Social Network of Smart-Metered Homes and SMEs for Grid-based Renewable Energy Exchange

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***Abstract*—This paper proposes a revolutionary approach to Smart Energy Grids which empowers communities of consumers as first-class citizens with a novel role in the management of their electricity by sharing excess electricity and therefore becoming energy producers (prosumers). The approach makes innovations on smart technologies and processes by building a demand-response decision support system on top of smart metering and social web technologies. This is achieved using a framework to connect dynamic, context-aware, heterogeneous virtual and real entities on the Internet of Smart Meters (IoSM) and by studying the behavior of communities on it. The smart electricity meters are transformed into fully-fledged intelligent computers on the IoSM, enabled to (i) securely collect data from heterogeneous meters and sensors and actuators, (ii) detect smart meters with similar goals, (iii) exchange and aggregate data from multiple autonomous physical or virtual meters, and (iv) manage the actual energy demand and ensure the achievement of demand response for the community involved. The approach is centered on the community and its respective DSOs, where each prosumer is represented as a node on the IoSM through their electricity meters, sensors and actuators. This allows for rational energy exchange between technical and non-technical participants by expressing their goals in a standardized language through hybrid ontologies.**

Keywords-smart-meter; demand-response; social network; community; prosumer; renewable energy; energy efficiency

I. Introduction and Motivation

Traditional utility grids focus on three types of activity: namely electricity generation, transmission and distribution. The business model of traditional utility grids has focused on the interactions between Distribution System Operators (DSOs), Transmission System Operators (TSOs), and generators. It is interesting to note that electricity consumers are not active participants in this model, nor are the renewable energy sources (completely) integrated in the picture. This creates an imbalance of financial power between the two players (individual consumers and power grids): power grids buy excess energy from individual consumers, which gives them much power to dictate the energy price.

The growth of urbanization has resulted in the surge of the energy demand required. As a result, many European[1] and worldwide initiatives started to focus on Smart Grids with the goal to enhance utility grids to efficiently deliver sustainable, economic and secure supplies based on the interactions between all the users who are connected to the energy grid. From an ICT perspective, Smart Grids rely on the *Internet of Things* to provide consumer with information and choice of supply. The Internet of Things relies on the numerous electronic devices (sensors and actuators), which form a collaborative digital ecosystem [1]. *Smart meters* are advanced meters, which are able (i) to collect data on consumers' electricity usage, (ii) to communicate this data to other power system participants on local utility grid, and (iii) to get pricing information from DSOs to stop/start household appliances.

A solution to combat the problem of steadily increasing electricity usage is to *combine smart meters with home management systems*. Thus, the information coming from these systems highlights how, where and when consumers could reduce their electricity bills by changing their day-to-day behavior. Similarly, utilities have designed *Demand-Response* (DR) programs to deal with occasional and temporary peak demand periods. More specifically, utilities offer *financial incentives* to (residential and business) electricity consumers who are willing to reduce their consumption when demand outweighs supply. For example, a utility company could switch on/off devices inside a customer's premises based on *demand and pricing*.

Alternatively, renewable energy has been proposed as a new source of energy. This solution has been adopted not only by large utility companies, but also by residential consumer and SMEs. As a result, a new paradigm takes shape, where consumers are allowed to play a novel role in the energy management by producing electricity, thus becoming prosumers.

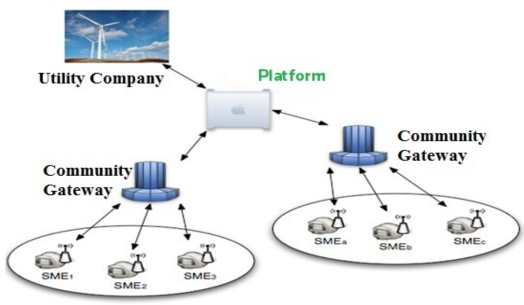

Figure 1. Framework overview

[1] http://www.smartgrids.eu/

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A third way to reduce a power shortage on utility grids would be for prosumers to sell their excess electricity to utilities, DSOs, or even other consumers. Suppose an SME has installed photovoltaic cells to produce enough electricity to cover ¾ of its monthly usage. Due to a temporary reduction in sales, the company is forced to reduce their workforce and production. Based on the information available from smart meters, the SME knows that its production of energy is going to be above their usual consumption and can take measures accordingly.

