, for example, the following data:

- Functional Properties: (1) ISIC rev 4 codes: 4762 (Retail sale of music and video recordings in specialized stores) & 4791 (Retail sale via mail order houses or via Internet); (2) Supported File Formats and Bitrates: MP3 (512 kbit/s), FLAC, OGG Vorbis (512 kbit/s); (3) Digital Rights Management (DRM): none

- Non-Functional Properties: (1) Download rate: from 50 KB/sec to 1 MB/sec; (2) Download availability: 99%

The exhaustive enumeration of the types of additional information in the service offerings is outside the scope of this work. Examples of such information

[1] ISIC Website: `http://unstats.un.org/unsd/cr/registry/isic-4.asp`

can be found in the pricing and legal profiles of the Unified Service Description Language (USDL)[2]. Interested reader will find in [Andrikopoulos 08] a generic way of representing functional and non-functional properties of offerings.

Each service offering in a service network belongs exactly to one participant. Notice that in a service network model there might be distinct service offerings that are equivalent because they contain exactly the same data. Equivalent service offerings may each belong to different participants, or multiple may belong to one participant that wishes the duplication for some reason. The ownership relation between participants and their service offerings is represented by the edges $\mathcal{E}_o$ that are formalized as:

$$\begin{aligned}\mathcal{E}_o \subseteq \mathcal{P} \times \mathcal{O} \ : \ \forall o \in \mathcal{O},\ \exists p \in \mathcal{P} :\ \exists (p,o) \in \mathcal{E}_o \wedge \\ \nexists p_1, p_2 \in \mathcal{P},\ o \in \mathcal{O} :\ p_1 \neq p_2 \ \wedge\ (p_1, o) \in \mathcal{E}_o \wedge (p_2, o) \in \mathcal{E}_o\end{aligned}$$

It is possible for participants not to have any service offerings (e.g. the customers in the running example).

4.4 Service Requests

A ***service request*** is a specification of the requirements that a participant sets on the services it needs, e.g. acceptable QoS or pricing. The structure of service requests is equivalent to service offerings' (i.e. functional, non-functional and additional information). However, while service offerings specify a description of an existing service, service requests specify minimal requirements that services must satisfy. For example, Bob's "Buy Music Request" might specify that he wants to buy music (e.g. in terms of the ISIC classification), the bit rate and file format desired, but do not set any requirements on the DRM systems.

The relation between the participants and their service requests are represented by the edges $\mathcal{E}_r$. Formally:

$$\begin{aligned}\mathcal{E}_r \subseteq \mathcal{P} \times \mathcal{R} \ : \ \forall r \in \mathcal{R} \ : \ \exists p \in \mathcal{P},\ \exists (p,r) \in \mathcal{E}_r \wedge \\ \nexists p_1, p_2 \in \mathcal{P},\ r \in \mathcal{R} :\ p_1 \neq p_2 \wedge (p_1, r) \in \mathcal{E}_r \wedge (p_2, r) \in \mathcal{E}_r\end{aligned}$$

Likewise service offerings, each service request belongs to exactly one participant. Participants may however have equivalent service requests. It is not mandatory for participants in a service network to have service requests (in the running example this is the case of PayDude, OverlordCard and Snowstorm Publisher). As a matter of fact in our modelling notation for service networks it is possible for some participant to have neither service offerings nor service requests, such as Mango Inc in the running example. This is a deliberate design

[2] The USDL specifications are available at: `http://www.internet-of-services.com/index.php?id=54`

decision to account for situations such as when a participant has discontinued its services – for example a company that gets bought out by another one – but still retains business relations with other participants.

4.5 Service Providings and Service Providing Dependencies

A ***service providing*** is a relationship that connects one or more service requests with one or more service offerings that satisfy them and the contract (e.g. the license) that regulates the provisioning. The set of service providings in a service network is denoted by $\mathcal{E}_p$, formally specified as:

$$\mathcal{E}_p \subseteq \wp(\mathcal{R}) \times \wp(\mathcal{O}) \times \mathcal{C}$$

We recall that $\mathcal{R}$, $\mathcal{O}$ and $\mathcal{C}$ denote the sets of the service requests, service offerings and contracts modelled in the service network, respectively.

We have a flexible approach to service providings. We allow multiple service offers and requests from multiple providers and consumers to be combined in one service providing. One service offering might satisfy multiple service requests in the same service providing. The opposite case is also applicable, i.e. a service request is satisfied by a combination of service offers. Moreover, both service requests and service offerings may be involved in multiple service providings. On one hand, this enables the modelling of situations in which a service consumer relies on multiple providers to satisfy a service request. In the running example this is the case of the "Payment Service Request" of SomeTunes Division, which is satisfied by two distinct service providings. On the other hand, we can model situations in which the same service offering is involved in multiple providings (i.e. it serves multiple customers), such as the "Sell Music Offering" of SomeTumes.

