Novel Energy Saving Opportunities in Smart Grids using a Secure Social Networking Layer

Florian Skopik, Christian Wagner
Safety and Security Department
AIT Austrian Institute of Technology
{florian.skopik|christian.wagner}@ait.ac.at

***Abstract*—The *Smart Grid* initiative aims at transforming the public power grid to a flexible and intelligent energy utility. With this advancement, numerous applications can be implemented which are hard - if not impossible - to realize with today's technologies. For instance, in case of rolling blackouts, the power supply of critical infrastructures such as hospitals or traffic lights, can be prioritized immediately over private households and the grid's structure reshaped accordingly. Moreover, the energy grid becomes participative by enabling traditional consumers to feed back energy generated by their private solar panels and wind turbines. We argue that when coupling smart grid stakeholders with a social network, even more advanced use cases provide unmatched energy saving opportunities. Online platforms enable a plethora of novel application use cases, such as energy saving campaigns and competitions, utilization of friends' solar power, and coordination and sharing of energy consumption plans. In this paper, we introduce a social overlay model for smart grids, present its implementation using service-oriented architectures, and evaluate scalability and applicability.**

***Keywords*-smart grid, community-driven energy sharing**

I. Introduction

The electric power grid is by far the most important technical infrastructure used today and the basis for modern life. It is fundamental to all modern networked services, such as telephone, television, or the Internet. With the emergence of electric cars, the power grid will also ensure our mobility and thus increase its role. Reliable, dependable and secure energy supply is thus of paramount importance not only for the industry, but for the whole society. Changing requirements on the power grid in terms of supply capacity, load conditions, and reliability lead to an ongoing modernization and a major shift from a static public power grid to a more flexible one that can cope with today's challenges. The *Smart Grid* initiative aims at advancing the traditional power grid to an intelligent utility [1]. As defined in [2], *a smart grid is an electricity network that can cost-efficiently integrate the behavior and actions of all users connected to it - generators, consumers, and those that are both - to ensure an economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety.* There are numerous advances which come with the smart grid compared to the traditional power grid, such as remote meter reading, fast failure detection and recovery, intelligent and prioritized energy distribution, and the integration of home solar panels and private wind mills (so called micro-producers). Although today's smart grid models and technologies are quite far advanced on the lower level (e.g., automatic meter reading, data transfer, data storage at the electric utility company), we argue that there is much more space left for innovation in order to unleash novel energy saving opportunities. For that purpose we combine traditional social network models and service-oriented computing concepts with the smart grid and thus, allow consumers to form communities according to their energy consumption behavior. These communities enable them to strengthen their energy awareness by allowing comparisons of energy consumption data with other community members, sharing of energy plans, and – in case of micro producers – sharing of privately produced energy itself.

We propose a **social overlay network model** which conceptually resides on top of the smart grid infrastructure. This concept employs a wide variety of social networking approaches and service oriented architectures (SOA) techniques, such as dynamic discovery of partners, flexible interactions, run-time setup of contracts and agreements on delivered services, and opportunistic utility assessment [3] to support wide-range interoperability and scalability. Furthermore, establishing security is an essential objective of this layer. This ensures the application of our model in a variety of novel community-driven use cases. In particular, the paper deals with the following contributions:

- *Smart Grid Social Overlay Model.* This concept enables innovative application use cases by allowing consumers to utilize the smart grid in novel ways.
- *Community Formation Algorithm.* We apply a well-known formation algorithm and demonstrate its application and configuration for smart grid communities.
- *SLA Model for Energy Sharing Communities.* We highlight a SOA-based model for contracts and service level agreements (SLAs) between community members.
- *SOA Architecture and Evaluation.* We present a Web services-based prototype architecture and evaluate its feasibility in complex socio-technical environments, such as large-scale smart grid communities.

0730-3157/12 $26.00 © 2012 IEEE
DOI 10.1109/COMPSAC.2012.75

The rest of the paper is organized as follows. Section II highlights the motivation for our work and states the benefits of a social overlay network as well as future use cases. Section III introduces a conceptual layer model and the theoretical background, i.e., the application of a social formation algorithm and the definition of mutual sharing agreements between consumers. An architecture and prototype implementation is discussed in Section IV. Section V deals with an evaluation of basic features for most use case scenarios and discussions on scalability of the prototype platform. Related work is outlined in Section VI and finally, Section VII concludes the paper.

II. Motivation and Use Cases

Major goals of the smart grid initiative include (i) reducing costs (billing, accounting), (ii) increasing reliability through fast failure detection and recovery, as well as active load balancing, and (iii) reducing energy consumption. Since traditional energy consumers can switch their roles and become (at least for short periods) energy producers, managing the smart grid becomes challenging.

A. What a Social Network Can Contribute

In the future power grid, we distinguish at least between the following stakeholders: (i) *energy producers* run various kinds of power plants; (ii) *energy consumers*, typically households and industry, as well as public facilities (e.g., hospitals) use energy; and (iii) the *electric utility* provides and maintains the public power grid for energy distribution and thus connects energy producers and consumers. Further separate organizations might be involved for managing meter readings, accounting and billing processes. An important aspect is that traditional consumers may integrate privately owned micro plants into the grid, e.g., wind or gas turbines as well as solar panels, and can become temporary producers. In that case, they are referred to 'prosumers'. We argue that strong and dedicated communities [4] considerably contribute to reaching ambitious energy saving goals. A social network supports social campaigns, discovery of reliable (energy sharing) partners, and interactions with other people. This is essential to create a sense of belonging and thus motivate people to act reliably and responsibly. There are various ways in which a social network which overlays the power network, will be beneficial:

