University of Zurich
Department of Informatics

Martin Waldburger
Burkhard Stiller

Toward the Mobile Grid: Service Provisioning in a Mobile Dynamic Virtual Organization

TECHNICAL REPORT – No. 2005.7

August 2005

University of Zurich
Department of Informatics (IFI)
Winterthurerstrasse 190, CH-8057 Zürich, Switzerland

M. Waldburger, B. Stiller:
Technical Report No. 2005.7, August 2005
Communication Systems Research Group
Department of Informatics (IFI)
University of Zurich
Winterthurerstrasse 190, CH-8057 Zurich, Switzerland
URL: http://www.ifi.unizh.ch/csg/

Toward the Mobile Grid: Service Provisioning in a Mobile Dynamic Virtual Organization

Martin Waldburger[1], Burkhard Stiller[1,2]

[1] Department of Informatics (IFI), Universität Zürich, Winterthurerstrasse 190, CH-8057 Zürich, Switzerland
[2] Computer Engineering and Networks Laboratory TIK, ETH Zürich, Gloriastrasse 35, CH-8092 Zürich

E-Mail: waldburger@ifi.unizh.ch, stiller@ifi.unizh.ch

Abstract

As today's grids show a lacking support of mobility, the need for a business model of mobile and even nomadic grid resources becomes obvious. Thus, this paper investigates in which sense a mobile grid needs functional extensions and what type of consequences the integration of mobile or nomadic grid resources will cause. Furthermore, the major and emerging business aspects of such mobile grids are outlined. In-line with a formalized investigation, the concept of a mobile dynamic virtual organization (MDVO) is introduced. By means of a business scenario within the application domain of e-health and tourism, relevant potentials of a mobile grid services-based platform are illustrated and key advantages of a mobile grid approach are derived in a general manner.

Keywords: *Business Grids, Mobile Dynamic Virtual Organization, Business Scenario Analysis*

1 Introduction

Grid computing receives a constantly growing attention as it has turned out to be a well suited environment for complex problem solving or data storage. Bringing a commercially oriented cooperation model into grid computing enables the transition from previous research, such as community-orientation, to completely new fields of applications. Typical grid application domains include tasks in the area of High Performance Computing (HPC), such as climate modeling [1]. Recent approaches, however, focus more on knowledge-intensive, adaptive workflows with the intent to adapt grid computing for instance toward e-health or disaster handling and crisis management [2]. As a consequence thereof, a grid architecture has to consider adjustments with respect to trust building mechanisms, security in general, and accounting methods in order to support new or adapted business models.

Besides those extensions, next generation grids will have to reflect another important shift towards the integration of mobility aspects. While today's grid solutions mostly consist of fixed resources, it is rather obvious that the need for mobile grid resources rises together with the ever-growing people's mobility. In e-health for instance, those mobile grid resources may cover updated patient records, metered data documenting a patient's medical situation, or on-site accomplished analysis results, and the access to those has to be supported via a wireless channel as well.

Both areas, commercialization and the support of mobility, impose demanding changes in the design of grid-based solutions. For commercialization, this embraces considerations on an adequate adoption of economic models. In particular, grid economics have to be investigated with respect to an understanding of prevailing market structures, grid-specific commodities, and participating grid players [3]. For mobility, the major challenge lies in integrating actively contributing mobile grid nodes into a grid infrastructure that focuses on fix nodes. Thus, mobile grid nodes are seen as resources being able to consume and to provide services. From a business process viewpoint this implies also that mobile nodes can be involved directly in workflow activities. As a consequence, mobile grids have to overcome portal- or proxy-based approaches for extending grids by mobile devices [4]. Besides these challenges, mobile grid computing offers a considerable business potential for providing highly complex services to solve knowledge-intensive tasks while not being bound anymore to a specific location, but even being able to profit from and integrate environmental information.

The commercialization potential of a mobile grid becomes apparent when looking for example at a typical situation in fleet management for a car rental company as visualized in Figure 1. By equipping cars with mobile devices that are able both to process metered status information about a car's current situation, as well as to provide drivers with content adapted to their location, the car rental company is able to get valuable information from the car and, at the same moment, to offer value-added services to their customers. The first can be used for optimizing the overall fleet utilization efficiency by forecasting periods of unavailability for a car due to maintenance and by transferring cars to rental offices where they are actually needed. In addition to that, location-based services that are provided by a content provider, such as support in route planning, recommendations on points of interest, and information about next-located gas stations, create value for customers while traveling. In case of malfunction or an accident, a car repairing or wrecking service is mobilized and a backup car is organized for the customer.

Respective changes to a grid architecture with regard to mobility support and a commercially exploitable service provisioning have to be reflected on one hand from an economic point of view, while on the other hand, they come inseparably connected with technical requirements on the underlying infrastructure. For instance, capabilities and offered services of a mobile device have to be detectable and respective workflows have to take this information into account since — to state only one example — it would not make sense to transfer a demanding simulation task to a mobile grid node whose battery power and whose storage capacity are almost used up. Accordingly, economic as well as technical aspects of mobile grid computing are highly relevant.

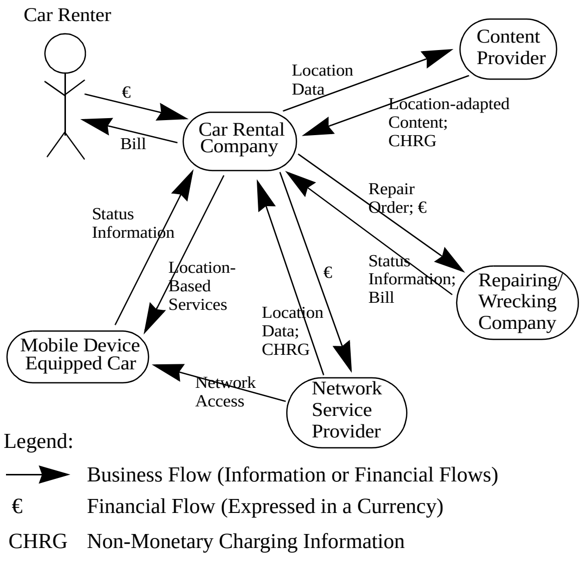

Figure 1: Key Actors with Respective Business Flows for Mobile Grid-Supported Fleet Management

From an organizational point of view, mobile grids — such as the presented example in fleet management — are characterized by dynamically joining and leaving organization members that are able to change locations. This results in the need on one hand for technical means that provide for dynamic and mobile grid resources and on the other hand for a business model that reflects both aspects. Accordingly, this paper focuses on the following four issues:

- The paper provides a definition of **mobile grids** by distinguishing grid computing from related concepts and by identifying key characteristics of mobile grids.
- **Mobile dynamic virtual organizations (MDVO)** are introduced extending virtual organizations (VO) with respect to dynamicity and mobility support.
- **Role models** are investigated on three levels (organizational, grid services, and network level) by analyzing a business scenario in the e-health and tourism application domain.
- Advantages of mobile grids in the sense of **added values** are developed.

The remainder of this work is structured as follows: Section 2 compares grid computing with related fields, which leads to a description of key features of mobile grids in Section . Thereupon, a mobile grid business scenario in the application domain of e-health and tourism is defined and analyzed for those three structural levels in Section 4. Section 5 finally shows the value addition in mobile grids, followed by a summary and conclusions being drawn in Section 6.