Service providings are associated with contracts that specify the terms under which the consumption of services takes place. In our running example, the "Sell Music Providing" may be associated with an End User License Agreement (EULA) that, among other obligations, forbids the redistribution of the songs, fixes the terms for the termination of the licenses, and establishes the conditions for the reuse of consumers' personal data. It is outside the scope of this work to model the structure of contracts. The interested reader will find examples of methods to formalize contracts in [Daskalopulu 99, Telang 09]. Additionally, it falls outside the scope of this paper to specify how service providings come into existence, e.g. in terms of the negotiation processes that leads to them (see for example [Dang 06, Maglio 09]), how the discovery is performed (e.g. [Meshkova 08]), or how the matching between service offerings and requests is carried out (see for example [Kritikos 09]).

The relations between service offerings and service requests within one service providing are represented by ***service providing dependencies***. Service providing dependencies mark the fact that in a service providing some of the service offerings may realize only some of the service requests. Modelling dependencies in complex providings through service providing dependencies aims at facilitating the change management of the service providings (e.g. when a providing is revised and consequently split in two distinct ones), and the mapping of service networks to the underpinning BPM layer (see Section 5). The service providing dependencies in a service network are formalized as follows:

$$\mathcal{D}_{prov} \subseteq \mathcal{O} \times \mathcal{R} \;:\; \forall (o, r) \in \mathcal{D}_{prov} \;\; \exists (\tilde{R}, \tilde{O}, c) \in \mathcal{E}_p : o \in \tilde{O} \wedge r \in \tilde{R}$$

Consider "Providing of Movie + Music" between SomeTunes and John. The service providing aggregates two distinct offerings of SomeTunes, i.e. "Sell Music Offering" and "Sell Movie Offering", and two requests of John, namely "Buy Music Request" and "Buy Movie Request". For readability, we have depicted only the service providing dependency between "Sell Movie Offering" and "Buy Movie Request". In general, service providing dependencies can connect (pairwise) any number of offerings and requests inside the one service providing.

4.6 Participant Internal Dependencies

Participant internal dependencies are another type of dependencies in service network models beside service providing dependencies. A participant internal dependency relates one service offering and one service request belonging to the same participant. Its semantics is that the ability to provide the service offering by the participant depends on the satisfaction of the correlated service request. For example, the offering "Sell Anthropoid Apps Offering" of SomeTunes has two participant internal dependencies to "Payment Service Request" and "Acquire Anthropoid Apps Request".

On top of the dependencies between service offerings and service requests, participant internal dependencies specify two additional pieces of information: ***multiplicity*** and ***timing***. The multiplicity denotes the ratio between the satisfaction of service requests and units of related service offerings that can be provided. In our example, each instance of the "Sell Anthropoid Apps Offering" requires the satisfaction of one "Payment Service Request" (every time something is sold there must be an interaction with the payment service). Multiplicities can also be specified as intervals: the satisfaction of the "Acquire Apps Request" one or more times (multiplicity "1..*") allows any number of occurrences of the "Sell Anthropoid Apps Offering" (i.e. "*" in terms of multiplicity) because once an application has been uploaded to the SomeTunes platform, SomeTunes Division can resell it any number of times.

The timing of a participant internal dependency specifies the temporal relation between the satisfaction of the service request and the ability to provide the

Timing	**Definition**
equals	offering / request
meets	offering / request
during	offering / request
finishes	offering / request
before	offering / request
overlaps	offering / request
starts	offering / request

Table 1: The definitions of the possible values of timing in participant internal dependencies

service offering. The timing is specified using Allen's interval algebra [Allen 83], which defines a set of relations that specify all the possible ways two time intervals can relate to each other, e.g. in terms of equality or overlap. The possible values for the timing of the participant internal dependencies are shown in Table 1.

The set $\mathcal{D}_i$ contains the participant internal dependencies in a service network model, and it is formally defined as:

$$\mathcal{D}_i \subseteq \mathcal{P}\times\mathcal{O}\times\mathcal{M}\times\mathcal{R}\times\mathcal{M}\times\mathcal{T} \ : \forall(p,o,m_o,r,m_r,t) \in \mathcal{D}_i \ : \ \exists(p,o) \in \mathcal{E}_o \wedge \exists(p,r) \in \mathcal{E}_r$$

$\mathcal{M}$ is the set of the possible multiplicities, and $\mathcal{T}$ are the possible timings (i.e. the entries of Table 1). Given the participant internal dependency (p, o, m_o, r, m_r, t), p denotes the participant, o is the offering of p, m_o is the multiplicity of o, r is the request of p, m_r is the multiplicity of r, and t is the timing.

5 Aligning Service Networks and the Business Process Management Stack

In order to make a service network happen, its participants have to field and employ a stack of technologies that are ubiquitous in the current practice of BPM and SOA like business process- and service composition models, service-oriented middleware, and software services. Service network models provide an overview of the relationships among participants while abstracting from the details of how the interactions among them take place, i.e. the operational details. Conversely, each business process realizes a part of a service network by specifying the operational details of the interactions among of some of the network's participants.

In general, a single business process model does not convey the entirety of the information available in a service network model because the business process (1) depicts operational information about only a part of the service network and (2) usually does not contain information on business relationships and contracts that occur between the participants. In other words, service network- and business process models have distinct – but related – purposes and perspectives, and therefore complete each other by tackling different aspects of the interconnections among businesses.