- *Coordination of Power Consumption:* Allowing users to coordinate their energy consumption can help to balance energy consumption from a temporal point of view. For instance, consuming power outside of peak hours can be rewarded by energy providers. However, reliable active coordination requires people to announce their energy consumption plans centrally, which compromises privacy and introduces a major security threat. So, how can people discover trustworthy potential partners for distributed coordination?
- *Establishing a Marketplace for Privately Generated Energy:* With the increasing number of wind turbines and solar panels in the home area, households become micro power plants. Typically one will consume his own energy, however, in some situations s/he might produce more than needed, e.g., if not at home. In that case people can feed back energy into the public power grid. However, creating a community to enable direct selling of energy is beneficial for both, the consumer and the producer, who can negotiate individual conditions.
- *Providing a Platform for Energy Traders:* In a more advanced scenario, two individuals might agree on utilizing each others' privately owned energy sources (e.g., i and j combine their produced solar energy, while i is using generated energy at 8 am and j at 9 am). However, in order to set up such an agreement they do not need to be neighbors, but can use the public power grid for transportation purposes (similar to public distributed computing, where personal computers are connected through the Internet to solve complex tasks while their particular owners do not utilize them). Even the infrastructure provider benefits from such agreements, since load capacities become predictable and there is no need to estimate future peak loads.
- *Enabling Cooperative Energy Storage:* With an increasing number of electric cars on the market, everyone can get a dense energy storage for his home [5]. However, cars are not needed every day and at peak hours their owners may allow others (or the central energy provider) to consume power from car batteries (at least partly) in order to avoid power blackouts in often unexpected generally high power consumption situations. Here, a social network alleviates the active coordination and setup of rules for energy abstraction within a community.
- *Strengthen Energy Consumption Awareness:* This objective can be addressed through a multitude of initiatives. Social campaigns teach the public the wealth of energy, amount of produced carbon, and efficient power saving opportunities. Online platforms enable customers to compare their energy consumption behavior with others, and energy saving competitions (as hosted already today by [6]) attract people to actively participate.

B. Illustrative Scenarios

Having these advantages in mind, we describe some illustrative scenarios and related challenges that we will address in the rest of this paper.

Use Case 1: Distributed Energy Storage. One major drawback of today's energy supply is that electricity cannot be efficiently stored at large scale. As a matter of fact, electrical energy should be consumed right away when it is produced. Thus, predicting customer's consumption behavior is essential for energy providers in order to cope with peak loads. Recent research investigates novel concepts to relax this situation. With the anticipated broad acceptance of electrical cars, car batteries can be utilized as buffers. *Challenge.* Customers will have to specify if and under what conditions they allow abstraction of electricity from their cars' batteries which is fed back into the public grid on demand. In order to do that, they need to negotiate and set up service level agreements (SLAs) [7] with their power supplier which formalize and regulate this process.

Use Case 2: Energy Marketplace. With the recent emergence of private energy generators traditional energy consumers can temporarily become energy providers in the smart grid. For that purpose, people own energy generators, whose electricity they sell or share if not needed. Finally, they might want to share energy with some particular individuals only, e.g., building an 'energy alliance' with their neighbors, and like to specify special conditions for them. That case would need a supporting social network, i.e., a *marketplace*, where social links reflect trustworthy relations used to model the aforementioned SLAs in an intuitive manner. *Challenge.* We argue that the application of social networking has a similar potential as mechanisms described in the previous use case to effectively distribute energy and avoid peak loads. However, in order to allow distribution of self generated energy through a marketplace, people need the ability to discover potential energy sharing partners, and auction (temporarily) excessive energy.

Use Case 3: Community-driven Energy Saving and Consumption Regulation. Both, active competition in a community as well as teaming up with people having same interests supports reaching ambitious goals. Energy saving competitions between single individuals or teams (e.g., groups having similar demographic background [6]) actively motivate community members to save energy. Furthermore, reaching a harmonic level of energy consumption with respect to the time of day through active coordination between energy consumers is a further goal. For that purpose people can populate their energy consumption plans and schemes (e.g., charging car batteries after coming home from work, heating up electric sauna on Friday evening) and get therefore rewarded with better price conditions by energy producers. *Challenge.* A critical mass of users needs to be attracted by a platform to make the whole concept taking off. The fundamental scientific concept is the application of coalitional game theoretic approaches [8] where the benefit for each individual increases through active collaboration.

III. Foundational Models

Various components from the social networking domain, social formation algorithms, and contract negotiation models are required to realize the aforementioned use cases. These mechanisms reside on top of the actual smart grid infrastructure.

A. Social Overlay Network Model

In order to establish a suitable social overlay, we propose a layered conceptual model as depicted in Figure 1. This model consists of:

1) *Physical Power Grid.* The physically static infrastructure connects the energy producers (virtually every type of power plant) and energy consumers (households, industry etc.). This layer represents a simplistic view on the state of the art[1].
2) *Smart Grid.* The smart grid deals with automatic meter reading (AMR), the ability of customers to integrate their own power sources into the public grid, and easy access to a liberal energy market, where customers can change their provider virtually instantaneously.
3) *Social Overlay Network.* Strong communities enable more sophisticated application scenarios, such as aforementioned marketplaces, social campaigns, and (perhaps most importantly) support to increase each individual's energy awareness. The focus of this paper is on the social overlay network layer.

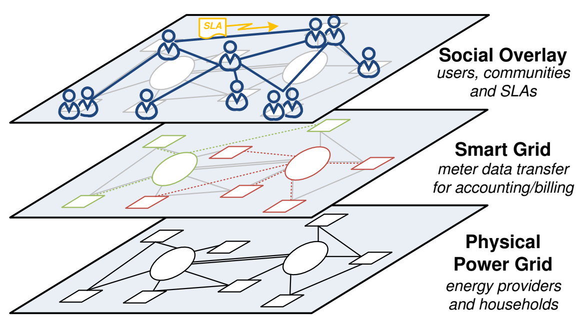


Figure 1. Conceptual framework for smart grid social overlay networks.

B. SOA-based Discovery

Web services play a fundamental role in supporting flexible collaboration and formation scenarios. The traditional 'SOA-triangle' approach [9], enables a *requester* (client) to discover a *service* flexibly at run-time by querying a *service registry*. We adopt this concept and apply it to the social overlay of the smart grid. Here, requesters (e.g., of energy sharing opportunities, social campaign setups etc.) can query for service providers (e.g., someone who provides energy from his own micro turbine) by querying the social network. By following the SOA paradigm, three essential steps are performed (1) *Publish.* Users have the ability to create services and publish (announce) them within the community network using a registry. Publishing a service is as simple as posting a blog entry on the Web. It is the association of the user's profile with a service description (WSDL interface

[1]We neglect all other complex grid mechanisms that are not related to the communication network of the smart grid; such as control networks for large-scale load balancing through the utility company.