2 Related Work

Grid computing, and thus also mobile grid computing, can not be distinguished in the first place without ambiguity from related concepts [5]. These include service-oriented architecture (SOA) and peer-to-peer (P2P) systems [6]. Even though a borderline between these three approaches is not easily be drawn as they may show an overlapping, a clear understanding of key characteristics in (mobile) grid computing is crucial for the work conducted throughout this paper. In order to reach a better notion of grid computing, service-oriented architecture, and peer-to-peer systems these terms are first described and secondly compared by means of major business and technical metrics.

2.1 Grids

Grid computing traditionally is associated with high computational power or a system that is able to handle large amounts of data to be processed [7] [8]. While these aspects are still true today, focus has shifted towards a wider understanding. Thus, grids are determined by three main characteristics [9]: First, a grid *“coordinates resources that are not subject to centralized control”*. Secondly, such a system is *“using standard, open, general-purpose protocols and interfaces”*. Finally, grids allow *“to deliver nontrivial qualities of service”*.

Structured in the same order as those criteria for grid systems, this means that grids facilitate inter-domain service provision across administrative borders which provides for building virtual organizations (VO) [10]. The use of standard, open protocols and interfaces is seen as an essential element for providing interoperability, particularly for resource sharing in an environment where collaborating VO-members remain organizationally and legally independent. Accordingly, grid systems are compared with the electrical power grid [7] that offers pervasive access to electricity. In a grid environment, heterogeneous resources are therefore virtualized by the use of standard protocols and interfaces [11]. In order to leverage commercially exploitable grid solutions, trust-building mechanisms are needed. Guarantees with respect to Quality-of-Service (QoS) are fundamental for this purpose since they are required for multi-organization supply chain management [12].

Grid systems are separated throughout this work into three categories arranged on top of each other:

- Grid computing
- Service grids
- Knowledge grids

These categories document the evolution of grid systems over time and consist of grid computing, service grids [13], and knowledge grids [14]. Grid computing in its traditional understanding is considered to cover high performance computing needs, thus cluster building is seen as a major concern, while aspects of virtual organizations are not reflected [8]. This view however is included in service grids. Service grids are targeted to an application domain-specific portfolio of services, for instance grid-based simulation services for automotive. Services are virtualized, i.e. they are provided by grid nodes that are geographically and organizationally distributed. This however has to be hidden from service consumers, for example by means of QoS mechanisms [15]. In knowledge grids finally, a complete overview of provided services, including relevant status information, is gained by the service aggregator. In contrast to service grids, mobile grids are not application field specifically designed. Knowledge grid is closely related to mobile grid computing whereas mobile grids differ from knowledge grids only in considering explicitly also wireless access to services. For that reason, the term mobile grid is used subsequently instead of knowledge grid.

2.2 Service-oriented Architectures

Service-oriented architecture (SOA), also referred to as service-oriented computing, describes an approach for designing calls on remote objects that offer well-defined services [16]. Services in turn, seen from a business viewpoint, are closely related to business processes since they are perceived as what customers are willing to pay for. From a technical perspective however, they are seen as interfaces providing a set of functions [17]. These services show three main requirements to be met [18]: They first have to be *"technology neutral"*, so that they can be accessed from as wide a range of devices as possible. This also implies that services make use of broadly established standards. Services secondly shall be *"loosely coupled"*, which means that implementation aspects on both client and server side are hidden and thus not needed to be known for service provisioning. The third requirement claims for *"location transparency"* in service provision so that services that have successfully been registered in a repository are accessible regardless of their actual location.

Service-oriented architectures consist of three structural elements, namely a service provider, a service requester, and an entity that serves as service registry and broker [19]. Interoperability of software components over standard interfaces is the key issue in service-oriented computing [16]. This is typically realized by platform-independent standards [20] such as eXtensible Markup Language (XML) [21], Simple Object Access Protocol (SOAP) [22], Web Service Definition Language (WSDL) [23], and Universal Description, Discovery, and Integration (UDDI) [24].

Service aggregation and service management are both not covered in basic service-oriented architectures. While the first embraces functionality in the areas of service coordination, monitoring, conformance and QoS, the second relies on service management and deals with service operations management and marketplaces [18].

2.3 Peer-to-peer Systems

Peer-to-peer (P2P) computing is based on the principle of equivalent communication partners, referred to as peers, what stands in contrast to the client-server metaphor [25] [26]. A peer thus can take both, the role of a client and a server. P2P shows its main characteristics in the areas of a direct peer-communication, end-to-end connectivity, and resource sharing which includes for instance CPU cycles, storage, or network bandwidth [27]. Algorithms for P2P systems typically deal with issues of scalability and efficiency in search, lookup, and routing [28].

While a P2P system's main challenge is to *"design and implement a robust distributed system composed of inexpensive computers in unrelated administrative domains"*, its key advantages are found in three areas [29]: Ad-hoc building is feasible since P2P systems usually do not require *"administrative or financial arrangements"*. With a high number of participating peers comes a considerable potential for sharing *"computation and storage resources"*. Decentralization as one of the most important design goals for P2P systems provides for robustness to *"faults or intentional attacks"*. Besides these advantages, interoperability between different existing P2P systems is not well supported [30].

2.4 Defined Key Characteristics

Characteristics and metrics for grids, SOAs, and P2P systems originate from the areas of business views and technical functionality. Thus, those two inter-related fields are determined separately below, where the set of key characteristics in each area has been defined explicitly. These characteristics have been coded in metrics, which are summarized and extended from the related areas of work mentioned above.

2.4.1 Business Metrics

The list below shows alphabetically ordered metrics, highly relevant for a characterization of grids, service-oriented architectures, and peer-to-peer systems with respect to commercial exploitation.

- **Ad-hoc Formation** is determined by administrative or financial arrangements to be taken before a system is operational.
- **Commercial Usage** specifies whether or not a typical system is used in a commercial environment, implementing respective business models.
- **Efficiency** characterizes a system with regard to mechanisms optimizing the usage of available resources in the most efficient way.
- **Inter-domain Service Provision** assesses a system's orientation towards support of virtual organizations.
- **Quality-of-Service** is coined by how well guarantees for QoS-related parameters such as bandwidth, response time, availability and security are supported.
- **Resource Coordination** considers a system's ability to involve multiple resources in a structured way into a business process.
- **Resource Sharing** analyses whether a system regularly features mechanisms for conjoint access to resources, such as computation or storage.
- **Scalability** deals with a system's correct behavior in reaction to an increasing number of communicating nodes, potentially resulting in a high system load, e.g. with respect to requested CPU cycles, memory usage or network bandwidth.
- **Service Aggregation** identifies a system's support for combining available basic services into composite advanced services.

2.4.2 Technical Metrics

According to the procedure presented for business-relevant characteristics, important technical metrics are listed and shortly described as follows:

- **CPU (Central Processing Unit)** characterizes a system with respect to its computational power exploitable by offered services.

- **Decentralization as Design Goal** determines whether or not planning typically treats a fully decentralized system architecture as a key issue.
- **End-to-end Connectivity** specifies how far connectivity reaches. End-to-end connectivity is achieved when peers are able to communicate in a direct way, irrespective of the nodes that exchanged packets have to pass across.
- **Interoperability** expresses a system's focus on defining services and respective interfaces whereas inter-connected nodes are of heterogeneous nature.
- **Location Transparency** marks the degree of incorporating location information in service provisioning. A service is provided in a transparent manner if location information is not bound to the service itself.
- **Robustness** assesses whether or not a system is prone to failure or intentional attacks.
- **Standards** considers how much a system relies on either open or widely accepted standards and protocols.
- **Storage** characterizes a system with respect to storage capacities exploitable by offered services.