The interplay of service networks and business processes is such that it should be possible to create skeletons (i.e. incomplete models) of one from the other. We call *top-down* modelling the creation of business process skeletons from service networks. Conversely, *bottom-up* modelling is the extraction of service network skeletons from sets of business process models employed by one or more participants. The alignment of service network models and the corresponding business process models is essential. On one hand, the modifications to service network models must propagate to the related business process models. On the other hand, service network models should be updated according to the evolution of the underpinning business processes, which in turn depend on the underlying service compositions and service infrastructures, see for example [van den Heuvel 08].

To the end of aligning service network- and business process models, this section (1) shows how service networks relate to the underpinning stack of BPM and SOA technologies that realize them (Section 5.1), and (2) investigates the correspondences between the constructs of service network- and business process models specified using BPMN (Section 5.2).

5.1 The Technology Stack for Enacting Service Networks

The implementation of service network models in terms of real-world software services is based on the layering of BPM and SOA technologies shown in Figure 2. The Services layer comprises the set of software services that are available in the service network. The software services may be realized using SOA standards like SOAP, WSDL, and other WS-* specifications. Overviews of the technologies involved in the realization of these services are provided, for example, in [Weerawarana (05), Papazoglou(07)].

The Service Compositions layer deals with combining existing software services into composed, value-added ones. For reasons of space, we can provide only an overview of the service composition field. We reference the interested reader to more comprehensive surveys such as [Dustdar 05, Wetzstein 08].

In the state-of-the-art of SOA there are two main and most popular approaches to service composition: service orchestration and service choreography [Peltz 03, Busi 05, Barros 05]. Orchestration and choreography are two flips of the same coin: orchestration specifies a service composition from the local point

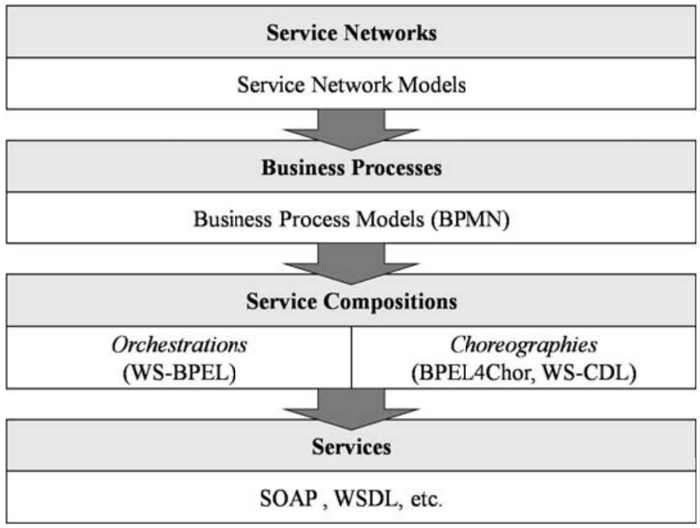

Figure 2: The technology stack for enacting service networks

of view of one single software service (the one that composes the others), while choreography assumes a global perspective on the service composition. On one hand, service orchestration is the service composition approach in which a new software service is created by invoking the composed software services and combining their outputs in some meaningful way. The internal logic of the new software service is specified using process flow languages, most notably the Web Service Business Process Execution Language (WS-BPEL)[3].

Service choreography specifies the ordering/sequencing of message-based conversations that are carried out by the composed software services. As opposed to service orchestration, each of the composed services is defined in terms of its perceived messaging behavior (called role), and its actual internal logic is not defined. Service choreographies are currently specified using languages and notations like BPEL4Chor [Decker 08] and Web Services Choreography Description Language (WS-CDL)[4].

The Business Process Models layer builds on the technologies and approaches specifies at the underpinning layers and deals with modelling abstract business processes. Abstract business process models are not executable, implementation-agnostic models of how the participants carry out the complex functionalities they provide. For example, abstract business process models define the ordering of the activities and interactions that are undertaken by the participants in order

[3] The WS-BPEL specification is available at: `http://docs.oasis-open.org/wsbpel/2.0/wsbpel-v2.0.html`
[4] The WS-CDL v1.0 specification is available at: `http://www.w3.org/TR/ws-cdl-10/`

Service Network Constructs	**BPMN Constructs**
Participants	Pools
Service Offerings & Service Offering Ownerships	Lanes and workflows
Service Requests & Service Request Ownerships	Lanes and workflows
Service Providings	*implicitly modeled in the interactions among workflows of providers and consumers*
Service Providing Dependencies	*implicitly modeled in the interactions among workflows of providers and consumers*
Contracts	*no corresponding construct*
Business Relationships (e.g. Affiliation and Subordination)	*no corresponding construct*
Participant Internal Dependencies	*implicitly modeled in the way related offerings and requests are grouped in workflows and lanes*

Table 2: Correspondences between Service Network and BPMN constructs

to execute the business processes. The aim of abstract process models is mainly to document and communicate how functionalities are going to be provided from a high level of abstraction. In order to be executed, abstract business processes are refined as service compositions, and deployed on the service infrastructure at the Services layer. The Business Process Models layer employs notations like the Business Process Modeling Notation (BPMN)[5] and Abstract BPEL, which is a subset of WS-BPEL that is also used at the Service Composition layer.