[9]). Interfaces provide the needed metadata support for the discovery of suitable services. (2) *Search.* The service requester performs a criteria-based search (e.g., reflecting the energy demand and valid time slots) to find services. Ranking is performed to find the most relevant service based on, for example, the degree of matching or community feedback of a user-provided service. (3) *Use.* The framework supports automatic user interface generation using XML-Forms technology[2]. This way the details of an SLA are set up, for instance, the amount of provided energy and respective compensation for using the service.

C. Community Formation Model

Users of the smart grid can join and form communities based on their demographic background, interests and needs. We adopt[3] a well-known model for group formation from economic sciences [10]. The basic properties of the original use cases are similar to the situation in the smart grid. In particular, self-interested individuals accounting for their own payoff can create and sever links to others based on dynamically changing requirements. Periodic re-evaluation of a cost-benefit ratio exposes the network to constant flux and change.

Formation Model. Each user is represented by a node in a graph-theoretical model $G = (N, E)$, consisting of nodes N and edges E. If a node i is connected to a node j, we denote this edge with ij. Each node $i \in N$ receives a payoff $u_i(g)$ when participating in a group $g \in G$. In detail, $u_i(g)$ is calculated by accounting for the payoff δ $(0 \leq \delta \leq 1)$ i receives for being connected to other agents, and cost c $(0 \leq c \leq 1)$ for maintaining a link. Since nodes can be connected via several hops (transitive links), $t(ij)$ represents the number of edges on the shortest path from i to j. Although the model is widely applied in various works, there are some specifics that need to be considered and require slight adaptations. First, the benefit δ of a connection from one member to another member relies on a set of different factors. For instance, when sharing energy, the covered amount of the whole demand is a basic factor to rate the benefit of a social relation. Since the degree of coverage is different among members, we need to personalize δ for each particular neighbor by considering specific SLAs that are set up between pairs of individuals and enabled transitive relations. Second, costs emerge for each individual based on neighborhood size, i.e., the number of connections to maintain. These costs typically reflect coordination effort, such as maintaining SLAs (re-negotiating and discussing conditions of active SLAs), answering individual requests, and monitoring a partner's reliability (at least roughly, because this is supported by SOA monitoring techniques). The final algorithms is formulated as given in Eq. 1, and Symbols explained in Table I.

$$u_i(g) = \sum_{j \neq i} \delta_j^{t(ij)} - \sum_{j:ij \in g} c_j \qquad (1)$$

Table I
DESCRIPTION OF SYMBOLS.

symbol	*description*
G	social network G with segments $g \in G$
$u_i(g)$	utility of i obtained from network segment g
ij	direct link from node i to node j
$t(ij)$	path length from node i to node j
δ_j	benefit committed by j to neighbors (e.g., i)
c_j	costs (e.g., of node i) caused by node j

Links and model variables as well as their application are further visualized in Figure 2. Social relations are established due to various reasons, for instance, typically before starting sharing energy. For that purpose, discovered community members (using SOA based service discovery mechanisms as discussed before), who promise highest benefit are linked as partners. After that, both parties negotiate terms of sharing and set up a service level agreement (SLA). This SLA is a formal document which captures, for instance in the marketplace use case, how much energy is exchanged between[4] nodes and in which time slots. The actually gained utility is periodically assessed using Eq. 1.

Transitive Benefit Propagation. Indirect links allow for modeling a dampened propagation of δ (e.g., energy sharing opportunities). Thus, according to Figure 2, δ_k^2 can be interpreted as j passes some benefit obtained from k to i, so, in other words, i benefits from k indirectly via j. For example, when sharing energy, there are network members with highly volatile energy consumption behavior, e.g., a whole house block with several parties being uncoordinated in terms of energy consumption, they can potentially pass on excessive energy. In Figure 2, this potential makes j more valuable to i. However, costs rely on concrete SLAs and are thus accounted between directly connected pairs of nodes only (non-transitive).

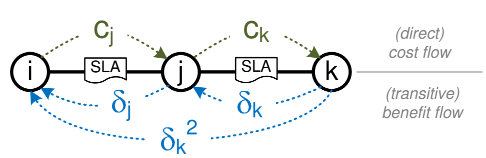


Figure 2. Flows from i's view in community formation processes.

[2]XML Forms: http://www.w3.org/MarkUp/Forms/

[3]Notice, we slightly extended the model by allowing for different δ committed by nodes. This is reflected by an index j. This δ_j reflects the maximum possible benefit that j's neighbors (such as i) can gain, which is further weakened based on the path length $t(ij)$ between i and j.

[4]In the simplest case a community member sells excessive energy to a major energy provider at any time. However, we argue, that this typically does not pay off compared to privately set up contracts, because terms and objectives cannot be negotiated with an industrial partner. Thus sharing among individuals is much more beneficial for both of them.

D. Contract Negotiation and SLA Setup

SLA Setup. Some reasons exist for a network member to swap the consumer and producer roles repeatedly. For instance, one might cover a fraction of his own energy demand with solar power, however, then most energy is produced around noon. Therefore, one might need the full amount of generated energy only on weekends, but not from Monday to Friday. Another community member might offer produced wind power on weekends, because then s/he is at another place. Thus both offer there excessively produced energy for sale at the marketplace. For that purpose they need to publish what type of energy they have, the expected availability at some (periodically reoccurring) time frames, and the provided amount[5].We adopt the WSLA standard [7], an SLA model which was initially developed for Web services in Serviced-oriented Architectures. We argue that both this model and SOA in general perfectly fit to a socially-enhanced smart grid environment, where consumers can dynamically become service (energy) providers and need to be discovered and 'utilized' on demand. The fundamental parts of WSLA are:

- Links and details to involved parties (*Service Provider* and *Service Consumer*)
- a *Service Definition* in form of a WSDL interface [9], containing single Web services operations for purchasing energy, credit-based compensation, etc.
- *SLA Parameters* and *Metrics* that are attached to operations.
- *Service Level Objectives (SLO)* describing the terms of the agreement, such as values of SLA parameters to be reached, e.g., minimum amount of provided energy in predefined time slots.