2.5 Comparison

By comparing grid computing with service-oriented architectures as well as peer-to-peer systems, a clearer notion for grids is gained, so that necessary functional extensions for mobile grids become apparent. Therefore, Table 1 picks up those business metrics defined in Section 2.4.1 and performs a respective comparison of grids, SOAs, and P2P systems. Table 2 proceeds likewise for all technical aspects as determined in Section 2.4.2. The range of possible parameter values in these tables covers for simplicity reasons only symbols "X", "+", and "0":

- "**X**" marks an attribute that is relevant and exists in the system in question;
- "**+**" denotes an aspect being relevant, however, not existent in current designs or implementations; and
- "**0**" is considered as not being relevant for a system.

Table 1: Business Metrics Characterization of Grid, SOA, and P2P Systems

Category		Ad-Hoc Formation	Commer-cial Usage	Efficiency	Inter-domain Service Provision	Quality-of-Service	Resource Coordina-tion	Resource Sharing	Scalability	Service Aggrega-tion
Grid Systems	Grid Computing	X	0	+	0	X	0	X	0	0
	Service Grid	+	X	+	X	X	X	0	0	X
	Mobile Grid (Knowledge Grid)	+[a]	X	X[c]	X	X	X	0	X	X
SOA		0	X	0	0[d]	+	+	0	0	+
P2P Systems		X	+[b]	X	+	0	0	X	X	0

a. Dynamicity is limited to mobile or nomadic grid nodes only.
b. Research on suitable business models for P2P systems is ongoing, whereas existing P2P systems typically are set in a non-commercial environment.
c. Handling of scarce resources, such as bandwidth or computational power, is a key issue for mobile grid nodes. Accordingly, efficient use of available resources is a vital key success factor for a mobile grid.
d. SOA provides for service provision across administrative domains, however due to missing service aggregation and service coordination functionality, formation of virtual organizations is not supported.

Table 2: Technical Metrics Characterization of Grid, SOA, and P2P Systems

Category		CPU	Decentrali-zation as Design Goal	End-to-end Connectivity	Interopera-bility	Location Transpar-ency	Robustness	Standards	Storage
Grid Systems	Grid Computing	X	0	0	X	X	0	X	X
	Service Grid	X	0	0	X	X	0	X	X
	Mobile Grid (Knowledge Grid)	0[a]	0	0	X	0[c]	+	X	X
SOA		0	0	X	X	X	0	X	0
P2P Systems		X	X	X	+[b]	+[d]	X	+[e]	X

a. Mobile grids potentially also offer high performance computing functionality, these services however are assumed to be included by a traditional grid operator.
b. Interoperability of different P2P systems is usually not supported.
c. Mobile grid services are supposed to consider location and context information.
d. Focus on decentralization implies the absence of central elements such as a service registry.
e. Community-wide standards only.

The detailed analysis conducted in Table 1 for business-relevant aspects as well as in Table 2 for technical facets, allows for a condensed comparison of the three architectural concepts. Consequently, Table 3 concludes the set of key issues for grid systems, SOAs, and P2P systems.

3 The Nature of a Mobile Grid

The conceptual comparison conducted in Section 2 provides those detailed cognitions that are essential to investigate further in mobile grids. This is performed by determining characteristics of mobile dynamic virtual organizations

Table 3: Key Issues for Grids, SOAs, and P2P Systems

Category	Key Issue
Grid Systems	Resource coordination and aggregation in virtual organizations
SOA	Interoperability of heterogeneous nodes
P2P Systems	Resource sharing among peers in the most decentralized form

and by providing as a second step usability criteria for mobile grids.

3.1 Definition of MDVO

Due to their strong focus on inter-domain service provision, grids are organizationally reflected by virtual organizations, also referred to as virtual enterprises or virtual communities (cf. Section 2.1). The concept of virtual organizations is manifold and its notion has evolved over time [31] [32]. With regard to a commercial, grid-oriented comprehension of virtual organizations, such as presented in [10], VOs are considered throughout this work as follows:

Virtual organizations allow for information and communications technology-supported, accountable and chargeable resource coordination across administrative domains, incorporating mechanisms for parameterizable secure authentication and authorization.

When defining mobile grids, however, this concept of VOs has to be altered in order to account for dynamically joining and leaving nodes as well as for nodes that are not bound anymore to a fixed location. For that reason, mobile dynamic virtual organizations are introduced as a respective extension of virtual organizations. MDVOs thus are conceived as follows:

Mobile dynamic virtual organizations are virtual organizations whose members are able to change locations while provided or consumed services remain available even after temporary loss of reachability, and while running or yet to be initiated workflows adapt to changed conditions, so that MDVOs are characterized by a strong dynamic element with respect to their organizational composition and their business processes.

In MDVOs, service provision is concerned with what organisational entity is providing which service and how services are composed in an inter-domain environment. Service provision thus is reflected from an application-centric viewpoint, whereas technical, protocol-specific implementation issues are not covered.

3.2 Characteristics of MDVOs

According to the introduced definitions for virtual organizations as well as for MDVOs, MDVOs show enhancements compared with VOs in the areas of mobility support and dynamicity. These elements determine key characteristics of mobile dynamic virtual organizations and are subsequently considered in further detail.

- **Dynamicity**: As members may join or leave the organization, taking either the role of a service provider or service consumer — or even both together, need for a managing and supervising entity arises during members' active existence in an organization. Even though a fully decentralized, peer-to-peer system-alike organization remains imaginable, a commercial mobile grid is assumed to rely partly on centralized components, being incorporated into the role of a VO manager. Respective tasks include clearing of charging and billing records for provided services across administrative domains, workflow execution management, service registry, and member management. A VO manager thus features a complete view of the current VO status. Furthermore, its business process execution mechanisms provide for adaptive workflows that are able to react on changed circumstances.
- **Mobility**: In an MDVO, not all members have to be mobile in order to denote a dynamic virtual organization as a mobile dynamic virtual organization. If a DVO (dynamic virtual organization) however, allows at least for a subset of its members to change locations and still being able to profit or to provide services while moving, such a DVO is regarded as a mobile dynamic virtual organization. Mobile or nomadic organization entities on one hand augment an MDVO with respect to altered context information and by widening the geographical range of service provision on scene. On the other hand, mobility support imposes non-trivial problems to be solved on both, organizational and infrastructure's level. For instance, as mobile members might temporarily find themselves uncovered by a communications network infrastructure, an MDVO's session model has to envision resumption of partly completed tasks when network coverage is available again. Mobility consequently shows a strong influence on the dynamic element in MDVOs. With changing environment grows the demand for adaptive workflows that are able to react on modified influence parameters.

The respective understanding of virtual organizations remains unchanged in MDVOs. Enhancements of VOs by means of dynamicity and mobility support are understood as additional requirements leading VOs to MDVOs. However, they do not show any consequences that interfere with concepts of a VO.

3.3 Usability of Mobile Grids

As the comparison of grids, SOA, and P2P systems in Section 2.5 depicts, these three concepts show similarities. This also holds for mobile grids, since they are seen as extensions of grid systems. Taking this into account and based on those characteristics of MDVOs presented in Section 3.2, a set of constructive criteria to determine a mobile grid's usability has been developed. These criteria constitute 2 main checkpoints, each equipped with 2 subordinated test points.

- **Field of Application**: A chosen application domain has to be suitable for mobile grids. This is provided if a field of application first is characterized by mobile or nomadic users and secondly deals with complex problem solving with a focus on knowledge-intensive tasks to be conducted.

- **Business Model**: Respective business models have to be able to benefit from mobile grids' characteristics. This especially is the case if various, legally independent organizations provide services that form together integrated business processes. Besides multi-domain service provision, a business model has to provide for centralized elements, such as a VO managing entity.

