P2P-based community concept for M2M Applications

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***Abstract*—This publication presents a novel concept to provide and use services in a Peer-to-Peer (P2P) connected Machine-To-Machine (M2M) community. Service compositions are presented that address several application fields like Ambient Assisted Living, traffic, energy, electro mobility, logistic or surveillance. The successfully implemented concept for optimisation of energy management in the local grid with P2P connected households became more generalised. Now it can be part of M2M application fields of 2nd and 3rd generation. The concept provides an overall solution for information exchange, extended by community mechanism, for convenient networking of peers to use and provide optimised services. Inside the community, the peers can operate as a single peer or operate as a cluster of peers to provide and use the services.**

Keywords—Smart Grid; Smart Home; Energy Management; Service Provisioning; Peer-to-Peer; Community; Machine-To-Machine; Ambient Assisted Living; Logistic, Traffic Management

I. Introduction

In the electric power grids of the future, the trend will be to increase production of volatile renewable energy using wind power and photovoltaic systems. Based on this trend, the proportion of centralised energy generation will decrease and replaced by distributed generation and supply. This shift has already started within the non-monitored local energy grid. To still ensure stability and good quality in the power supply, the local grid has to be expanded and especially has to get smarter through information and communication technology. This development is commonly described by the term "Smart Grid" [6]. The published solutions to manage the Smart Grid outline several gaps or deficiencies, described in [1; 4], and propose centralised or hybrid centralised/decentralised approaches for optimisation with no consideration of independent clustering of households. Because of these gaps a completely different solution, which follows the approach of "control through price signals" [7], is proposed in [1-5] to control and manage single Smart Homes as well as a cluster of Smart Homes. A concept of a P2P networked Energy-Community is presented that is a novel solution for completely decentralised optimisation of the aggregated energy usage. This solution is introduced more detailed in chapter II and III. That concept offers the possibility to connect devices, service platforms, environment and people using IP-based communication networks and exchange information between them to make each of them more intelligent. The possibility to create and provide services in a comfortable way can be defined for several application fields. This publication proposes a generalised concept for M2M applications, based on the solution for decentralised energy management with P2P connected communities. The proposed concept is part of M2M application fields, that [8] classifies as 2nd generation (M2M end user/ devices/ environment interaction) and 3rd generation (Social M2M, integration of people and networking of people). In chapter IV and V the concept is proposed that uses the advantages of providing the infrastructure for different kind of services in different M2M application fields with same and cost efficient hardware and the independence of central service provider.

II. Concept of P2P networked Energy-Community

In [3; 4] a Service Management Framework (SMF), consisting of Service Delivery Platform (SDP) and Service Creation Environment (SCE), is proposed where the customer can develop optimisation services for energy management in an easy and convenient way using a web-based Graphical User Interface (GUI). The SMF provides the personalised value-added services for the Smart Home, especially for energy management, and includes the integration of multimedia communications. In addition the framework provides a mechanism for convenient networking of households, energy suppliers, distribution network operators and others with the objectives cost savings, avoidance of grid expansion, energy savings, CO2 reduction, reduction of residual load etc.

Energy optimisation of single households does not have enough influence to the grid; therefore a simultaneous optimisation of households is required. Optimisation of multiple households requires the exchange of information between the households and in consequence the networking of the households to exchange information between each other. The approach, proposed in [1-5], is based on completely decentralised structure and forms a P2P network of households that exchange information for optimisation like e.g. current or forecasted consumption, information about existing energy generators and storages (batteries, electric vehicles), energy rates and/or network fee). The peers represent households, energy suppliers, and distribution grid provider.

To solve issues for networking, avoid legal restrictions, optimisation, missing mechanisms to form the P2P network or the fact that user aim different goals for optimisation (e.g. cost reduction, obtain only “green energy”, most benefit for energy supply) the P2P networking approach was extended by community mechanism. The community-based approach forms a new comfortable way to join a network of peers, whereby the connection of peers is done by joining the users to a social network. Fig.1 shows the structure of the P2P connected households within an Energy-Community.

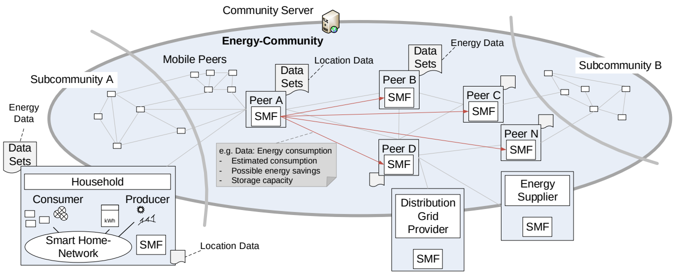

Fig. 1. P2P connected households within an Energy-Community

According to the principle of a social network, the community may grow independently and every participant may accede to his free will. Existing infrastructure can be used to provide different kind of services in different application field with same and cost efficient hardware. Using IP-based Information exchange guarantees the applicability by everyone that has access to the Internet. Therefore the realisation is possible with minimal costs. Inside that Energy-Community not only the single customer goals are considered, the goal is to reach a benefit for every participant in the community. In addition the participants can form sub-communities to address common shared interests (e.g. energy saving, cost reduction, obtain only “green energy”).