Two nodes establish an SLA along their connecting social link which is created in the (periodically executed) formation process. A particular instance of an SLA is given in the implementation section of this paper.

Re-Negotiation. Because of the mentioned high volatility of energy consumption behavior, each node will *periodically*[6] re-evaluate its obtained utility (energy, credits, support etc.) from the network in order to decide about establishing new links and releasing existing ones respectively, or re-negotiate SLAs. Here one could argue that this re-evaluation can be performed per SLA only instead considering the combined net outcome by applying the previously introduced group formation algorithm. However, there are situations where one benefits above average from one partner because of being connected to a considerable amount of 'friends of friends' through transitive relations, which is not reflected by SLAs. This transitive relations however are essential for the discovery of future partners in the social network.

The variable $\overline{t_x}(u_i(g) > 0)$ describes the number of positive evaluations in a time span $\overline{t_x}$, e.g., $\overline{t_{24h}}$. In other words, this is the number of evaluation operations where the obtained utility was greater than zero. In contrast to that $\overline{t_x}(u_i(g) < 0)$ counts how often costs paid exceeded the obtained benefit and thus the overall utility $u_i(g)$ was less than zero.

So, if on average (e.g., over a week or month), costs exceed the benefit (cf. Eq. 2), a node will attempt to release links with a low benefit-cost ratio ($\frac{\delta}{c}$) and form new ones.

$$\overline{t_x}(u_i(g) < 0) > \overline{t_x}(u_i(g) > 0) \tag{2}$$

IV. Architecture and Implementation

We basically discuss the mapping of introduced concepts to concrete technologies, and the implementation of a prototype system using state-of-the-art frameworks, components, and protocols.

A. Service-oriented Architecture

The basic architecture as shown in Figure 3 comprises four layers (1) The *Data Sources Layer* unifies platform specific data (e.g., user registry and profiles, or member recommendations) with data from electric utilities, such as smart meter readings, which are either available through generic Web interfaces or through third party platforms; e.g., Google PowerMeter[7]. (2) The *Network Management Layer* collects and aggregates all available data and creates a graph model on which the network formation process relies. (3) The *Resource Management Layer* supports the user with setting up SLAs, handles deployed SLAs, monitors respective

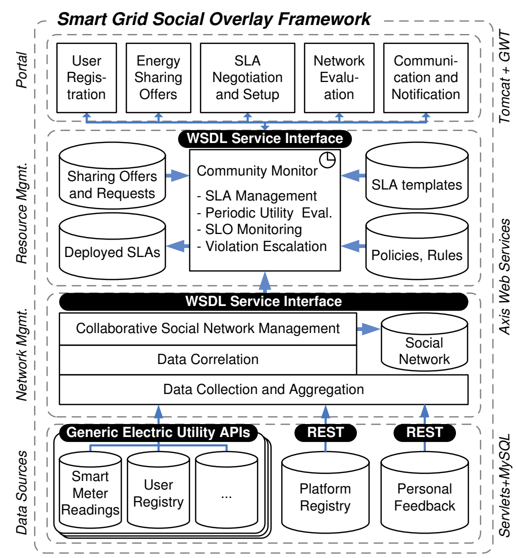


Figure 3. Architectural view showing major components.

[5]Notice that this is only an estimation, because most green energy sources (wind, sun) are inherently unreliable. Thus, we introduce an uncertainty factor in the next section.

[6]This means in time intervals of a fixed length.

[7]http://www.google.com/powermeter/about/

SLOs, and reports violations by notifying concerned users. The centrally located Community Monitor periodically runs through these steps and applies the social formation algorithm to compare benefits and costs per user with respect to predefined thresholds (policies and rules). (4) The top located *Community Portal*, provides the user with various tools/apps for setting up SLAs, evaluating benefits and costs, and communicating with other community members.

The most complex block here is the *Community Monitor*. It basically implements an autonomic computing cycle [11], where based on monitored events and a thorough analysis, targeted actions are executed to remain in a stable mode of operation. This process is configured through various policies and rules, e.g., to notify the user, if a network partner violates SLAs, automatically dissolve links, or inform about new energy sharing offers in time slots of interest. The engine for SLA enforcement is discussed in detail in previous work [12]. Here, we apply this work in different context.

B. Implementation Details

We utilize various well-established Web technologies from the area of Web services and the Semantic Web. In this section, we demonstrate major parts of our prototype framework. Notice that we took care to use major Web- and WS standards only and not any 'home-brewed' proprietary protocols.

Social Network Representation. In recent years, numerous models and protocols have been proposed to represent humans on the Web. One of the most widely used open approaches is Friend-Of-A-Friend (FOAF) [13]. Various attempts have been undertaken to secure FOAF, e.g., by combining it with SSL [14] or access rights management [15]. In particular, we discussed in previous work [16] an approach to the integration of FOAF and the Web of Trust ontology[8], as well as public key infrastructures (PKI) [17]. Listing 1 shows a simplified example of a public FOAF profile, containing basic personal properties (`name`, `interest`) and social relations (`knows`). The Web of Trust (WoT) RDF ontology is used to integrate concepts of a public key infrastructure into FOAF profiles. The property `haskey` links a public key (`pubkeyAddress`), `hex_id`, and `fingerprint` to a `person`. Furthermore, a person's private key is used to sign the own FOAF profile and therefore, to guarantee for integrity and authenticity. In smart grid communities, members can link energy sharing offers (basically SLA drafts that are further negotiated with and accepted by one of the linked neighbors) to their profiles (see list of `foaf:Projects`). Access to parts of a FOAF document may be restricted to certain users (whose public keys are used to encrypt those parts). We utilize this concept in particular for (i) linked SLAs, which are encrypted to be kept confidential between concerned parties; (ii) private information, such as private phone numbers or chat accounts that can only be decrypted and used by close neighbors (connected via `knows`), and (iii) personal ratings to reward and punish behavior, e.g., in terms of reliability of energy sharing among connected neighbors.