If the above listed checkpoints apply to a planned solution, a mobile grid implementation is assessed as being useful. If however one or more aspects deviate, an orientation towards peer-to-peer systems or service-oriented architectures may be valuable.

Mobile grids focus on solving complex problems by exploiting knowledge as their main input factor. High performance computing facilities become less important than in traditional, fixed grid systems. Data and computational power are still regarded as being helpful; they however are rather accessed via computational or data-related services that are offered by a dedicated fixed grid service provider than being considered as a core competence in the mobile grid itself. In contrast, a mobile grid's core competence is found in extending the range of complex, adaptive business processes onto mobile nodes, technically represented by mobile devices and its services, being operated by a human being who is regarded as a highly valuable resource.

4 Business Scenario Development

To visualize a typical mobile grid implementation as a detailed example, the respective business scenario in the application domain of e-health and tourism has been developed. This domain has been chosen as it shows key requirements that fully match those criteria for adopting mobile grids (cf. Section 3.3).

Travelers embody mobile or nomadic users and e-health deals by definition with non-trivial questions, especially when patients are abroad, finding themselves in an environment they are unfamiliar with. Furthermore, the scenario sketches a mobile grid-based travel insurance solution in which an insurance company acts as a service aggregator for its roaming customers. The insurance company, thus, takes a central role with respect to business process execution while various, organizationally and legally independent, third parties are involved as grid service providers.

Figure 2 depicts the generic organizational alignment for the chosen business scenario. On it, the key players are visualized. These consist of the insurance company, the insured travelers, and possibly several tiers of third parties. The insurance company hereby offers travel insurance to its customers and sources services from specialized third parties which again can buy services from second tier third parties and so on. One, but possibly multiple business roles are assigned to each player. For instance, an insured traveler will play both, the roles of a service provider when transmitting metered medical data, as well as the role of a service consumer when receiving recommendations whether to contact a local medical facility or not. All collaborating players main-

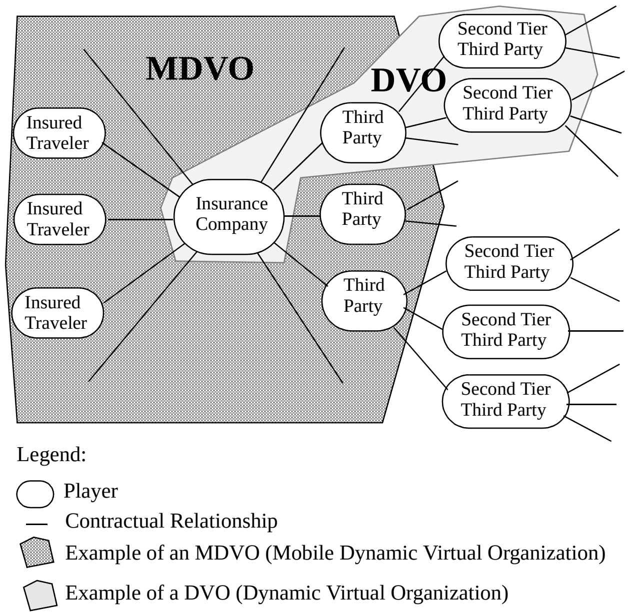

Figure 2: Generic Organizational Alignment of Business Scenario Players

tain mutual contractual relationships, ranging potentially from short-period valid service level agreements to long-term contracts. In this scenario however, the case of fully dynamic virtual organizations is not considered where virtual organizations are formed in an ad-hoc manner in order to provide a single service only, after what the organization is dissolved again. Consequently, mobile travelers are the only completely dynamic VO members as they probably join and leave a virtual organization spontaneously — be it deliberately or unintentionally. Under these circumstances, a VO has to support different types of mobility, such as user, terminal, and service mobility [33].

In this configuration, travelers are the only mobile or nomadic grid nodes. This is caused by key limitations that come with the integration of mobility aspects, such as restricted battery capacity, computational power, memory and storage size, low and unsteady bandwidth as well as with respect to haptics and visualization capabilities. Accordingly, the cross-hatched area in Figure 2 consists of the core MDVO, whereas the area, slightly shaded in grey, determines an example of a DVO without any mobile or nomadic grid nodes. With a view to draw as realistic a scenario as possible that would be feasible to be implemented within the next years, mobile devices still will have to be considered as being confronted with aforementioned restraints. However, mobile devices' evolution proceeds with a growing demand on the market which will be supported on the supply side by promising emerging technologies such as fuel cells or low-current processors [34]. Taking these considerations into account, the scenario has been designed to support mobile nodes which are able to conduct simpler tasks such as a blood analysis of received sensor data or multimedia presentations while guiding the user through the different steps in a process.

4.1 Travel Insurance Scenario

In order to facilitate an in-depth examination, the business scenario has been divided into 7 phases that document the course of actions and events both from a chronological angle as well as in terms of a distinction between different problems to be solved.

Travel activities are structured into the following overall stages: The trip or journey itself forms the central element of every travel-related undertaking. The anticipated complexity in traveling determines those requirements on the preceding stage of trip preparations. Finally, the time after returning back home is influenced by experiences made during travel. Therefore, Table 4 lists all 7 scenario phases and assigns them to one or more stages in the journey.

Table 4: Overview of Scenario Phases and Assignment to Overall Journey Stages

Phase	Name	Overall Journey Stage
0	Distribution	Trip Preparations
1	Motivation for a Traveler	Journey
2	Introduction	Journey
3	Questionnaire and First Results	Journey
4	Basic Physical Examination and Recommendation	Journey
5	Validation	Journey
6	Administrative Assistance	Journey, After Return Settlement

From the point of view of an insurance company, standing in a contractual relationship with its insured customers, these stages are of a different importance with respect to risk assessment. An insurance company is highly interested in lowering the total amount of incidents to be covered. While medical relevant incidents often will occur and will be recognized during the journey itself, respective treatments and therewith connected administrative tasks can still show effect long after the travelers have returned back home. Taking this into account as well as assuming that an early diagnosis significantly lowers the period of treatment, an insurance company is motivated by two main arguments for offering mobile grid-backed travel insurance:

1) By means of the offered e-health services, a traveler easily is able to decide whether a medical condition indicates the consulting of medical facilities or not, thus, resulting in an overall lower number of unnecessary and costly consultations.
2) In the case of infectious diseases, like malaria, early diagnosis and initiation of the therapy show a positive effect in the treatment as a whole with respect to associated costs and duration of illness.

The business scenario itself consecutively is sketched from Section 4.1.1 to Section 4.1.7. The respective sections represent each a phase as denoted in Table 4. Due to a time-wise nonlinear narrative, phase 1 is discussed before phase 0.

4.1.1 Phase 1: Motivation for a Traveler

Miss Brown is on a three-week's trip to the South-East of India. After some days staying there she begins to feel sick. At first, she is not worried as she heard from other tourists that this sort of inconvenience is quite common among newly arrived travelers. However, two days later and her situation being still unchanged she thinks of consulting a physician. But as she is not familiar with the Indian health care system she feels reluctant to look for local medical advisory: Especially, she worries about:

- How severe is her medical condition?
- Who might cover the treatment costs?
- To whom should she address herself?