This paper proposes a methodology and a framework (Figure 1) to bring together and support the three approaches to smart energy consumption, using a user-centric approach. The aim is to provide communities of consumers with a novel role in the management of their electricity by sharing excess energy and by using personalized smart energy consumption. A key role in this approach is represented by the semantic technologies, and more precisely by the hybrid ontologies [2], which ensure the interoperability between the heterogeneous devices and between those devices and the human user on the Internet of Things.

The goal is to reduce the asymmetric situation between DSOs and individual consumers, taking into account the demand-response capability and the renewable energy. The difficulty consists in finding similar interests among a group of consumers (communities with similar goals). This approach generalizes the idea of cooperative. The communities are formed based on similar goals and geographical location. Each stakeholder in the community of consumers is represented as a node on the Internet of Things through their electricity meters (and sensors and actuators). The important aspect is introduced by the social network of smart meters, which becomes the community. The community is organized to create virtual entities acting as small power centers, where stakeholders will not only consume, but also produce (and sell) their energy. This brings a fair deal to the consumer, allowing for rational energy exchange between partners of comparable strengths by expressing community goals in a standardized language (ontology).

II. Related Work

A series of initiatives exist concerning innovative infrastructures for energy efficiency (e.g. SmartHouse/SmartGrids [2], BeyWatch [3], BeAware [4]), the Internet of Energy (e.g. Smart Watts[5]), semantic technologies for energy efficiency (e.g. SESAME [6] and SESAME-S [7]), demand response (e.g. DR 3 [8], SmartCamp [9]), or smart solutions for home automation (e.g. EcoGrid[10], DiYSE[11]).

[2] http://www.smarthouse-smartgrid.eu/
[3] http://www.beywatch.eu/
[4] http://www.energyawareness.eu/beaware/
[5] http://www.smartwatts.de
[6] http://sesame.ftw.at/
[7] http://sesame-s.ftw.at
[8] http://www.ieso.ca/imoweb/consult/demandresponse.asp
[9] http://arc.gov.au/pdf/LP10_R2/Curtin_University_of_Technology.pdf
[10] http://energinet.dk/EN/FORSKNING/Energinetdk-research-and-development/EcoGrid/Sider/EU-EcoGrid-net.aspx
[11] http://dyse.org:8080/pages/viewrecentblogposts.action?key=hometest

The current state-of-the-art in energy production and distribution is insufficient to cope with the DR dilemma - the more we produce, the more we waste. In addition, climate change imperatives will progressively place limits on the amount of energy generated through fossil fuels. This requires the demand to be responsive to the energy and power supply available. In addition, the increasing use of renewable energy locally has opened up the possibility for this to be sold back into the grid. In order to produce energy smartly and to consume energy efficiently, a crucial move is to integrate the cyber world and the physical world. This will allow both digital information and traditional energy (e.g. electricity) to flow through a two-way smart infrastructure connecting everything surrounding us.

This leads to the recent development of Cyber-Physical Systems (CPS) that is simultaneously computational and physical. One of the biggest challenges of CPS research is the real-time, secure, and safe group communication methods, protocols, algorithms in a dynamically changing environment amongst various computing devices and equipment. To undertake this challenge, in this study we have used the Internet-of-Things (IoT) computing paradigm [1]. To fulfill the architecture of Internet of Things, we adopted the Resource-Oriented Architecture (ROA) style which was first proposed in the work of Richardson et al [3]. Four key concepts were defined for a ROA: Resources, URL, Representation, and Links. Jagatheesan and Helal [4] proposed a framework fostering the service discovery amongst hierarchical communities and a set of related protocols built upon the private UDDI nodes – Syndication Matchmaker. The notion of service here can be interpreted as utility in the context of our study. Verma et al. [5] provide a scalable Web services discovery architecture – WSDI – composed of multiple registries, namely community gateways. More importantly, the project MSDI employed and customized the JXTA framework [6] as the peer-to-peer protocol to facilitate the federated cooperative service (i.e. utility information) discovery amongst these distributed ontology-augmented registries (community gateways).