[8] http://xmlns.com/wot/0.1/

```
<foaf:Person rdf:ID="me">
 <foaf:name>Florian Skopik</foaf:name>
 <foaf:mbox_sha1sum>12c683...</foaf:mbox_sha1sum>
 <wot:haskey rdf:nodeID="KeyFS" />
 <foaf:interest rdf:resource="http://..." />
 <foaf:currentProject>
  <foaf:Project>
   <dc:title>WindMillSharing</dc:title>
   <dc:description>green energy, weekdays</dc:description>
   <dc:identifier rdf:resource="http://../EnergyOffer#42"/>
  </foaf:Project>
 </foaf:currentProject>
 <foaf:knows>
  <foaf:Person>
   <foaf:mbox_sha1sum>73c479...</foaf:mbox_sha1sum>
   <foaf:name>Thomas Bleier</foaf:name>
  </foaf:Person>
 </foaf:knows>
</foaf:Person>
</rdf:RDF>
```

Listing 1. Example of a public FOAF profile.

Web Service-based Interaction. Each member offering a service, e.g., sharing of energy or coordination of consumption, deploys a customized WS. Technically, the creation of these Web services is supported with predefined interface templates and rich user interfaces (XForms), so virtually no special technical skills are required for this step (see [18] for details – out of scope here). The discovery of these services is supported by the social overlay model, where 'friend(s) of a friend' are recommended within the community.

```
<!-- excerpt wsdl interface -->
<wsdl:portType name="EnergySharingPT">
<wsdl:operation name="ClaimEnergy">
 <wsdl:input xmlns="http://www.w3.org/.../addressing/wsdl"
   message="ClaimEnergyMsg" wsaw:Action="urn:ClaimEnergy">
 </wsdl:input>
 <wsdl:output message="AckClaimEnergy" />
</wsdl:operation>
<wsdl:operation name="PutCredit">
 <wsdl:input xmlns="http://www.w3.org/.../addressing/wsdl"
   message="PutCreditMsg" wsaw:Action="urn:PutCredit">
 </wsdl:input>
 <wsdl:output message="AckPutCredit" />
</wsdl:operation>
</wsdl:portType>
<wsdl:binding name="HALSOAPBinding" type="EnergySharingPT">
 <soap:binding style="document"
 transport="http://xmlsoap.org/soap/http"/>
</wsdl:binding>
```

Listing 2. Web Service for member interactions.

We roughly outline here the basic steps to enabling energy sharing through SOA from a provider's perspective as follows (1) *Service Suite Creation* using predefined PortTypes, to (i) enable potential customers to retrieve offers (i.e., discovery of available energy in particular time slots); (ii) allow interested costumers to negotiate conditions and deploy SLAs; (iii) support the actual energy sharing actions, such as claiming energy in certain time slots and providing credit-based compensation. (2) *Service Interaction* to trade energy against credits, change the requirements of customers (e.g., time slots of sharing), or extend offers. (3) *Service Quality Assessment* of involved parties by accounting for defined service level objectives. In case of violations an escalation strategy may be enforced, e.g., send warnings to the violating party. Listing 2 shows an excerpt of an energy provider's service interface, expressed in Web services description language (WSDL). Here, a customer who is bound to this service, can claim energy through one service operation and provide credits for compensation through a second one. See [18] for more details on dynamic service creation by humans.

SLA Specification and Enforcement. The used agreement model is based on work from IBM and the GRAAP Working Group (see Section VI). The overall structure, as given in the excerpts, includes header, agreement items, and terms. The header of an SLA comprises involved parties details and contact information. In the contractual items the agreement subjects are listed. These include the service content (i.e., for Web-services the WSDL location, endpoint, and operation) along with metrics, their representation and method of measurement.

```
<wsla:SLA
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:wsla="http://www.ibm.com/wsla"
name="SLA4711-WeekendBalance">
 <wsla:Parties>
  <wsla:ServiceProvider name="EnergyProvider">
    <!-- foaf:mbox_sha1sum ... -->
  </wsla:ServiceProvider>
  <wsla:ServiceConsumer name="EnergyConsumer">
    <!-- foaf:mbox_sha1sum ... -->
  </wsla:ServiceConsumer>
 </wsla:Parties>
 <wsla:ServiceDefinition name="ClaimEnergy">
  <wsla:Operation name="ClaimEnergy"
    xsi:type="wsla:WSDLSOAPOperationDescriptionType">
   <wsla:SLAParameter name="Energy" type="int" unit="kWh">
    <wsla:Metric>EnergyCount</wsla:Metric>
   </wsla:SLAParameter>
   <!-- further parameters and config -->
  </wsla:Operation>
  <wsla:Operation name="PutCredit"
    xsi:type="wsla:WSDLSOAPOperationDescriptionType">
   <wsla:SLAParameter name="Credit" type="int" unit="Credits">
    <wsla:Metric>EnergyCost</wsla:Metric>
   </wsla:SLAParameter>
   <!-- further parameters and config -->
  </wsla:Operation>
 </wsla:ServiceDefinition>
<!-- wsla Obligations -->
</wsla:SLA>
```

Listing 3. SLA excerpt.