4.1.2 Phase 0: Distribution

That is when she remembers the little box she rented from an insurance company for the duration of her trip. A sales representative at the travel agency where she booked her tour arrangement made her aware of the possibility to get software bundles adapted to mobile phone enabled PDAs (Personal Digital Assistant) and similar smart devices. Among other things, such as an interactive tourist guide for India, Miss Brown was especially interested in that health care package that she could order directly in the travel agency or - as she found out later - also from her medical insurance company as well as at the tropical medicine's institute where she had been sent for the purpose of getting a prophylaxis against tropical diseases like malaria. She decided to order that package right away when she finally booked the arrangement since the offered service appeared to her as being quite useful and reasonably priced. For 10 € per week she was subscribed to a travel insurance embracing coverage in emergency situations. In addition to financial protection, she was granted the right to contact specially trained staff via an international toll-free number in the case of medical issues, and she was also explained that with the box and in conjunction with her PDA she would be able to carry out some tests while on travel in order to find out whether it would be necessary to consult a local medical facility. It would have been possible to have a compatible smart device rented as well for the time of her trip, but in Miss Brown's case this was not necessary as she already owned a PDA that supported all necessary technical requirements.

4.1.3 Phase 2: Introduction

She unpacks the box which has about the size of a book. Among other things a red-colored memory card catches her eye as it is lying on top of all other pieces. Attached to it she finds a short introduction on how to use the box' contents. First, she has to insert the memory card into her PDA whereupon she is guided automatically through the box' contents. She realizes that it comprises the following parts:

- ECG (electrocardiogram) sensors
- Temperature sensors
- Blood pressure meter
- Equipment for urine analysis
- Equipment for blood withdrawal and analysis

After that first introduction wherein she also learned that her mobile device will have to establish a packet switched connection to the insurance company's systems the main application is started on the PDA.

4.1.4 Phase 3: Questionnaire and First Results

As Miss Brown resides at that moment inside her hotel room her PDA's GPS (Global Positioning System) antenna does not get any positioning data. That is why her current location is determined by means of location services provided by the mobile network operator. Miss Brown now is asked in a first step to localize on a three-dimensional visualization of the human body areas hurting as well as to go through an interactive questionnaire of about 20 questions. When she suddenly feels a strong bellyache, she lies down and continues to answer the questions, which are presented in audio-visual form, orally. She then has to wait for some seconds until she gets a first result presented.

4.1.5 Phase 4: Basic Physical Examination and Recommendation

According to the information given in the first step, Miss Brown is asked to fulfill the following tasks as they are regarded to be of particular relevance in her current situation. In doing so, Miss Brown is instructed in an audio-visual manner. She has to conduct a body temperature's measurement with the aid of the temperature sensors provided in the box. Measured data is transferred via Bluetooth to the PDA. Afterwards, she needs to apply on her finger a small, dedicated device with a lancet to gain drops of blood. Subsequently, the blood probe is analyzed and results are transmitted to the PDA. Shortly after having accomplished that, she is noticed of the current outcomes: Miss Brown is recommended to check with a local medical facility.

4.1.6 Phase 5: Validation

In order to organize everything the system offers her to get in touch with an employee of the insurance company's customer care center. She accepts, whereupon automatically a voice connection is established. After a few seconds, she is talking to a customer care agent who has been trained to give first advice in medical concerns. He shortly verifies all the previously given symptoms and asks her some additional questions. As it seems to be rather clearly indicated in Miss Brown's case to consult local medical assistance it is not necessary to confer with the associated doctor who would be available for the customer care agent as an additional adviser.

4.1.7 Phase 6: Administrative Assistance

The customer care agent asks Miss Brown to hang up and wait for some minutes in order to organize all the necessary steps to get an appointment in the closely-located hospital which is achieved by means of an elaborate and regularly updated information system allowing its users to contact (primarily) medical facilities for a wide range of countries. Fifteen minutes later, Miss Brown receives a call wherein she is informed about when and where to address herself to the hospital. She is also requested to bring along a stool sample for further analysis in the hospital. Miss Brown will not have to pay the treatment costs on the spot — these steps will be arranged between the insurance company and the local hospital. Actually, all treatment costs will be covered by the insurance for what the insurance company already has committed itself in accordance with the local hospital. In the mean-time, the service center's employee will send relevant medical data to the hospital and can organize upon personal wish a translator to be present as well as a taxi to bring Miss Brown to the hospital.

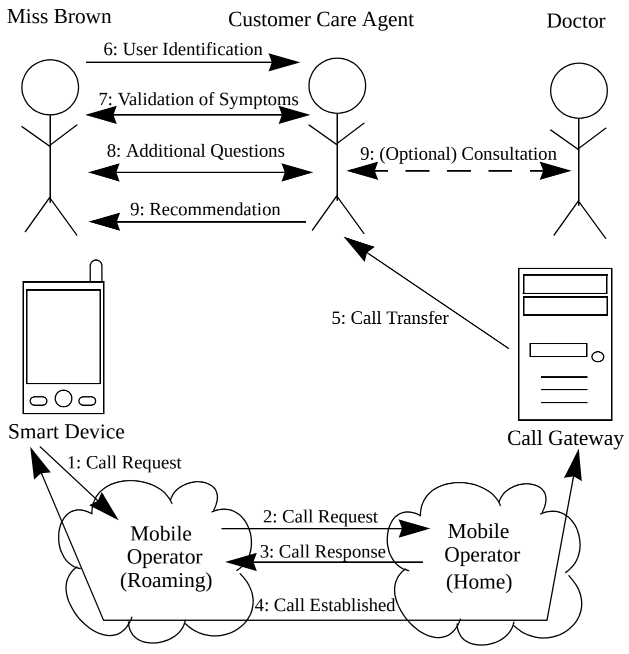

Figure 3: Chronologically Ordered Course of Actions in Scenario Phase 5

4.2 Scenario Assessment

Scenarios serve as demonstrators, exemplarily presenting concepts, motivations, and organizational alignment by means of concrete cases. This is on one hand helpful for gaining a more intuitive notion of abstract coherency since scenarios limit decision ranges to one instantiation. On the other hand, depicted cases are supposed to be sketched in likewise generic form so that respective limitations reduce complexity with regard to scenario analysis, allowing however for applying similar, non-conflicting ideas to another case, for which other parameters are set.

The business scenario shows in its 7 phases a complete travel case, embracing those three journey stages presented and assigned to phases in Table 4. It determines key actors together with respective roles and motivations while being fully compliant with that generic organizational alignment, relevant for MDVOs and DVOs as depicted in Figure 2. Focus is put on interactions taking place between Miss Brown, as an insured traveler, and the insurance company that acts as a VO manager, aggregating services provided by third parties or insured travelers. While dynamic aspects of MDVOs are broadly covered by workflows adapting to a traveler's medical condition, mobility support is less pronounced, though implicitly assumed, for instance with respect to content transmission and presentment according to a mobile device's capabilities. As argued above, both main criteria for usability of mobile grids, namely a suitable field of application and an appropriate business model such as denoted in Section 3.3, are fulfilled. Nevertheless, the scenario opens a window of opportunities for parameterizing this and similar cases with respect to an actual design of how multi-domain service provision is realized, especially from a commercial point of view, when allocating shares in revenue streams to respective cost elements.

4.3 Three-level Mobile Grid Analysis

Having determined mobile grid systems' characteristics from a conceptual angle and having provided a specific mobile grid case, a three-level analysis of that business scenario is performed. This is achieved by looking at organizational arrangements that represent an MDVO, followed by moving from business-oriented considerations toward more technical aspects of underlying grid services, and focusing on the communications infrastructure on network level.

4.3.1 Organizational Point of View

Figure 4 outlines players with respective contractual relationships for the presented business scenario. This organizational layout is understood to reflect a possible implementation, thus incorporating actors that are named in the scenario as well as players that are not explicitly mentioned. The latter category is by definition not deterministic, it however consists of players that facilitate implementing a case as shown in the scenario. For reasons of clarity, financial institutions and internet service providers are not covered in Figure 4.