Finally, the Service Network layer sits on top of the Business Process Models layer, providing the means of analyzing, simulating and optimizing service networks.

5.2 Aligning Service Network and Business Process Models

Unlike business process models, service network ones abstract from the operational details of the processes (e.g. workflows) and focus on the business relationships occurring among the participants, the participants' offerings and requests of services, and the service providings and the relative contracts. The difference in focus and complementarity of service network- and business process models implies in the need of aligning them as one or the other changes in order to preserve the consistency.

[5] The BPMN v1.2 specification is available at: `http://www.omg.org/spec/BPMN/1.2`.

As a first step towards achieving this alignment, in this section we outline the correspondences between the constructs in service network- and business process models. We assume BPMN version 1.2 as the modeling notation for abstract business process models. It is outside the scope of this paper to provide formal means of transforming from service network- to business process models and vice versa. The interested reader will find an initial investigation of how service network models are refined to abstract business processes in our previous work [Bitsaki 08b].

The relations between service network- and abstract business process models are exemplified using the subset of the running example highlighted in Figure 3 and the corresponding BPMN business process that models shown in Figure 4. Table 2 summarizes our findings, which are detailed in the remainder of the section.

5.2.1 Service Network Constructs Explicitly Mapped to BPMN

Each service network participant is mapped to a BPMN pool. For each service offering and service request we create a lane in the participant's pool. In BPMN, a pool can contain multiple distinct workflows, each one included in a lane. In a sense, BPMN lanes are a way to define for the same participant multiple processes. The lanes of a pool can be related through control flows or other types of associations (e.g. events).

Service offerings and requests are mapped to lanes. Since lanes in BPMN are contained in pools, there is no need to explicitly represent service offering- and request ownerships. The workflow in each lane specifies the logic for realizing one or more service offerings and requests of one participant. If a service offering of a participant is related to some service requests by the means of participant internal dependencies, the relative operational logic of that participant that deals with the connected service offering and requests can be expressed by a single workflow. In other words, participant internal dependencies do not have a directly corresponding construct in BPMN, but are instead used to "cluster" the service offering and requests they relate in lanes. Consider for example the SomeTunes Division in Figure 4. The "Sell Anthropoids Apps Offering" has a participant internal dependency on the "Payment Service Request". Because of the clustering of the operational logic realizing service requests and offerings related by participant internal dependencies, there is no dedicated lane for 'Payment Service Request" and instead its logic is incorporated in the "Sell Anthropoids Apps Offering" lane.

As anticipated in the beginning of the section, service network models provide no information concerning the details of the logic that realizes service requests and offerings of participants. We have refined the workflows of Alice and SomeTunes in Figure 4 for explanatory purposes. What can be generally generated

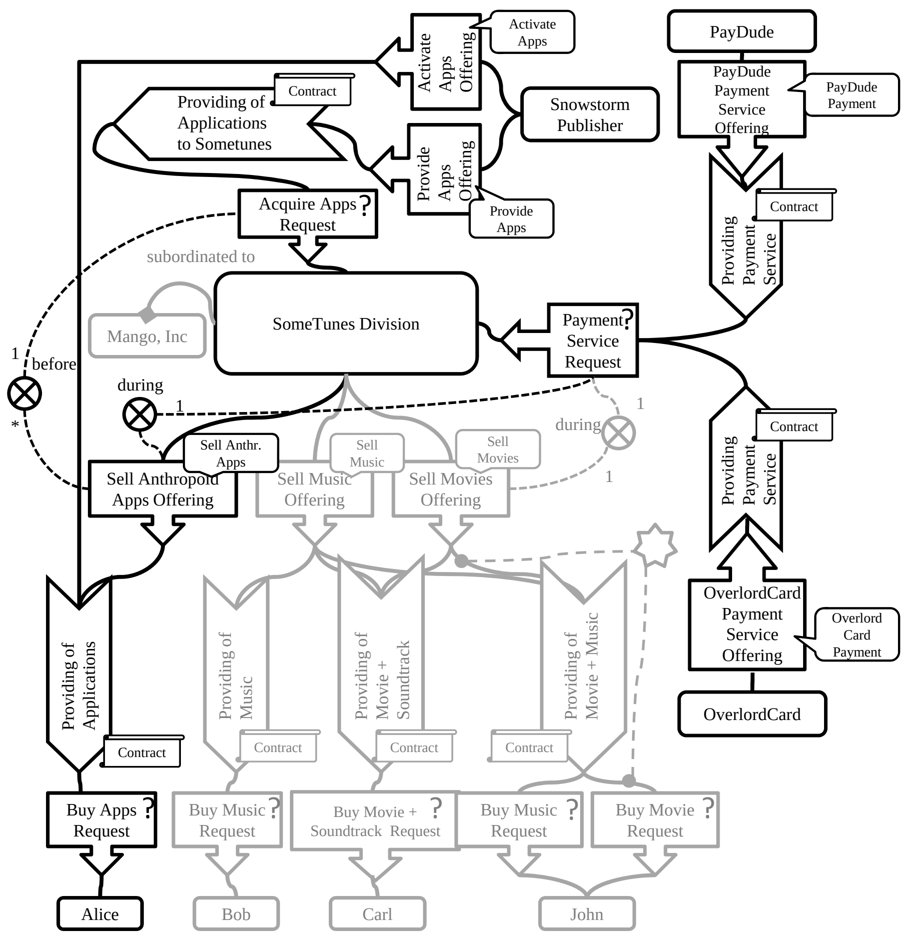

Figure 3: The subset of the running example that we use to explain the mapping between constructs of service network- and abstract business process models