As mentioned before, this research eliminates the un-equal relationship between large and small players that will be beneficial to the SMEs or prosumers while sharing their energy. The idea is to have collective bargaining power among the group of small players that will give them the negotiation power to be on a par with the big players and eliminate the gap dividing them. In order to have such a bargaining power, collaborations need to be formed among the different players (prosumers and SMEs) in the form of virtual communities. The literature presents numerous approaches of working with virtual communities, which can be distinguished as two broad categories. The first category of approaches apply virtual communities in different areas such as education [7], health care [8], multimedia business applications [9] whereas the second type of approaches deal with improving the virtual communities in different aspects such as developing trust-enabling functionalities [10][11] supporting pervasive computing services by using multi-agent technologies [12] developing architectural framework for supporting mobile business [13] developing the business models [14].

III. Background

A. Ontology Engineering

The knowledge in this study is modeled following DOGMA (Developing Ontology Grounded Methods and Applications) methodology [15]. DOGMA is an integrated methodology for ontology engineering from scratch, inspired by various scientific disciplines, in particular database semantics and natural language processing. Based on this approach, prosumers are able to represent the domain of discourse in terms they understand rather than the one used by electricity engineers. GOSPL [16] was used, as tool for community-driven hybrid ontology engineering [2]. Semantic decision tables (SDT) [17] were used for the semantic decision support system for reasoning purposes.

B. Cyber-physical Systems and the Internet of Things

In this paper, we aim to build an architecture for DR Cyber-Physical Systems in order to tackle the critical energy shortage issue and to utilize it in an efficient way (Figure 2). It builds on the IoT computing paradigm that creates a network by which the different devices proactively interact with each other, thus turning into smart devices and achieving demand-response; rather than just behaving as standalone entities. A key element to facilitate IoT architecture is to deploy sensors on different devices with flexibility and mobility. The Resource-Oriented, IoT framework for DR consists of five layers: IoT Device, IoT Kernel, IoT Overlay, IoT Context and IoT API.

The community based context aware demand forecasting in this study builds on the widely used methods proposed by Sestito et al. and by Szkuta et al. in [18][19] which are based on adaptive neural networks. The proposed framework pursues promotion of energy awareness via its community services on the existing social network sites, following up already established practical experiments in this area 0.

IV. Use Case Scenarios

Three categories of actors are identified in this approach:

1) The user community. Typically geographically clustered, for example represented by prosumers residing in a given town or area (e.g. residential users, farmers, etc.). This type of community may use the proposed environment to exchange energy among themselves (take the example of Mark, who has solar panels installed on his roof; Mark is preparing to go on vacation and wants to sell his excess energy during this time; his neighbour, Jim, needs energy to charge his electric car, so he buys the excess energy from Mark). The community may also potentially offer energy to the grid at an optimised price and conditions. The DSO clearly must be involved in both types of services. Adapting the model developed in the work of Papazoglou 0, this category is led by a community leader, who has the specific role to bootstrap the community and to help it become sustainable.

2) The DSOs. Several DSOs are considered in this approach, all of which are known to share part of their respective agendas. The DSOs usually operate regionally.

3) The service providers, who build appropriate services for the user communities and the DSOs on top of the proposed platform. The services respond to different functions needed by a community and are to become partly embedded in the smart meters (ontology-based software driven smart meters).

The platform ensures the secure data transmission and processing from end to end. Several sustainable energy sources are to be taken into account: solar, wind, biomass, etc. In this approach, several use cases may be encountered illustrated around two use case scenarios, as follows:

The Smart Metered Homes Community Use Case. In this scenario, several smart homes in a neighborhood are connected via our framework. Suppose the user of such a home, named Mark, is at home and he wants to have a certain degree of comfort in the house while keeping the energy consumption low. This is achieved by Mark setting rules on the house appliances and the energy consumption based on various parameters, e.g. the current power load, energy price, indoor air quality, temperature, time of the day, etc. This can be done on site, let's say when he arrives at home, or remotely, for example when he's still at work and he prepares to get back home. Mark can also decide to switch between installations (gas, electricity, heat) when one has more advantages over the other(s) when, e.g. the prices change. When Mark is away on vacation in the summer time, the system is predicting an excess of energy (due to the little amount of energy used in the house and to the energy produced by Mark's PV cells) which Mark can sell directly to his neighbors or to the grid. He publishes the available dates and prices on a community portal, through which people from the same community can purchase. He also sets rules on the prices at which he wants to sell in case he has no access to the portal. In this case the system dynamically manages Mark's excess energy.