Finally, the terms provide the objectives (see Listing 4), and their validity period. Threshold values express the desired relation between objectives and metrics defined in the items (Notice that WS operations (`ClaimEnergy`, `PutCredit`) match the interface defined before.) In the given example, SLOs describe agreed amount of delivered energy and compensation through the customer, as well as escalation strategies in case of violations. An SLO consists of an `Obliged Party`, a validity period, and expressions that can be combined with logic expressions (e.g., `And`). The content of an expression connects the pool of SLAParameters of the items to a predicate (e.g, `GreaterEqual`) and a threshold value (`Value`). The final tag `QualifiedAction` defines the consequence of an SLO violation. In the example case, if a threshold of SLO `sloEc` is violated an action of type Notification is called.

```
<wsla:Obligations>
 <wsla:ServiceLevelObjective name="sloEp"
  serviceObject="ClaimEnergy">
  <wsla:Obliged>EnergyProvider</wsla:Obliged>
   <wsla:Expression>
    <wsla:Predicate xsi:type="wsla:Equal">
     <wsla:SLAParameter>Energy</wsla:SLAParameter>
     <wsla:Value>75</wsla:Value>
    </wsla:Predicate>
   </wsla:Expression> <!-- evaluation weekly -->
 </wsla:ServiceLevelObjective>
 <wsla:ServiceLevelObjective name="sloEc"
  serviceObject="PutCredit">
  <wsla:Obliged>EnergyConsumer</wsla:Obliged>
  <wsla:Expression>
   <wsla:Predicate xsi:type="wsla:GreaterEqual">
    <wsla:SLAParameter>Credit</wsla:SLAParameter>
    <wsla:Value>50</wsla:Value>
   </wsla:Predicate>
  </wsla:Expression>
  <!-- expressions for reliability, uncertainties ... -->
  </wsla:And>
  <wsla:EvaluationEvent>TaskAssignment</wsla:EvaluationEvent>
 </wsla:ServiceLevelObjective>
 <wsla:QualifiedAction>
  <wsla:Party>CommunityBroker</wsla:Party>
  <wsla:Action actionName="violation" xsi:type="Notification">
    <wsla:NotificationType>Violation</wsla:NotificationType>
    <wsla:CausingGuarantee>sloEc</wsla:CausingGuarantee>
    <wsla:SLAParameter>EnergyCost</wsla:SLAParameter>
    <!-- expressions for reliability, uncertainties ... -->
  </wsla:Action>
 </wsla:QualifiedAction>
</wsla:Obligations>
```

Listing 4. SLO instance.

A number of quality metrics (Table II) can be automatically monitored, determined, and enforced in our system, and thus, are aligned to the described protocol structures.

Table II
NEGOTIABLE AGREEMENT ATTRIBUTES.

quality attributes	*description*
energy amount	delivered and consumed energy (kWh).
credits	compensation for delivering energy.
availability	predicted availability of energy provisioning depending on energy source and own fluctuating consumption in a predefined time span (e.g., a week or a month)
production uncertainty	fraction of the amount of energy that might not be delivered due to inherent production uncertainties or concurrent[9] SLAs.
consumption uncertainty	fraction of the amount of energy that might not be consumed due to inherent consumption uncertainties[10].

[9]One might decide to agree to more customers than s/he can actually serve – similar to flight companies which overbook their airplanes, because they know, some guests never show up.

[10]Who knows the energy demand for an electric heater in a few weeks?

V. Evaluation and Discussion

We conducted several experiments to discuss the feasibility of our social overlay approach, chosen technologies, and SOA concepts on top of social smart grids.

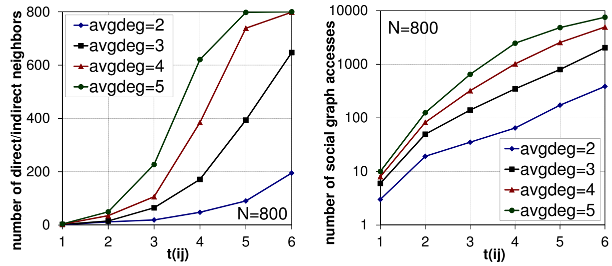
A. Discovery Scalability and Group Formation

Since we have not yet applied our approach in real large-scale environments, we do not have sufficient real testing data. Therefore, we generate artificial scale-free network structures that we would expect to emerge under realistic conditions [19] to test and discuss our framework. We utilize the preferential attachment model of Barabasi and Albert [19] to create graphs with power-law distributed degrees. These network structures are the basis to conduct our experiments following realistic assumptions. However, we do not study the formation process here (refer to [10]), but focus on discovery mechanisms in the social overlay.

The social network is used to discover trustworthy community members, i.e., members that direct friends are linked to. In other words, a transitive relationship $t(ij) = 2$ from node i to node j with a single intermediate node k can be emphasized as a recommendation of k through j towards i. The reasons for discovering new partners in the social network are manifold, for instance, long-term partners disappear or change their energy sharing behavior; or novel requirements emerge that can not be covered by current partners. From a technical point of view we measured how many indirect neighbors are reachable *on average*[11] in a network. The results heavily depend on two factors: (i) the interconnectedness of the graph, expressed here as the average node degree ($avgdeg$), i.e., the average number of neighbors one member has; and (ii) the maximum number of edges $t(ij)$ a transitive relation (path) from node i to node j can consist of.

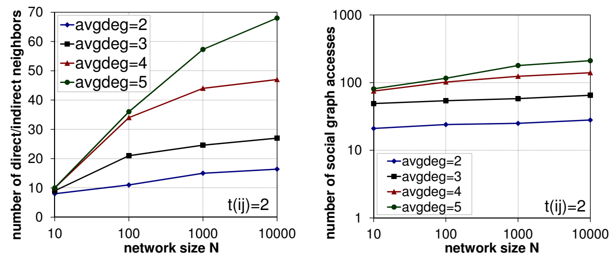
Figure 4(a) shows the average number of reachable nodes in a network of N=800 for different graph densities ($avgdeg = (2, 5)$) when applying $t(ij) = (1, 6)$. Under realistic conditions networks have an average node degree between 2 and 3; however, this value can be increased by introducing synthetic relations based on common properties (such as matching interests or co-location). Figure 4 demonstrates that only small $t(ij)$ are feasible to obtain a distinguished set of partners, while the majority of users is not recommended. Another interesting aspect is the number of social graph accesses when traversing the network and determining indirect neighbors for each single participant. For higher $t(ij)$ the number of required graph operations, and thus the computational effort, significantly[12] increases (see Figure 4(b)). These operations are carried out through Web services, each call requiring parsing FOAF files and thus causing costs in terms of execution time.

[11] Notice, that we are talking about power-law distributed node degrees.
[12] Notice the logarithmic scale.



(a) member discovery efficiency. (b) graph operations.

Figure 4. Fixed size graph and varying transitive path lengths.



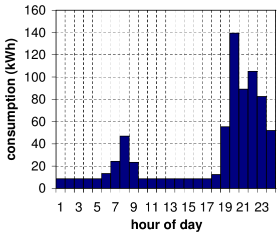
(a) member discovery efficiency. (b) graph operations.