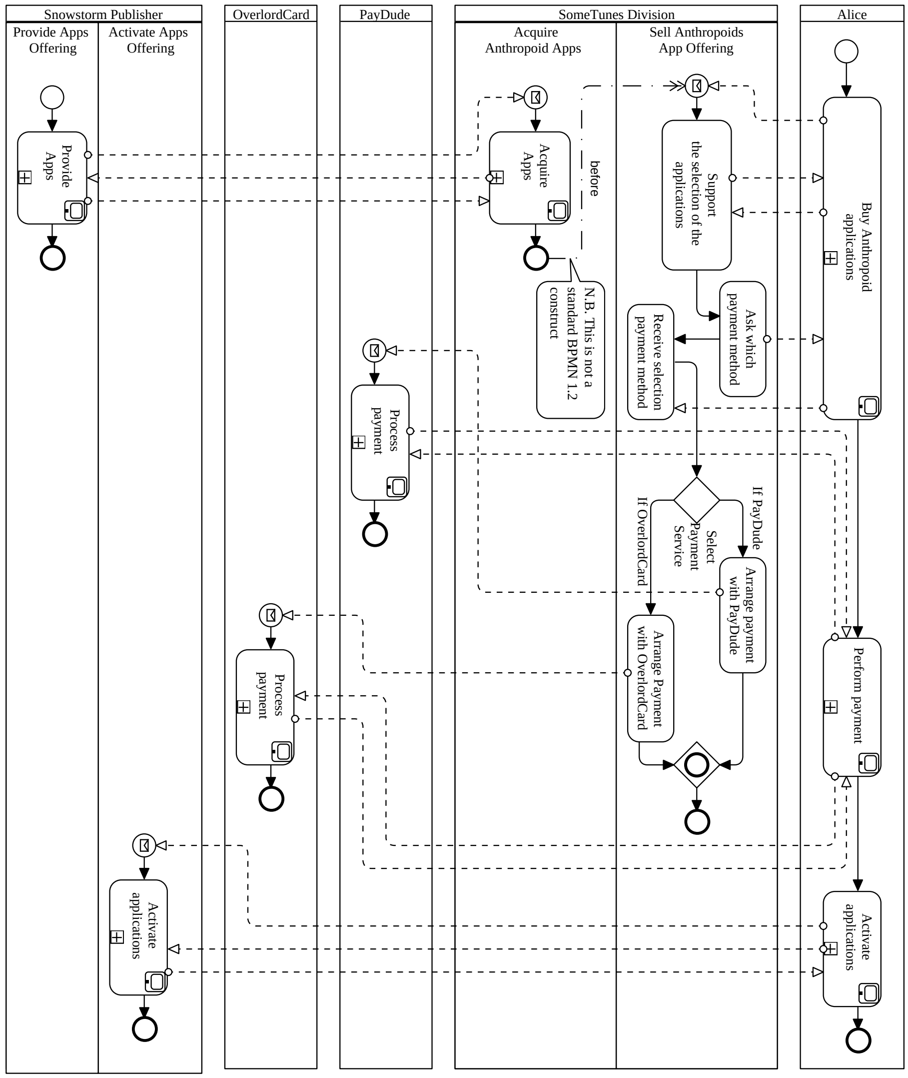

Figure 4: A BPMN process that specifies the operational details of the “Buy Anthropoid Applications Providing”

in terms of BPMN from a service network model are trivial workflows that contain subprocesses, e.g. in the case of the lanes of PayDude, OverlordCard and Snowstorm Publisher. The message exchanges connecting the workflows of the participants are also approximated. We assumed that whatever may be the logic of the workflows of PayDude, OverlordCard and Snowstorm Publisher, they would engage in message-based conversations with SomeTunes and Alice. We represent these message-based interactions as message flows in Figure 4.

5.2.2 Service Network Constructs not Explicitly Mapped to BPMN

Service providings and their dependencies are implicitly represented in BPMN by the interactions among the workflows of service requests and offerings of the participants. For example, the service providing "Providing of Applications" is represented in BPMN by the interactions between the "Sell Anthropoid Apps Offering" lane of SomeTunes and Alice's "Buy Anthropoid Apps" request.

In similar fashion to service providings, participant internal dependencies and the associated temporal relations are implicitly modelled in the workflows that represent the service requests and offerings of one participant. The temporal dependencies between workflows that do not interact with each other cannot be modeled in BPMN. This is for example the case of the "before" temporal dependency between "Acquire Anthropoid Apps Request" and "Sell Anthropoid Apps Offering". For explanatory purposes we have modeled this temporary dependency using an informal notation (shown in the BPMN model).