The participants inside the Energy-Community have different roles (community operator/provider, energy supplier, household, distribution grid provider). The peer household can define boundary conditions for its personal optimisation (e.g. restrictions for Demand Side Management or definition of date/time when electric vehicles have to be fully charged). With consideration of these boundary conditions a special algorithm defines an optimised schedule for energy consumption and supply. The distribution grid provider and energy supplier can offer better rates for reaching a permitted load curve within a region (benefit for the distribution grid provider: load reduction in a region; benefit for the energy supplier: reach the forecast for energy supply).

The optimisation algorithm is implemented inside of every SMF and operates based on e.g. using battery storages that supply power to the grid or charge battery to reduce the load. The decision to supply energy is taken inside the local SMF, based on the information received from other peers. The data storage, required for the services, information exchange and optimisation is also completely decentralised using Distributed Hash Tables (DHT).

III. Realisation of P2P Networked Energy-Community

A. *Service platform for households*

The Service Management Framework (SMF) offers the possibility to the user to create services like e.g. start charging of an electric vehicle (EV) if the energy price is below a defined threshold (the process for service creation via the user interface is described in [3; 4]). Fig. 2 shows an overview of the relevant parts of the SMF.

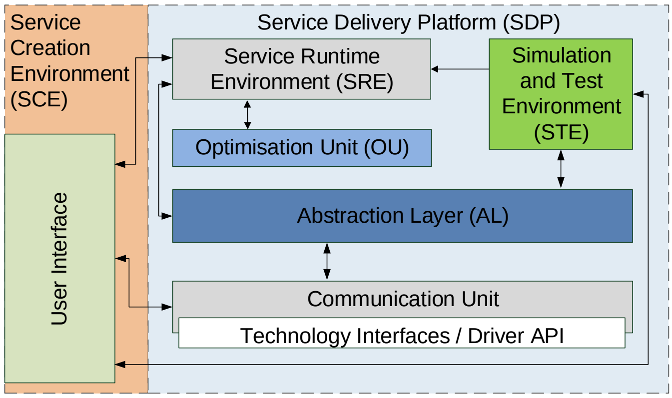

Fig. 2. Overview of relevant parts of SMF

The Service Runtime Environment (SRE) interprets the service description (formal service notation using State Chart XML, SCXML) and executes the actions described in it. For this, the SRE communicates with the Abstraction Layer (AL) and thus controls the actions in the connected devices. For abstraction of communication and connection of different bus systems for Smart Home controlling (e.g. KNX, EnOcean, MBus, ZigBee) the AL has been designed. This makes it possible to connect a variety of Smart Home and multimedia communication techniques, as the AL unifies communication between services, part services, Smart Home bus systems as well as elements for multimedia communications. To implement this integration of different communication and Smart Home systems, the architecture includes a Communication Unit (CU), which is connected directly to the AL, allowing the device and technology specific control of devices. All connected devices are registered at the AL and are controlled within the services in an abstracted way. The Optimisation Unit (OU) implements the above described optimisation of services through re-configuration of pre-defined services. This is done taking into account the constraints and optimisation objectives, which the user has defined via the user interface.

B. *Process for participation in Energy-Community*

To join the Energy-Community and the P2P network (illustrated in Fig. 3), the user registers via the Web Browser at the Energy-Community and joins his sub-community. After registration the user gets his access data which he configures at his SMF. The SMF requests a list of all participants in the community/sub-community and connects to the P2P network (via the Bootstrap Peers).

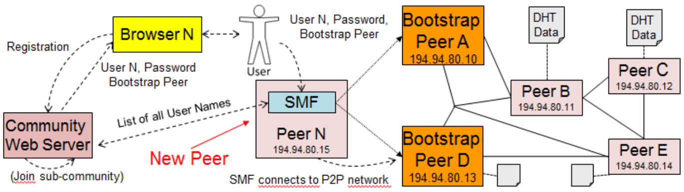

Fig. 3. Joining the P2P networked Energy-Community

C. Information exchange in the P2P network

The information exchange between the peers is based on the Session Initiation Protocol (SIP) [12]. The SIP protocol is used because of its standard in multimedia communication, which was defined as a requirement for the platform, to offer total communication possibility. Also SIP has standardised functionality for transport of XML-data and mechanisms for reliable communication, realised in Application Layer that offers the functionality to act in heterogeneous networks. In addition, Interactive Connectivity Establishment (ICE) [14] can be used to avoid Network Address and Port Translation (NAPT) or Firewall issues.