Figure 5. Fixed transitive path length and varying graph size.

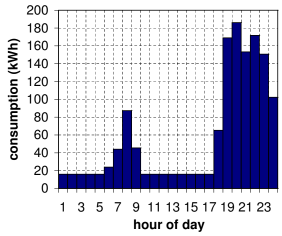
Figure 5 shows the scalability of member discovery for smaller and larger graphs up to 10000 nodes. Here we apply a fixed $t(ij) = 2$, equal to the natural notion of recommendation with one intermediate hop, and investigate the number of discovered network partners and number of required graph operations for different network sizes. We found out that while the number of discovered nodes sharply increases when enlarging the network, the number of graph operations does not, which means a good scalability of the discovery approach (applying $t(ij) = 2$).

B. Evaluation of Security Mechanisms

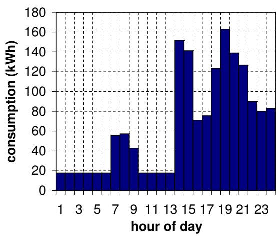
For privacy and information security reasons, personally identifiable data sent over the communication channel needs to be protected from unauthorized access or modifications. Whereas the transport layer is easily protected by employing HTTPS/SSL, end-to-end security in the proposed SOA environment is achieved by implementing the WS-Security [20] standard. By this means the content of the exchanged SOAP messages is directly encrypted and digitally signed. Due to the additional SSL handshake, the impact of HTTPS/SSL communication is greater for shorter messages [21], but not very significant in general. In internal testing we have found out, that the response time is on average 10 times higher when WS-Security is used. We have used GlassFish 3.1.1 as application server, a very simple Web service, and soapUI 4.0.1 for load testing. Server and client were located in the same organization-wide local area network. Our findings are compliant to [22] and show that adding message-level security to SOAP conversations has significant impact on the system performance in terms of message throughput.



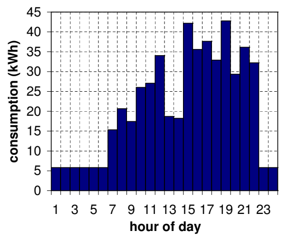
(a) 234 single adult.



(b) 218 two adults.



(c) 156 adults with children.



(d) 159 single pensioners.

Figure 6. Daily energy consumption profiles for different households.

C. Estimated Energy Saving Opportunities

Recently, the University of Stratclyde performed a thorough evaluation of existing user groups and their energy consumption behavior, and furthermore, developed an energy demand profile generator for further experiments [23]. We use this tool to study the potentials for energy savings in more detail. Private households can be classified according to their occupancy in a number of groups from which we picked the four most common ones. These groups cover around 75% of the population: (i) single adult, (ii) two adults, (iii) two adults with children, and (iv) single pensioner. Corresponding energy consumption profiles are depicted in Figure 6. These profiles show the average energy consumption in kWh of a group over the period of 24 hours. Notice, the particular data to create these profiles was taken from [23]. Thus, energy demands of all households of the same group are aggregated here leading to a population of 767 members (when using the four largest groups only).

Assuming each household can cover up to 40% of its demand with self-generated green energy from renewable energy sources [24], studying the distribution of energy consumption profiles and sizes of different user groups reveals that there is great potential for energy sharing. Especially when using solar power, most energy is produced at midday, but a considerable amount of the community members is not at home at this time and can share produced energy with pensioners. They, however, do not have a great need after 10pm, and could share geothermal or wind power with others. At these times of a day (9am to 1pm; 1pm to 5pm; and 10pm to 12pm), utility is highest for community members. Subsequenly, members from different groups having different consumption profiles are expected to form strong energy sharing alliances. On a regular weekday, we calculated with the given data that the amount of saved energy through sharing is up to 15% of the daily consumption in the whole community; for 40% average coverage of the electricity demand through self-generated (and thus shareable) energy.

D. End User Perspective and Applicability

On top of the social network layer and Web services based environment a collaboration portal supports the various features required in order to: (1) *Manage Profiles*, such as register a new user, add further profile data (interests, typical consumption profiles etc.). This is invaluable information for setting up energy sharing contracts with community members, however, one needs to act with caution not to compromise his privacy. (2) *Discover new Energy Sharing Partners*. We picture a platform that allows to announce energy sharing opportunities through an electronic marketplace. Currently, however, we do not employ formal mechanisms, but let people discuss their requirements in a threaded discussion forum. Although, here energy providers can post SLA templates that another party can agree with. Furthermore, in order to facilitate the discovery of new network partners, we employ recommendation mechanisms for friends-of-friends (transitive relations) who frequently offer excessive energy. (3) *Set up SLAs*, once two members have agreed on the objectives. Here, we utilize XForms to render an SLA and its objectives. So, involved members do not need to edit XML files but can conveniently fill in online forms. (4) *Monitor and Visualize the Network*, including monitoring SLO violations to trigger escalations; and visualizing social connections and deployed SLAs. Figure 7 shows this feature from the perspective of the centered user (here: 'Florian Skopik'). Other users are one, two or three hops away (Notice the circle layout). (5) *Send Notifications and Enable Escalations*. In case of SLO violations several options exist depending on the severity of the infringement; beginning with simple warnings, repeated violations may cause blacklisting a member or blocking her/him from the community portal at all.

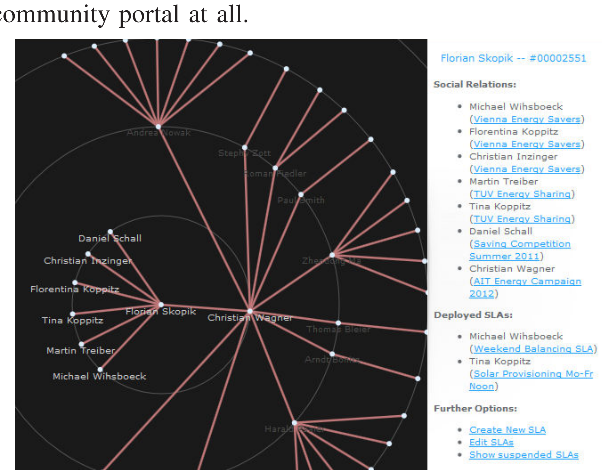


Figure 7. Community member perspective.