BPMN cannot represent some of the constructs of service networks, namely business relations and their contracts, and the contracts associated with the service providings. We underline that this is not an issue of service network models, BPMN, or their interaction, but it is merely a consequence of the differences of their scopes. BPMN focuses on the operational dimension of a business process, i.e. the ordering of activities in the workflows. Contracts, instead, pertain to the legal aspect of business processes. Some aspects of contracts, such as the deadlines for the provisioning of service, can be reflected in the operational specification of business processes, e.g. using timers in BPMN. Other type of contractual obligations like non-competition clauses find no natural representation in BPMN.

6 Related Work

Service networks are a multidisciplinary subject, and authors from various communities have been investigating them from different perspectives. A comprehensive overview of the related work on the various aspects of service networks would require a survey. For reasons of space we limit ourselves to the modelling notations for service networks that have been proposed so far.

Allee proposes a graph-based notation to model value flows inside a network of business entities [Allee 00]. The value flows from an entity to the other through the exchange of goods and services, knowledge (e.g. customer data), or intangible benefits (for example improved branding). The proposed notation takes into account only the value flows among the business entities, and does not consider either other types of business or technical relations, hence limiting the synergies with the technology stack and the related practices.

In the same lines of Allee's work, Gordijn and Akkermans propose *e3value*, a sophisticated graphical notation to describe the economical aspect of value propositions of e-business models [Gordijn 01]. Other works in the area of value flow modelling are, for example, the contributions of Biem and Caswell [Biem 08], and Andersson et al. [And. 05]. Our work is orthogonal to the ones on value flows. Potentially, value models can be super-imposed to our service network models in order to, for example, estimate the profitability of the networks. Moreover, the analysis methods and change operators for service networks could be correlated with their equivalents for value flows, thus bringing together the operational and value aspects of service networks.

Steen et al. propose Rapid Service Develepment (RDS), a notation to describe interactions of actors in networked enterprises [Steen 02]. Instead of dealing with services, they model exchanges of information, goods and money, collectively referred to as "items". Items and exchanges over bilateral channels that connect the actors that perform the exchanges. Our formalism and RDS have considerable differences in their scopes. RDS focuses rather on the operational side of service networks by modelling the behaviour of the participants using a basic workflow notation – an aspect that we consider out of the scope of a service network model, and delegate to dedicated notations like BPMN. Moreover, RDS does not consider the contracts that bind the participants, which we find of great importance in service networks.

The work of [Blau 09] proposes a formalism for modeling Service Value Networks (SVNs) as a demand-driven, ad-hoc network of providers and their service offerings. Each SVN model targets the satisfaction of one (complex) service request. The SVN is represented as a graph that describes all the feasible combinations of service offerings that may satisfy the given service request. The best alternative is then selected by e.g. aggregated price. The scope of our work and the SVNs is different, in that we support the modeling of business relationships among participants, while [Blau 09] treats only the selection process of potential service compositions for the satisfaction of a service request. In this respect, the SVN selection mechanism could be applied to highlight potential short-term ad-hoc service providing in the service networks.

The aspect of business relationships among participants has been investigated by Telang and Singh, who propose a formulation of service networks –

called business models – defined as sets of business relationships among agents (that are equivalent to our participants) [Telang 09]. In their work the agents have goals and capabilities, i.e. abstractions of tasks that the agents can perform. Each business relation imposes commitments on two or more agents that are satisfied by the execution of the required tasks. Business model commitments can be manipulated using change operators such as creation, delegation, detachment and cancellation. On the basis of their formalization of business models, the authors investigate four recurring patterns in business models: outsourcing, unilateral commitment, commercial transaction, and standing service contract. Assuming process models specified by the means of UML sequence diagrams, the authors define methods for verifying (1) the satisfactions in the process models of the commitments specified in a business model, and (2) the achievement of the actors' goals. In a sense, agents, commitments and capabilities can be mapped to participants, service providing and their contracts, and service offerings respectively. With respect to our work, the business models of Telang and Singh focus on goal modelling, whereas we provide more flexible constructs to model the service network-level interactions among the participants. In principle it would be possible to bridge between the two approaches and bring goal modelling to our formalism for service networks. However, this would compromise the separation of concerns that we wish to infuse in our approach by trespassing the domain of business strategy modelling.

7 Summary

Service networks are a promising multidisciplinary field that has recently attracted a considerable amount of interest and research efforts. In this paper we have discussed aspects of service networks modelling in relation with the practices of Business Process Management (BPM) and Service Oriented Architecture (SOA). We have presented a formalism to model service networks with the emphasis on software services and the interplay of service requests, offerings and providings among the participants. The concepts presented in this work have been exemplified using a running example depicting the service network surrounding a fictional online media store.

We have underlined the paramount relevance of two aspects of the (future) practice of service networks modelling: (1) analysis and (2) change management. The state of the art of analysis methods for service networks is still in its infancy and it is currently mostly focused on the value flows among the participants. However, more refined and wide-reaching analysis methods are needed in order to render service networks into a valuable tool for supporting strategic business decisions and the management of the enterprises. In particular, we believe that the future research will need to investigate the optimization of aspects of service networks stemming from both the technical and economical perspectives.