All peers observe the state of all other peers in the community. The observation of the state with the SIP protocol is done via a process that is specified in [11] as “SIP-Specific Event Notification”. Every peer offers a service to provide his energy information. All peers send a SUBSCRIBE Message to all participants in the sub-community. This indicates to the receiving peers, that the requesting peer (service consumer) is interested in its energy information. At defined intervals (e.g. 15 minutes) the peers send its own energy information to all other peers in the sub-community (peers that subscribed for the event). This occurs via the SIP message NOTIFY. For description of the energy data, the XML format is used. Another option for SIP-based information exchange between the peers is to use SIP MESSAGE (specified in [13]) to push messages directly to peers.

As an alternative to SIP-based information exchange, the calculation methods of Distributed Hash Tables (DHT, described in section III.D) can be used to collect the energy data from all peers. Especially to collect data (e.g. summation like determination of residual load) DHT can be used. Every peer can store its energy information directly inside the DHT and every peer can request the total energy data of the sub-community.

The option for information exchange (SIP or DHT) depends on whether it is a data- or a message-centred service. SIP-based information exchange is advantageous if direct communication between the peers is required. Also if the peers have to exchange data that should not be send to the whole sub-community but only to a certain peer or group of peers. To select the type of data exchange, the use case (message- or data-centred service) has to be determined and the resulting amount of data as well as the number of required messages has to be estimated. As optimisation SIP Compact Headers [12] or SIP over Websocket protocol [15] can be used. SIP Compact Headers reduces the data volume. SIP over Websocket protocol can also avoid NAPT or Firewall issues.

D. Distributed data storage in the P2P network

To avoid central authorities, achieve scalability and redundancy, the necessary data management is distributed based on DHT (Distributed Hash Table) and the Chord algorithm [9]. The DHT stores e.g. data of a location service to provide the address information of peers. The SMF of sending peer gets a list of all participants (usernames) from the Community Web Server (refreshed periodically). The SMF detects the contact address (temporal SIP URI) of the other peers via the Location Service, implemented in the P2P network. Fig. 4 shows a simple architecture of the chord topology.

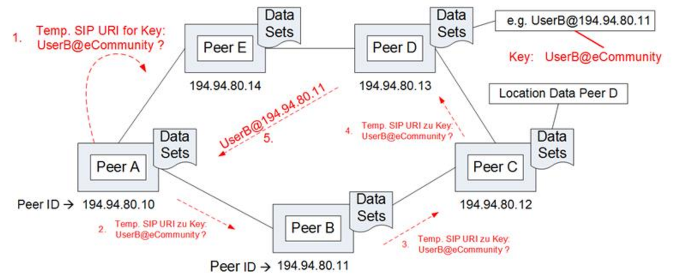

Fig. 4. Chord-based Location Service

If e.g. peer A requests for the temporary SIP URI of peer B, then the SMF requests the corresponding data to the Chord topology. The request is forwarded from one peer to the next until the peer is detected that stores the dataset. This peer responses the dataset directly to the requesting peer.

E. Optimisation of P2P networked households

The households connected by an Energy-Community or by sub-communities, as introduced in section II, can work together and implement application scenarios, such as avoiding peak loads, avoiding regulation energy, optimisation of the energy costs, incentives to save energy etc. (see [2]). They use the more flexible options that come up through the use of distributed storages, generators and/or time shifted activation of consumers (demand-side integration (DSI)). Depending on the use case, this may result in benefits to the distribution system operator, the balancing group managers, energy suppliers, consumers or the environment etc.

Fig. 5 presents a section of the algorithm that is used to implement a scenario for peak load reduction in a region.