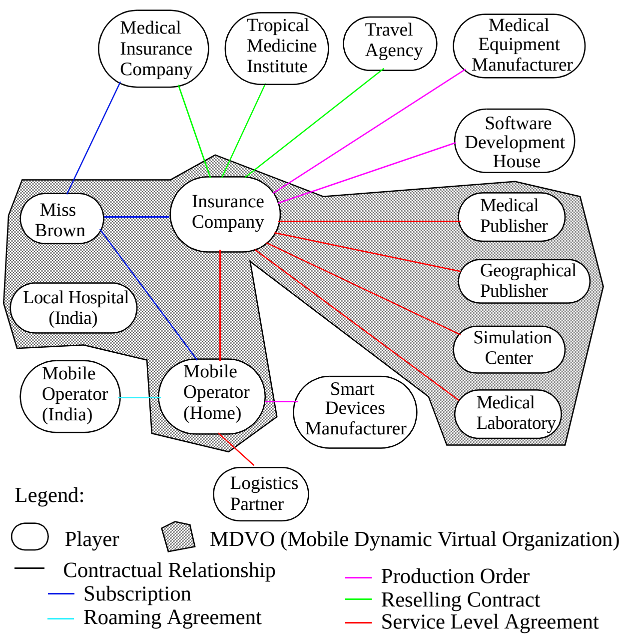

Figure 4: Organizational Alignment of Business Scenario Players

All players maintain contractual relationships to one or more players. The only exception to this rule is found in the local hospital in India as it is bound ad-hoc to the mobile dynamic virtual organization. Contractual relationships between different players are manifold as visualized by the color code used in Figure 4. In order to implement a business case such as a mobile grid-based travel insurance, not only electronic services are of relevance. Necessary tools and infrastructure have to be supplied and subsequently distributed. On the production side, medical equipment manufacturers and smart device manufacturers are responsible to supply required hardware resources. Analogously, a software development house is in charge of developing software components to be run for example on a mobile device. On the distribution's side, both the insurance company and the mobile operator rely on reselling, roaming and logistic services provided by respective partners. The core MDVO players however focus on electronic services. The insurance company coordinates grid resource usage and aggregates provided services and content.

From an organizational viewpoint, analysis of mobile dynamic virtual organizations is of highest importance. Structurally, MDVOs consist of members that are represented by players. Players have resources at disposal and are assigned to one or more roles which affect their behavior. To the purpose of determining appropriate role models, interactions of identified players are examined. These interactions are combined to adaptive electronic workflows, which again are integrated into business processes, with the overall target in mind of solving complex problems. Interactions between players consist of different types of business flows, such as information, financial, and product flows. Figure 5 shows

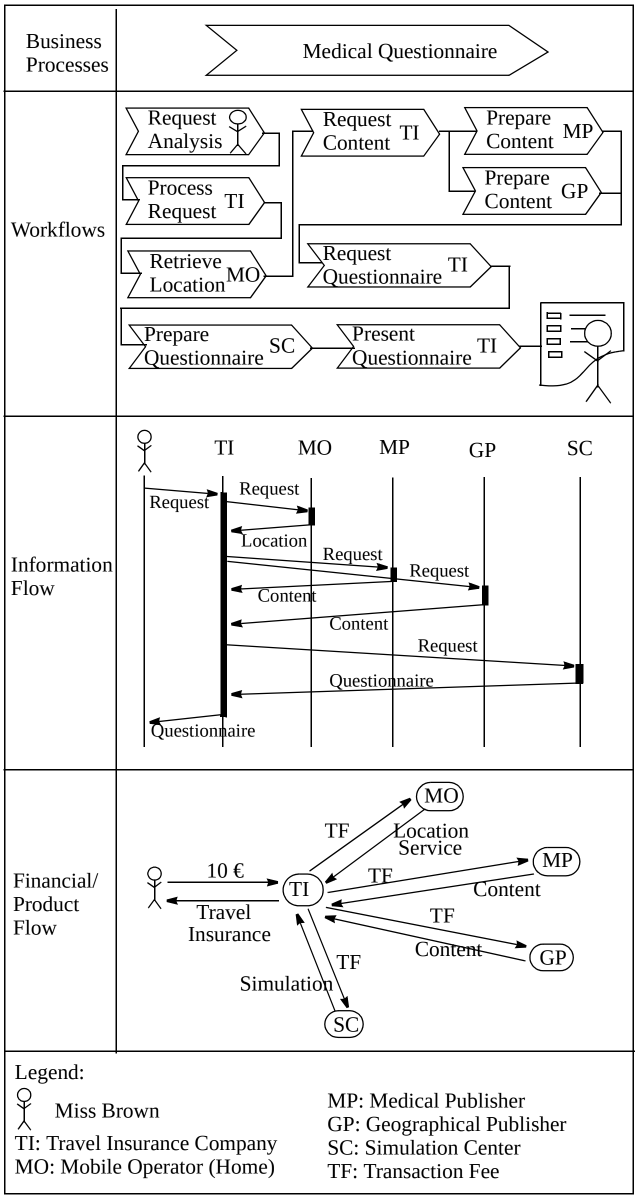

Figure 5: Business Flow Analysis for Exemplary Business Process

exemplarily on the basis of a business process the respective analytic steps for dimensions of workflows, information flows, and product/financial flows. For different dimensions, corresponding role models apply. These models vary with respect to the role assignment, even though players remain the same. *E.g.*, Miss Brown takes the role of an insured traveler when considering product flows. At the same time she also takes the role of a service requestor when looking at information flows. Furthermore, for other business processes, she additionally acts as a service provider with respect to information flows. As a consequence, multiple non-trivial role models exist in parallel from an organizational viewpoint.

4.3.2 Grid Services Point of View

While role models are highly complex when sketched from an organizational viewpoint (cf. Section 4.3.1), from a grid services' perspective fewer roles are identified. For an existing grid service platform, roles embrace platform provider, platform operator, service providers and service consumers as Figure 6 shows.

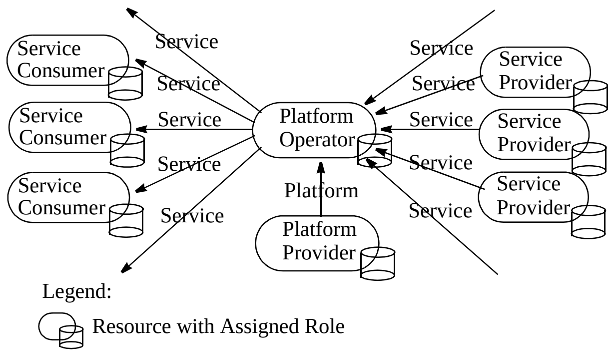

Figure 6: Grid Service Role Model

This limited range of possible business roles is caused by an exclusive focus on grid services. Everything that is electronically provided is seen as a service, i.e. a well-specified functionality that is offered through a defined interface. Thus, content providers and service registries — to name 2 roles exemplarily — are not differentiated, but regarded both as service providers. In contrast to organizational considerations, where analysis is performed on various aspects, services with corresponding interfaces and protocols for information exchange are centered. Entities are no longer represented by actors such as companies or humans, but by resources only. For example, Miss Brown's PDA is regarded as a resource that offers services. According to grid services' main aim, which is found in providing services with agreed Quality-of-Service parameters and appropriately accounted and charged resource usage, resources with respective service-qualities have to be detected reliably. The grid service perspective thus is characterized by taking both economic and technical aspects into account. Quality-of-Service underlines this mutual orientation, since QoS-related requirements originate in business needs while actual realization depends on technical constraints of available resources.