Moreover, the optimization methods will necessarily support both local (i.e. a subset of the participants) and global (i.e. optimizing the entirety of the network) perspectives.

The ultimate goal of analysis methods is to outline what to modify service network models to reach a goal (e.g. value-flow optimization). However, to apply those modifications to actual service networks and the technology infrastructure that realizes them, there is the need of a comprehensive approach to the change management of service network. Such change management will have to embrace and deal with all the technological layers of service networks and their implementations. In this work we have laid the foundations for the change management of service networks by investigating the correspondences between the constructs of the service networks modelling formalism we proposed and the ones provided to business process modelling by the Business Process Modelling Notation (BPMN) version 1.2.

Acknowledgements

The research leading to these results has received funding from the European Community's Seventh Framework Programme under the Network of Excellence S-Cube - Grant Agreement n° 215483.

References

[And. 05] Birger Andersson, Maria Bergholtz, Ananda Edirisuriya, Tharaka Ilayperuma, and Paul Johannesson. "A declarative foundation of process models." In Oscar Pastor and João Falcão e Cunha, editors, *CAiSE*, volume 3520 of *Lecture Notes in Computer Science*, pages 233–247. Springer, 2005.

[Andrikopoulos 08] Vasilios Andrikopoulos, Salima Benbernou, and Mike P. Papazoglou. "Managing the evolution of service specifications." In Bellahsene and Léonard [Bellahsene 08], pages 359–374.

[Allen 83] James F. Allen. "Maintaining knowledge about temporal intervals." *Commun. ACM*, 26(11):832–843, 1983.

[Allee 00] Verna Allee. "Reconfiguring the value network." *Journal of Business Strategy*, 21(4), July 2000.

[Allee 08] Verna Allee. "Value network analysis and value conversion of tangible and intangible assets." *Journal of Intellectual Capital*, 9, No. 1,:pp. 5–24, 2008.

[Biem 08] Alain Biem and Nathan Caswell. "A value network model for strategic analysis." In *HICSS*, page 361. IEEE Computer Society, 2008.

[Barros 06] Alistair P. Barros and Marlon Dumas. "The rise of web service ecosystems." *IT Professional*, 8(5):31–37, 2006.

[Barros 05] Alistair P. Barros, Marlon Dumas, and Phillipa Oaks. "Standards for web service choreography and orchestration: Status and perspectives." In Christoph Bussler and Armin Haller, editors, *Business Process Management Workshops*, volume 3812, pages 61–74, 2005.

[Bitsaki 08a] Marina Bitsaki, Olha Danylevych, Willem-Jan van den Heuvel, George Koutras, Frank Leymann, Michele Mancioppi, Christos Nikolaou, and Mike P. Papazoglou. "An architecture for managing the lifecycle of business goals for partners in a service network." In Petri Mähönen, Klaus Pohl, and Thierry Priol, editors, *ServiceWave*, volume 5377 of *Lecture Notes in Computer Science*, pages 196–207. Springer, 2008.

[Bitsaki 08b] Marina Bitsaki, Olha Danylevych, Willem-Jan van den Heuvel, George Koutras, Frank Leymann, Michele Mancioppi, Christos Nikolaou, and Mike P. Papazoglou. "Model transformations to leverage service networks." In George Feuerlicht and Winfried Lamersdorf, editors, *ICSOC Workshops*, volume 5472 of *Lecture Notes in Computer Science*, pages 103–117. Springer, 2008.

[Blau 09] Benjamin Blau, Jan Kramer, Tobias Conte, and Clemens van Dinther. "Service Value Networks." In *IEEE International Conference on E-Commerce Technology*, pp. 194–201, 2009.

[Buford 01] John Buford. "Telecommunication Services and Service Management Challenges." Journal of Universal Computer Science, 7(5):355–365, 2001.

[Busi 05] Nadia Busi, Roberto Gorrieri, Claudio Guidi, Roberto Lucchi, and Gianluigi Zavattaro. "Choreography and orchestration: A synergic approach for system design." In Boualem Benatallah, Fabio Casati, and Paolo Traverso, editors, *ICSOC*, volume 3826 of *Lecture Notes in Computer Science*, pages 228–240. Springer, 2005.

[Bellahsene 08] Zohra Bellahsene and Michel Léonard, editors. *Advanced Information Systems Engineering, 20th International Conference, CAiSE 2008, Montpellier, France, June 16-20, 2008, Proceedings*, volume 5074 of *Lecture Notes in Computer Science*. Springer, 2008.

[Camarinha-Matos 04] Luis M. Camarinha-Matos. *Virtual Organizations: Systems and Practices*. Springer-Verlag TELOS, Santa Clara, CA, USA, 2004.

[Camarinha-Matos 06] Luis M. Camarinha-Matos and Hamideh Afsarmanesh. "Towards a reference model for collaborative networked organizations." In *Information Technology For Balanced Manufacturing Systems (BASYS'06)*, pages 193–203, 2006.