VI. Related Work

Establishing Smart Grids [5] is a major aim of the European Union [2], as well as covering a considerable amount of the energy demand with green energy [24]. While the basic technologies are currently under development, applications far beyond automatic meter reading are lively discussed; for instance social networking for smart grids is motivated by [4]. For that purpose coalitional and cooperative game theory [8], [10] is a promising approach to form strong communities. In our work, we selected the FOAF protocol as the technical basis to model social networks However, security [17] and privacy [25] concerns must be properly addressed when using this technology. Thus, various extensions exist, such as FOAF-SSL [14] and D-FOAF [15] to ensure secure social networking. There has been substantial research on translations of service level agreements (SLAs) to a Web-service applicable standard [26], [7]. These approaches present similar XML-based SLA models, however, differ in the details. IBM's WSLA focuses on defining agreement objectives, their constraints and combination. For this purpose parameters can be linked to SLOs together with thresholds. In our work we reuse the parameter schema to define our quality attributes. In the last years, SOA and Web services [9] have been in the focus of both academia and industry research. Convenient technologies allow for easy interoperability and automation. Especially when combining SOA with SLAs [12] powerful applications can be realized with minimal or completely without human intervention. Here, human-provided services [18] are a further building block of service networks, such as energy sharing communities.

VII. Conclusion

This paper described a SOA-based framework to enable efficient and secure social networking using open standards, such as PKI and the Web of Trust ontology. The implementation is fully compliant to Web services standards, SLA models and Web communication protocols, enabling a seamless integration of social network members and their provided services. The demonstration of these technologies in context of smart grid communities, an innovative new application area, is an important contribution of this paper. Future work includes a demonstration set up for a small real community. With the continuously proceeding roll out of smart meters, people will be able to monitor their energy demand in fine grained time intervals. We plan to study different ways on how to map these data into online platforms in order to finally apply the described framework in a real environment. However, major privacy concerns arise here, which need to be addressed, e.g., by pseudonymization.

Acknowledgments

This work is considerably based on previous joint research with Daniel Schall and Harald Psaier.

References

[1] Massoud and B. F. Wollenberg, "Toward a smart grid: power delivery for the 21st century," *IEEE Power and Energy Magazine*, vol. 3, no. 5, pp. 34–41, Sep. 2005.

[2] European Regulators Group for Electricity and Gas, "Position paper on smart grids no. e09-eqs-30-04," Berlin, 2010.

[3] F. Skopik, D. Schall, and S. Dustdar, "Opportunistic information flows through strategic social link establishment," in *WI*. IEEE, 2011, pp. 308 – 315.

[4] C. Chima, "How social media will make the smart energy grid more efficient," 2011, *http://mashable.com/2011/02/08/smart-grid-social-media/*.

[5] A. Ipakchi and F. Albuyeh, "Grid of the future," *Ieee Power And Energy Magazine*, vol. 7, no. 2, pp. 52–62, 2009.

[6] OPower Company, 2011, *http://opower.com/*.

[7] H. Ludwig *et al.*, "Web service level agreement (wsla) language specification, version 1.0," 2003.

[8] M. J. Osborne and A. Rubinstein, *A Course in Game Theory*. MIT Press, 1999.

[9] G. Alonso, F. Casati, H. Kuno, and V. Machiraju, *Web Services: Concepts, Architectures and Applications*. Berlin: Springer, 2004.

[10] M. Jackson and A. Wolinsky, "A strategic model of social and economic networks," *Journal of Economic Theory*, vol. 71, pp. 44–74, 1996.

[11] IBM, "An architectural blueprint for autonomic computing," *Whitepaper*, 2005.

[12] H. Psaier, F. Skopik, D. Schall, and S. Dustdar, "Resource and agreement management in dynamic crowdcomputing environments," in *EDOC*, 2011, pp. 193–202.

[13] D. Brickley and L. Miller, "Foaf vocabulary specification 0.98," 2010, *http://xmlns.com/foaf/spec*.

[14] H. Story, B. Harbulot, I. Jacobi, and M. Jones, "Foaf+ssl: Restful authentication for the social web," last access: 2012, *http://esw.w3.org/Foaf+ssl*.

[15] S. R. Kruk, S. Grzonkowski, A. Gzella, T. Woroniecki, and H.-C. Choi, "D-foaf: Distributed identity management with access rights delegation," in *ASWC*, 2006, pp. 140–154.

[16] F. Skopik, D. Schall, and S. Dustdar, "Managing social overlay networks in semantic open enterprise systems," in *WIMS*, 2011, pp. 50:1–50:12.

[17] H. C. A. van Tilborg, Ed., *Encyclopedia of Cryptography and Security*. Springer, 2005.

[18] D. Schall, "A human-centric runtime framework for mixed service-oriented systems," *Dist. Par. Datab.*, pp. 1–28, 2011.

[19] A. Reka and Barabási, "Statistical mechanics of complex networks," *Rev. of Modern Phys.*, vol. 74, pp. 47–97, 2002.

[20] Organization for the Advancement of Structured Information Standards (OASIS), "WS-Security 1.1," 2006.

[21] D. Sosnoski, "Java web services: The high cost of (ws-)security," 2009.

[22] M. Novakouski, S. Simanta, G. Peterson, E. Morris, and G. Lewis, "Performance analysis of ws-security mechanisms in soap-based web services," Berlin, 2010.

[23] University of Stratclyde, "Energy demand profile generator (last access: Nov. 2011)," 2007, *http://www.esru.strath.ac.uk*.

[24] World Wind Energy Association, "World wind energy report 2010," Feb 2011.

[25] M. Yokoo, V. Conitzer, T. Sandholm, N. Ohta, and A. Iwasaki, "Coalitional games in open anonymous environments," in *AAAI*, 2005, pp. 509–514.

[26] A. Andrieux *et al.*, "Web services agreement specification (ws-agreement)." Open Grid Forum, 2007.