The Farm Cooperative Use Case. This scenario illustrates the management of energy resources in a cooperative of farmers, let's say a milk farmer cooperative. When a farm is producing and storing (freezing) milk, the energy demand is high. Therefore, it might need to purchase energy from the other farms around (or from the grid). We compare the energy demand, the energy available and the offers from the other farms in the system. In the opposite situation, when the energy consumption is low and the energy produced (via PV cells, biomass, wind mills, etc. that are available at the farm) exceeds the demand, the farmers can put together their excess energy and sell it to the grid. This happens when the system decides that the level of excess energy is high enough and it is safe to sell it.

V. Approach

In the business model of this study, electricity prosumers have an active interest in reducing their electricity bill and CO_2 consumption. We achieve this by encouraging the development of "*goal focused*" communities through so-called Social Web technologies. By goal focused communities, we mean on-line communities that would emerge, in this case encouraged by enabling web technology, to achieve a particular goal compared to "*person focused*" communities that merely share a common interest. For example, Facebook encourages its users to create communities based on common interests such as reading, while LinkedIn aims to bring together professionals with interest in similar topic like green energy.

We propose a platform and integrated knowledge base to enable communities of prosumers as first-class citizens on utility grids to share excess electricity. Three pillars are identified which will support a complete architecture life cycle:

a. Demand Response Management through Cyber Physical Systems;
b. Knowledge Base (KB) Management;
c. Community Evolution for Sustainable Growth.

We explain the three pillars in the following sub sections.

A. Demand-response

We propose to develop a layered demand-response architecture consisting of two essential components:

- The *Smart Device Layer* (SDL); and
- The *Demand-Response Layer* (DRL).

SDL is aimed at constructing an integrated framework for ubiquitous intelligence and computation. The challenges associated with this layer are: (i) creating abstractions and semantics for smart devices and event representations so that a composition of devices to deliver particular information is possible; (ii) constructing robust wireless devices and networks that support real-time storage, structure and retrieval of the large amount of smart device data. This is achieved by creating middleware to seamlessly integrate, tailor ad-hoc devices and support network and device security. A key aspect of this is to ensure that either the smart meter device itself has an IP address or a collection of smart meter devices locate a smart gateway that has an IP address. Behind the smart gateway, the smart meter devices could use other protocols such as ZigBee[12] for locating individual devices; (iii) designing user interfaces for visualizing, configuring, monitoring and controlling such device networks and their outputs. This can be achieved through the convergence of technologies to deliver truly synchronized wireless information including consumption, prices, and other system data.

DRL sits on top of the first layer, thereby providing a demand-response infrastructure and value-added services that allow energy to be safely, efficiently, and effectively consumed, delivered, provided, stored and traded based on dynamically-changing factors along several dimensions including consumer preferences, community bargaining power, utility availability and demand, consumer/community pricing strategies, government economy and utility policies, and so on. This layer consists of a number of key components including smart links, smart gateways for household and community, protocol for community management, communication, signal management, algorithms for pricing data response collection, intervention recommendation, and real-time price forecasting, and pricing forecasting algorithms real time re-scheduling of community member demand and automated processes for settlement, billing, collection, bookkeeping, and dispute resolution.

No work has been done for demand forecasting at a community level as envisaged in this paper. This will be breaking new ground but is a crucial element for the real-time decision support system needed. A key element to being able to achieve this interoperability between the two layers as well as between devices and software components is the *ontology*.

B. Knowledge Base Management

Secondly, the approach aims to support the *semi-automatic management of the knowledge base*. The challenges related to this component are: (i) creating ontologies based on the goals of a community. The goals of each member of a community are often expressed in natural language (e.g. English). However, these goals need to be represented using ontologies to enable communication amongst software agents. Hence, a generic method to convert these goals into ontologies needs to be developed; (ii) supporting semantic annotation of data collected by smart meters, sensors and actuators. This will be achieved by a combination of automated process-based annotation, information extraction methods, and lightweight local manual annotation, including linking and tagging. As the knowledge base will contain more than one ontology, we take into account the challenge of matching ontologies; (iii) systematic and comprehensive information integration and data entries management in a pragmatic, secure and distributed environment provided by the platform; and (iv) semantic decision support tables and reasoning system which are able to connect smart objects, social applications and open linked data.