[Caswell 08] N. S. Caswell, C. Nikolaou, J. Sairamesh, M. Bitsaki, G. D. Koutras, and G. Iacovidis. "Estimating value in service systems: a case study of a repair service system." *IBM Syst. J.*, 47(1):87–100, 2008.

[Daskalopulu 99] Aspassia-Kaliopi Daskalopulu. *"Logic-Based Tools for the Analysis and Representation of Legal Contracts"*. PhD thesis, Imperial College London, 1999.

[Dang 06] Jiangbo Dang and Michael N. Huhns. "Concurrent multiple-issue negotiation for internet-based services." *IEEE Internet Computing*, 10(6):42–49, 2006.

[Decker 08] Gero Decker, Oliver Kopp, Frank Leymann, Kerstin Pfitzner, and Mathias Weske. "Modeling service choreographies using bpmn and bpel4chor." In Bellahsene and Léonard [Bellahsene 08], pages 79–93.

[Dustdar 05] Schahram Dustdar and Wolfgang Schreiner. "A survey on web services composition." *IJWGS*, 1(1):1–30, 2005.

[Gordijn 01] Jaap Gordijn and Hans Akkermans. "Designing and evaluating e-business models." *IEEE Intelligent Systems*, 16(4):11–17, 2001.

[Jung 09a] Jason J. Jung. "Knowledge Distribution via Shared Context between Blog-based Knowledge Management Systems: a Case Study of Collaborative Tagging." *Expert Systems with Applications*, 36(7):10627-10633, 2009.

[Jung 09b] Jason J. Jung. "Semantic Business Process Integration Based on Ontology Alignment." *Expert Systems with Applications*, 36(8):11013-11020, 2009.

[Karastoyanova 08] Dimka Karastoyanova and Frank Leymann. "Service oriented architecture - overview of technologies and standards." *it - Information Technology*, 50(2):83–85, 2008.

[Kritikos 09] Kyriakos Kritikos and Dimitris Plexousakis. "Mixed-integer programming for qos-based web service matchmaking." *IEEE T. Services Computing*, 2(2):122–139, 2009.

[Meshkova 08] Elena Meshkova, Janne Riihijärvi, Marina Petrova, and Petri Mähönen. "A survey on resource discovery mechanisms, peer-to-peer and service discovery frameworks." *Computer Networks*, 52(11):2097–2128, 2008.

[Maglio 06] Paul P. Maglio, Savitha Srinivasan, Jeffrey T. Kreulen, and Jim Spohrer. "Service systems, service scientists, ssme, and innovation." *Commun. ACM*, 49(7):81–85, 2006.

[Maglio 09] Paul P. Maglio, Stephen L. Vargo, Nathan Caswell, and Jim Spohrer. "The service system is the basic abstraction of service science." *Inf. Syst. E-Business Management*, 7(4):395–406, 2009.

[Osterwalder 04] Alexander Osterwalder. *"The Business Model Ontology - a proposition in a design science approach"*. PhD thesis, Université de Lausanne, 2004.

[Papazoglou(07)] Mike P. Papazoglou. *"Web Services: Principles and Technology"*. Prentice Hall, 2007.

[Peltz 03] Chris Peltz. "Web services orchestration and choreography." *IEEE Computer*, 36(10):46–52, 2003.

[Papazoglou 07a] Mike P. Papazoglou, Paolo Traverso, Schahram Dustdar, and Frank Leymann. "Service-oriented computing: State of the art and research challenges." *IEEE Computer*, 40(11):38–45, 2007.

[Papazoglou 07b] Mike P. Papazoglou and Willem-Jan van den Heuvel. "Service oriented architectures: approaches, technologies and research issues." *VLDB J.*, 16(3):389–415, 2007.

[Papazoglou 08] Mike P. Papazoglou, Paolo Traverso, Schahram Dustdar, and Frank Leymann. "Service-oriented computing: a research roadmap." *Int. J. Cooperative Inf. Syst.*, 17(2):223–255, 2008.

[Steen 02] Maarten W. A. Steen, Marc M. Lankhorst, and R. G. van de Wetering. "Modelling networked enterprises." In *EDOC*, pages 109–119, 2002.

[Telang 09] Pankaj R. Telang and Munindar P. Singh. "Business modeling via commitments." In *SOCASE*, pages 111–125, 2009.

[van den Heuvel 08] Willem-Jan van den Heuvel. "Survey on business process management." Deliverable PO-JRA-2.1.1, S-Cube Consortium, July 2008.

[Weerawarana (05)] Sanjiva Weerawarana, Francisco Curbera, Frank Leymann, Tony Storey, and Donald F. Ferguson. *"Web Services Platform Architecture: SOAP, WSDL, WS-Policy, WS-Addressing, WS-BPEL, WS-Reliable Messaging and More"*. Prentice Hall PTR, Upper Saddle River, NJ, USA, 2005.

[Wetzstein 08] Branimir Wetzstein. "Overview of the state of the art in composition and coordination of services." Deliverable PO-JRA-2.2.1, S-Cube Consortium, July 2008.

[Zirpins 09] Christian Zirpins and Wolfgang Emmerich. "Pattern-based e-service modelling for virtual service enterprises." *Service Oriented Computing and Applications*, 3(1):65–98, 2009.