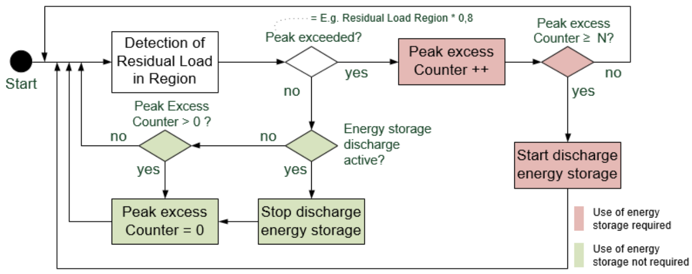

Fig. 5. Algorithm for peak load reduction

Firstly, each peer determines the residual load in the region, which represents the difference between the energy demand and the supply by renewable energy. If the calculated residual load for the region exceeds the defined limit, energy storages present in this region will discharge and supply additional energy to the grid. The demand will be met locally through the local supply, preventing the supply of additional power from upper voltage level. Recharging the energy storage takes place in line with defined lower limits of the residual load. Fig. 6 shows the part of the algorithm that is responsible for the calculation of the residual load in a region.

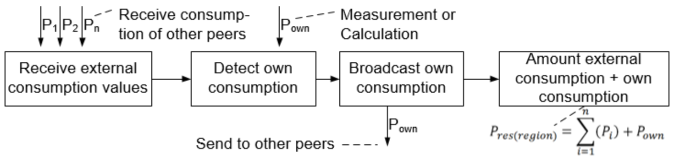

Fig. 6. Part of algorithm for calculation of residual load

Each peer receives the energy requirements of all other peers. The required data is transmitted via SIP messaging, based on the networked households described in section II. After the energy demand of all households was received, the individual energy requirement is determined and distributed to other peers. To determine the residual load, each peer adds its energy demand to the sum of the received energy demands of all peers. This determination of the total energy demand is the basis for the decision to discharge existing energy storage as described above.

To demonstrate the effectiveness of the outlined energy community below the result of a concrete, simulated application scenario of the proposed algorithm is presented. For more detailed description of the test bed and the validation of the simulation see [4]. The scenario covers "avoidance of peak load" by using battery storages for a community of 1000 households. The results shown in Fig. 7 indicate that, for a 20% peak load reduction (from 45.9kW to 36.7kW), already 23 battery storages are sufficient, that means only 2.3% of households would have to be equipped with a battery storage.

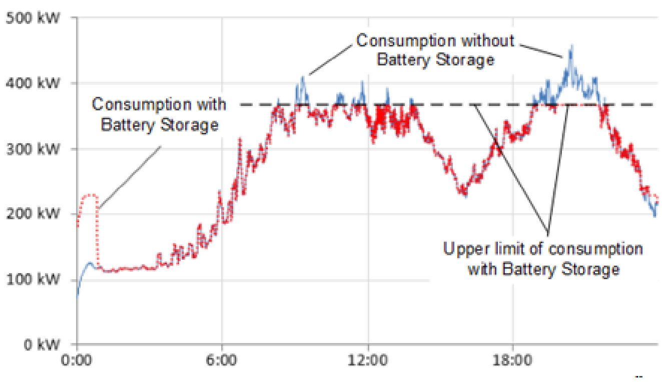

Fig. 7. Results peak load reduction using Battery Storages

Worth mentioning here is that not the storage capacity of the battery, but the maximum discharge power is the limiting factor. The simulation shows that battery storages are very effective for peak load reduction. This result was also confirmed by the simulation of additional scenarios on the same topic "Avoiding peak load" (see [2; 4]).

IV. P2P Networked Community inside a M2M Environment

The concept of P2P networked households within an Energy-Community presents an overall and very powerful solution for energy management and optimisation of households or cluster of households. The advantages of that solution are not limited to the energy sector, but can also be applied in various sectors of M2M applications.

The P2P networked community concept offers advantages in all application fields where decentralised challenges exist and central solutions for service provisioning or optimisation are not realisable (e.g. because of costs or infrastructural precondition). The joint optimisation is realisable, based on information exchange between the peers. On the one side information are exchanged from machine to machine (SMF to SMF, device to device, device to SMF, SMF to device) and from machine to process (optimisation algorithm and other services), one the other side information become available for customers (machine to human and human to human information exchange). The participants have the possibility to provide services and to use services according to their personal interests. The formation of sub-communities allows multiple peers to jointly offer and use services to achieve common interests. Thus, a variety of targets can be achieved in various sectors.

The challenges to M2M platforms or IoT (Internet of Things) mentioned in [10] (scalability, robustness, openness, flexibility etc.) are addressed/solved by the SMF and the P2P networked community concept. The SMF form a platform for automated information exchange (using communication networks) between devices, humans and interaction/networking of people. The SMF is the basis for exchange of information with limited human interaction. The integration of different house automation systems and communication technologies into SMF brings the possibility to build many services based on M2M. These services can be provided by one or many peers and used by one or many peers (service user and provider are linked in a n-n constellation).

Using a mobile implementation of the SMF, the mobile phone (with e.g. Android as operating system) is the runtime environment and at the same time the interface to the customer. The implementation on mobile platforms offers possibilities for many applications and services, independent of the location, using location data and environment information.