C. Community Management

Thirdly, the approach develops a *sustainable community management system*. This implies (i) evolving the Community Groups: Techniques are developed that encourage prosumers/SMEs to join a particular group relevant to their objectives or goals. Some of the strategies include developing approaches that show the users the benefits which they will achieve by joining a particular group of community, providing different levels of incentives (e.g. financial reward) to early adopters, innovative and effective ways of advertising (e.g. solar panels advertised with a deal for the prospective customer) via social networks, newspapers, magazines, local TV channels and social networks, Web 2.0 framework, word-of-mouth strategies etc. Note that the people in a neighborhood that are not joining any prosumer community will continue to follow the classical approach; and (ii) managing the Community Groups for Sustainable Growth. As the community evolves, the challenge of making these communities sustainable is considered. This are achieved by developing strategies for risk assessment and risk management which continually determine beforehand the chances of negative events occurring and take actions to resolve those.

D. System Architecture

The key architectural components of the DR framework are the demand response small and medium enterprises (DR SME), DR Community, and DR Fabric. A Demand Response SME is an IoT framework-embedded computing unit that has a

[12] http://www.zigbee.org/

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physical (wire or wireless) connection with a smart meter using the IoT Device, and sets out its functionalities to the DR Community and DR Fabric through IoT Overlay realized in the DR Fabric. Each smart meter collects consumption information and sends it back to the DR SME node. The DR SME may transform this information into a DR event processed by the IoT Kernel, which may then liaise with other DR SME through the DR Community. DR applications (desktops, Web, mobile) use IoT API to interact with IoT Context to retrieve interesting application scenarios and to further control the DR system. DR Fabric consists of in-network system functions (routing, admission control) that are provided either by applications themselves (e.g. extending DR Community) or by a customizable DR Fabric reference implementation.

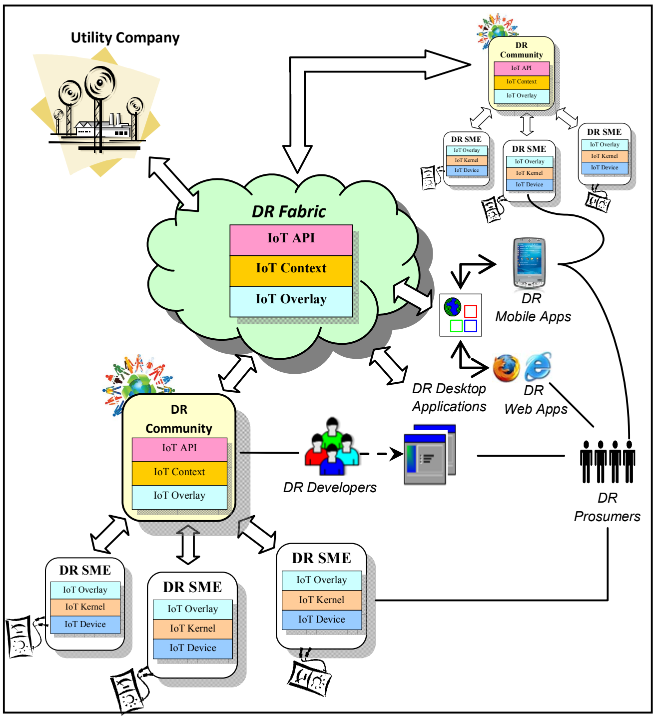

Figure 2. Resource-oriented, Internet of Things (IoT) framework for Demand Response (DR)

The platform consists of *four main layers* (

Figure 3); namely the (1) *Smart Device* layer; the (2) *Demand-Response* layer; the (3) *Client* layer; and the (4) *Security* layer. The smart device layer manages the smart devices (i.e. electricity meters, sensors and actuators) and provides services for the aggregation, analysis and mining of knowledge from autonomous devices. The demand-response layer (Figure 2) provides (i) an infrastructure and services that allow energy to be safely, efficiently, and effectively consumed, delivered, provided, stored and traded based on dynamically-changing factors along several dimensions; (ii) a decision support system that includes community level demand forecasting based on aggregation of collected data and contexts defined by system pricing level and contingencies which require intervention to maintain power system security. Note that this layer also manages the community through social networking technologies.