4.3.3 Network Point of View

From a network perspective, the communications infrastructure is the key. Main goals are to provide access to communication services for correctly authenticated and authorized users as well as to reliably account network service usage. This viewpoint differs from organizational and grid services' considerations in the way that corresponding role models appear in the first place to be purely technology-centered, since network infrastructure builds the technical basis for grid services which are supposed to hide technical aspects from users. Network-relevant roles consist of network infrastructure providers, network operators, communication service providers and network service consumers.

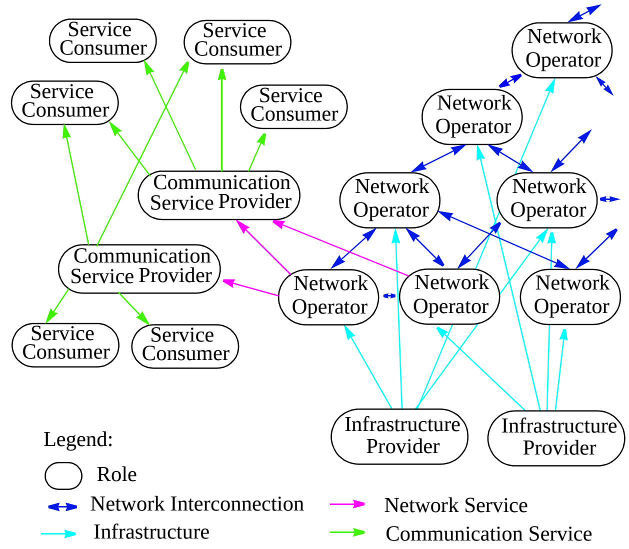

Figure 7: Network Role Model

Figure 7 depicts these roles and demonstrates how complexity of such a role model exceeds the one of a grid service role model such as presented in Figure 6. A high number of all role types increases possibilities of cooperation. Accordingly, business aspects are equally of interest as they are for grid services and organizational considerations. For instance, the assumption of a single-bill solution for all services in relation to the travel insurance offered to Miss Brown, influences the way by which involved role takers cooperate on network level. If Miss Brown is supposed to receive one bill only from the medical insurance company, then all voice and data communication services have to be accessible for Miss Brown without any additional costs, besides the 10 € she pays per week for the whole service bundle. This implies an international toll-free voice and data communication service that is offered by the domestic mobile operator to the travel insurance company. When Miss Brown's PDA transmits data to the travel insurance's systems, authentication and authorization for network access is first checked by means of a roaming agreement between the Indian and the home mobile operator. In a second step, an authorization request for using travel insurance-related services is sent to the travel insurance company. If authorization is granted, data packets are routed through and network service usage is accounted by both mobile operators.

5 Value Addition through the Mobile Grid Approach

The presented design together with its analysis can be evaluated in terms of functionality, performance, and with respect to the values added. Thus, the business scenario highlights functionally all key concepts as well as all necessary mechanisms, as shown for instance in Figure 5. Thus, functionality of the mobile grid in support of the mobile service provisioning is performed successfully. The implementation started on Akogrimo's middleware platform [35] and it will address possible performance considerations in a second step. Accordingly, the evaluation at this stage will focus subsequently on a potential value added by the MDVO concept and mobile grid approach. This is performed by discussing the scenario's value addition through mobile grids.

The most important advantage of a mobile grid is found in adopting the multifarious potential of grid computing, such as resource coordination among multiple administrative domains, in new fields of application. This, however, focuses less on high computational performance, but more importantly on knowledge management. In a mobile grid, it is possible to transmit content to a mobile grid node whenever needed as well as to send back processed content. This content has to fulfill two requirements. First, it is adapted to the mobile device's capabilities and secondly, it takes into account the device user's current situation. An important means for fulfilling these requirements is the support of nontrivial service qualities that allow subtle charging schemes and QoS-bundles according to device capabilities and business models.

Mobile and fixed grid nodes are organizationally integrated in a mobile dynamic virtual organization whereas both types of nodes are able to provide services. MDVOs base upon principles of focusing on core competencies and outsourcing. They thus profit from increased efficiency by means of specialization. A service provider of one VO can offer the very same or a similar service to another virtual organization. Hereby, the potential for economies of scale is gained. While providing services, know-how is exposed in fragments only — the service provider keeps full control over its resources and is protected against competitors copying the service.

From a user's point of view, integration of user, terminal, and service mobility adds crucial values: Location-independent accessibility of location-aware content as well as transparency with respect to underlying communications infrastructure is permitted. The user gains pervasive access to the MDVO, no matter whether he or she is using e.g. a GPRS or UMTS network. Adaptive business processes increase the chance of solving complex problems by considering changing context information.

From a system's architecture angle, the use of standard interfaces and open technologies diminishes efforts of developing and porting for service providers. Service-orientation shifts the focus from interacting objects and their properties towards the fact what they are able to deliver.

6 Summary and Conclusions

An extensive comparison of grid computing, service-oriented architectures, and peer-to-peer systems, regarding relevant business and technical metrics, has led to an advanced understanding of grid systems. This investigation provided the key basis for characterizing commercially oriented mobile grid systems, which are perceived as an enhancement of grid computing with respect to their support of mobile and nomadic grid resources, and thus being optimized for knowledge management.

From an organizational point of view, mobile dynamic virtual organizations have been introduced as a new concept by extending virtual organizations with functionality in terms of dynamicity and mobility. Additionally, key criteria for the usability of mobile grids have been determined. Subsequently, they have been tested in a business scenario characterized by mobility and a complex problem solving approach. By analyzing this scenario on the organizational, grid service, and network level, respective role models were defined. Based on a detailed analysis and the proposed business flows the added value through mobile grid systems has been identified.

Determined by the respective usability criteria, the mobile grid approach is applicable to a wide field of domains. The business scenario presented shows exemplarily, how travelers abroad are able, on one hand, to provide services, for instance by means of metered data, and on the other hand, how they can access complex, knowledge-intensive services, that are composed in an MDVO by a service aggregator depending on a service user's current needs. Practical benefit results for all involved actors, if underlying business models are designed accordingly. The travel insurance company is able to differentiate from its competitors by offering an understandable product for their customers being available on site exactly when needed. In turn, travelers profit from a solution that reflects their individual needs while delivering medical advice in a familiar, homelike manner. According to the type of partnership with a grid solution provider, mobile network operators open up either new means of transaction-based income streams or they can take over further services, such as customer management or billing. Service and content providers can concentrate on providing their services efficiently by focusing on core competencies only.

Accordingly, future work will consider continuing the scenario-analysis in order to reveal, on the basis of a concrete case, how economic potentials can be provided by means of a technical implementation.

Acknowledgement

This work has been performed partially in the framework of the EU IST project Akogrimo "Access to Knowledge through the Grid in a Mobile World" (FP6-2004-IST-2-004293). Discussions with Thomas Bocek in particular with respect to single bills, with Frode Flægstad for cooperation models in telecommunication, and with Cristian Morariu and Peter Racz in general Akogrimo technology issues are acknowledged.

References

[1] D. Bernholdt, S. Bharathi, D. Brown, K. Chanchio, M. Chen, A. Chervenak, L. Cinquini, B. Drach, I. Foster, P. Fox, J. Garcia, C. Kesselman, R. Markel, D. Middleton, V. Nefedova, L. Pouchard, A. Shoshani, A. Sim, G. Strand, D. Williams: *The Earth System Grid: Supporting the Next Generation of Climate Modeling Research;* Proceedings of the IEEE, Volume 93, No. 3, March 2005, pp 485-495.