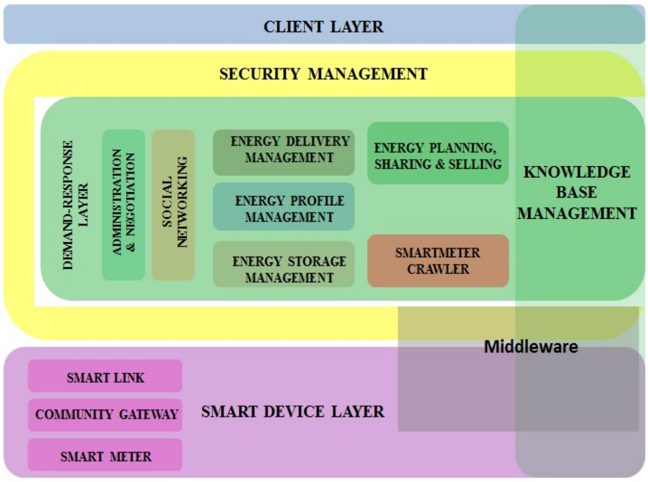

Figure 3. Platform architecture

The client layer uses services exposed by the Demand-Response layer for providing information to end-users, while the security layer supports the security functionality and needs between the different layers. Finally, the knowledge base enables interoperability between the different layers. The combination of these components monitors the community and enables their smart meters to adequately respond to demand and/or contracts. This entire system is controlled by the ontology defined in the knowledge base.

The middleware will be based on a service-oriented architecture (SOA), providing proxies across physical networking protocols and operating systems to transparently manage devices in a uniform way (for example as web services as part of the middleware). The proposed development will allow handling in a harmonized and cost-effective fashion, sensors, actuators, smart-meters, and other equipment that is needed in a co-generation environment integrated with the smart energy grid.

VI. PERSPECTIVES

This section analyses our proposed solution to energy efficiency with respect to its feasibility and the expected impact. The identified impacts are summarized in TABLE I.

TABLE I. IMPACT AND INFLUENCING FACTORS

Identified Impact	Meaning	Influencing Factors
Social and Eco nomic	- Prosumers are allowed to play an active role in the management of their energy consumption; Significant reductions of energy consumption;	Energy price The public opinion on saving energy
	- Reliable (stable) and secure price for electricity; - Raising awareness of energy consumption/saving; - Motivating the communities to invest	The emancipation of local communities

	in the renewable energy production and the reduction of energy consumption with economic and ecological incentives; - The energy efficiency becomes a social process through the social dedicated tool.	Prices Competition Political change in energy providing countries
Eco logical	- Reduction of the overall environmental impact of electricity grids (via decentralized energy use, supply and storage); - Facilitating the integration of renewable energy in the grid and energy savings through feedback and demand side management.	National/international laws Adoption of the approach by large communities
Standardization	- Contribution to the standardization in order to make possible interoperability and integration (also by considerably reducing the costs).	Adoption of the approach Laws

VII. Conclusion and Future Work

This paper analyses the state-of-the-art regarding the energy efficiency and, as a result, proposes an innovative approach for energy efficiency based on a demand-response system built on top of social web technologies. The approach is based on two main architectural components: (i) a layered demand-response architecture, which consists of two essential layers (the Smart Device Layer and the Demand-Response Layer); and (ii) an open, rich, integrated, multi-disciplinary knowledge base for supporting knowledge sharing and management amongst system power participants on utility grids.

Related to similar initiatives worldwide, the approach in this paper extends the existing methods and techniques in the following ways: (i) it develops an architecture that will assist the individuals to form communities and influence the way they purchase and sell energy in the Smart Grids platform; (ii) it provides a two-way communication framework between the prosumers and DSO by using the Internet of Things principles; (iii) it enables linked-data services in the energy domain based on social networks; and (iv) it extends the interoperability on the Internet of Smart Meters via the use of hybrid ontologies, which map user incentives expressed in natural language to technical concepts processable by the smart devices.

Our approach goes beyond the state of the art in forming, evolving and maintaining pull-in based communities by developing intelligent algorithms for (i) determining which prosumers or SMEs should be targeted and for which part of the community; (ii) increasing the awareness and the benefits among the prosumers or SMEs in joining the community; (iii) determining which prosumer should be targeted for increasing the participation of other prosumers and SMEs in the community; (iv) determining the financial rewards or incentives to be given to early adopters and for active promoters of the community; (v) assisting the community members to act for the betterment of the community; and (vi) managing the community for self-sustenance.

Presently, the proposed architecture exists as individual components. Ongoing work is focusing on implementing the proposed solution, integrating the components and validating the framework. Future work aims at validating the technology against two field-tests involving communities from two distinct geographical areas.

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