[2] Information Society DG, European Commission: *Building Grids for Europe;* August 2004, ftp://ftp.cordis.lu/pub/ist/docs/grids/grids_brochure_2004.zip, August 2005.

[3] H. L. Choong, S. Jinwoo, P. Kyoungmin: *Grid and P2P Economics and Market Models;* 1st IEEE International

Workshop on Grid Economics and Business Models (GECON 2004), April 2004, pp 3-18.

[4] T. Phang, L. Huang, C. Dulan: Challenge: *Integrating Mobile Wireless Devices Into the Computational Grid;* 8th Annual International Conference on Mobile Computing and Networking (MobiCom 2002), June 2002, pp 271-278.

[5] G. Fox, D. Gannon, S. Ko, Sangmi-Lee, S. Pallickara, M. Pierce, X. Qiu, X. Rao, A. Uyar, M. Wang, W. Wu: *Peer-to-peer Grids;* in Grid Computing: Making the Global Infrastructure a Reality, John Wiley & Sons, 2003, pp 471-490.

[6] D. De Roure, M. A. Baker, N. R. Jennings, N. R. Shadbolt: *The Evolution of the Grid;* in Grid Computing: Making the Global Infrastructure a Reality, John Wiley & Sons, 2003, pp 65-100.

[7] I. Foster, C. Kesselmann: *The Grid: Blueprint for a New Computing Infrastructure;* Morgan Kaufmann, San Francisco, 1999, Chapter 2, http://www.globus.org/alliance/publications/papers/chapter2.pdf, August 2005.

[8] F. Berman, G. Fox, T. Hey: *The Grid: Past, Present, Future;* in Grid Computing: Making the Global Infrastructure a Reality, John Wiley & Sons, 2003, pp 9-50

[9] I. Foster: *What is the Grid? A Three Point Checklist;* GridToday, Volume 1 No. 6, June 2002, http://www-fp.mcs.anl.gov/~foster/Articles/WhatIsTheGrid.pdf, August 2005.

[10] I. Foster: *The Anatomy of the Grid: Enabling Scalable Virtual Organizations;* First IEEE/ACM International Symposium on Cluster Computing and the Grid, May 2001, pp 6-7.

[11] S. Padmanabhundi, J. Ganesh, D. Moitra: *Web Services, Grid Computing, and Business Process Management: Exploiting Complementarities for Business Agility*; IEEE International Conference on Web Services 2004 (ICWS 2004), July 2004, pp 666-673.

[12] I. Foster, C. Kesselman, J. M. Nick, S. Tuecke: The Physiology of the Grid; in Grid Computing: Making the Global Infrastructure a Reality, John Wiley & Sons, 2003, pp 217-249.

[13] D. X. Adamopoulos, C. A. Papandreou: *Enabling Web Services: Towards Service Grids*; Ninth International Symposium on Computers and Communications 2004 (ISCC 2004), Volume 1, June & July 2004, pp 38-43.

[14] M. Cannataro, D. Talia: *Semantics and Knowledge Grid: Building the Next-generation Grid*; IEEE Intelligent Systems, Volume 19, No. 1, January-February 2004, pp 56-63.

[15] D. Zou, W. Qiang, X. Shi: *A Formal General Framework and Service Access Model for Service Grid*; 10th IEEE International Conference on Engineering of Complex Computer Systems 2005 (ICECCS 2005), June 2005, pp 349-356.

[16] R. Agrawal, R. J. Bayardo Jr., D. Gruhl, S. Papadimitriou: *Vinci: A Service-oriented Architecture for Rapid Development of Web Applications;* 10th International Conference on World Wide Web (WWW10), May 2001, pp 355-365.

[17] R. Perrey, M. Lycett: *Service-oriented Architecture;* Symposium on Applications and the Internet Workshops (SAINT03 Workshops), January 2003, pp 116-119.

[18] M. P. Papazoglou: *Service-Oriented Computing: Concepts, Characteristics and Directions;* Forth International Conference on Web Information Systems Engineering (WISE 2003), December 2003, pp 3-12.

[19] M. N. Huhns, M. P. Singh: *Service-oriented Computing: Key Concepts and Principles;* IEEE Internet Computing, Volume 9 No. 1, January-February 2005, pp 75-81.

[20] Z. Stojanovic, A. Dahanayake, H. Sol: *Modeling and Design of Service-oriented Architecture;* 2004 IEEE International Conference on Systems, Man and Cybernetics (SMC 2004), October 2004, pp 4147-4152.

[21] World Wide Web Consortium (W3C): *Extensible Markup Language (XML) 1.1*; http://www.w3.org/TR/2004/REC-xml11-20040204/, February 2004.

[22] World Wide Web Consortium (W3C): *SOAP Specifications*; http://www.w3.org/TR/soap/, June 2003.

[23] World Wide Web Consortium (W3C): *Web Services Definition Language (WSDL) 1.1*; http://www.w3.org/TR/wsdl, March 2001.

[24] Organization for the Advancement of Structured Information Standards (OASIS): *UDDI Version 3.0.2*; http://uddi.org/pubs/uddi_v3.htm, October 2004.

[25] M. Milenkovic, S. H. Robinson, R. C. Knauerhase, D. Barkai, S. Garg, A. Tewari, T. A. Anderson, M. Bowman: *Toward Internet Distributed Computing;* Computer, Volume 36 No. 5, May 2003, pp 38-46.

[26] D. Schoder, K. Fischbach: *The Peer-to-peer Paradigm;* 38th Annual Hawaii International Conference on System Sciences 2005 (HICCS '05), January 2005, p 199.

[27] D. Barkai: *Technologies for Sharing and Collaborating on the Net;* First International Conference on Peer-to-Peer Computing 2001 (P2P2001), August 2001, pp 13-28.

[28] J. Mischke, B. Stiller: *A Methodology for the Design of Distributed Search in P2P Middleware;* IEEE Network, Volume 18 No. 1, January-February 2004, pp 30-37.

[29] H. Balakrishnan, M. F. Kaashoek, D. Karger, R. Morris, I. Stoica: *Looking Up Data in P2P Systems;* Communications of the ACM, Special Issue: Technical and Social Components of Peer-to-peer Computing, Vol. 46, No. 2, February 2003, pp 43-48.

[30] D. Schoder, K. Fischbach, C. Schmitt: *Core Concepts in Peer-to-peer Networking;* In Peer-to-peer Computing: The Evolution of a Disruptive Technology, Idea Group Publishing, 2005, Chapter 1.

[31] Y. P. Shao, M. K. O. Lee, S. Y. Liao: *Virtual Organizations: The Key Dimensions;* Academia/Industry Working Conference on Research Challenges 2000 (AIWoRC '00), April 2000, pp 3-8.

[32] L. M. Camarinha-Matos: *Infrastructures for Virtual Organizations - Where We Are;* IEEE Conference Emerging Technologies and Factory Automation 2003 (ETFA '03), September 2003, pp 405-414.

[33] A. Litke, D. Skoutas, T. Varvarigou: *Mobile Grid Computing: Changes and Challenges of Resource Management in a Mobile Grid Environment;* 5th International Conference on Practical Aspects of Knowledge Management (PAKM 2004), http://www.akogrimo.org/modules.php?name=UpDownload&req=getit&lid=28, December 2004.

[34] M. A. Viredaz, L. S. Brakmo, W. R. Hamburgen: *Energy Management on Handheld Devices;* Queue, Vol. 1, No. 7, October 2003, pp 44-52.

[35] The Akogrimo Consortium: *Akogrimo Overall Architecture;* Version 1; http://www.akogrimo.org/modules.php?op=modload&name=UpDownload&file=index, July 2005.