The more generalised consideration and implementation of the P2P-based community approach offers many new application fields for community-based services and optimisations like energy, traffic, logistic, Ambient Assisted Living (AAL). A non-exhaustive overview is presented in Chapter V.

V. P2P Networked Community Services in M2M Environments

The platform, described above, forms the main part in provision and use of M2M services by connecting service providers and service users, using an overall solution for information exchange. The focus is the P2P connection of all participants and the community mechanism. Based on that concept, different kind of services are realisable in different application fields. Fig. 8 describes the generalised structure for service provision and usage in P2P networked communities.

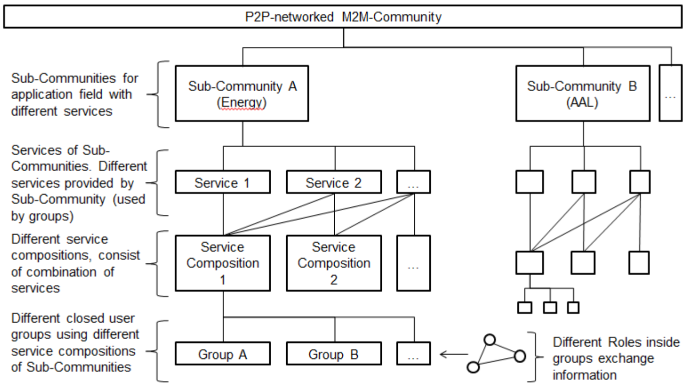

Fig. 8. Generalised structure of P2P networked M2M communitiy services

The concept identifies several elements in the structure: The P2P networked M2M-Community itself, sub-communities for different application fields, different services provided by the sub-communities, different service compositions consisting of several services and different closed user groups that use the service compositions. Within the groups different roles exist that are central parts for the service realisation. This structure was used to apply the concept for several M2M applications like energy management, traffic management, electro mobility, logistic, Ambient Assisted Living. According to that structure, below several sub-communities are defined (with their community services, service compositions, groups and roles) that are already partly implemented.

A. *Sub-community for traffic management*

The sub-community for traffic management can provide services for local/urban public transport optimisation as well as private transport organisation.

Community service public transport: The public transport provider and transport customer act as peers. Also private transport providers are part of this community. They exchange information relating to current timetable, transport offers, transport requests, rates, locations of the peers and route information, using the mobile SMF. As service composition dynamic and personalised time tables can be created, according to transport offers of the transport providers and the requests (subscriptions) of the customer. The integration of private transport provider enlarges the flexibility by flexible combination of public and private transport offers.

Community service share taxi: The private peers (customer) can subscribe for share taxi whereby the taxi control centre, the taxies and the customer act as peers. They exchange information about timetable, taxi requests, taxi positions, rates, special offers, stops and route information. As service composition the services are used to create a personalised timetable and create detailed navigation information to the relevant stops by matching requests and offers of all participating peers.

Community service car sharing: The car sharing provider, the car and the car-user act as peers. They exchange information about car availability, car positions, subscriptions for cars and route information, using mobile SMF. As service composition the personalised, timed and regional optimised allocation of vehicles can be displayed to the car sharing user, according to their subscriptions.

Community service lift-arranging agency: The provider of a trip as well as the user of a trip act as peers. The user of that service can be several groups with attendance of relatives and friends. They exchange information for requests for drives (user), offer for drives (provider), location information of peers, and route information. As service composition personalised, timed and regional optimised trips can be organised, according to requests and offers. In addition the communication between peers can be done directly via IM and audio call.

B. *Sub-community for electro mobility*

Community service electric vehicle (EV) charging: The EV and the provider of a charging station for EVs exchange information about location, route information, charge state of the EV and requests for charging. The EVs subscribe at the charging station provider. The charging station provider notifies the EV if charging is possible. If not, the charging station provider sends alternative locations of other charging stations to the EV. In extension an algorithm optimises the allocation of charging stations which generates optimal route information for all EVs that are currently located in an area. The distribution grid provider and the energy supplier can also be part of the community, whereby they publish information about current energy rates or residual load in a region. Using this information the optimisation of EV charging in a region (by e.g. optimal scheduling) is possible (cost and load optimisation).

C. *Sub-community for logistic*

Community service delivery tracking: The complex structure of supply chain is an issue for delivery tracking. During the delivery of goods no networking between logistic providers exists. The solution for information exchange inside the P2P networked community offers the possibility to create an overlay network which can detect and store the current position and additional information about the delivered goods. The tracking station subscribes for the state information of the goods and the good itself notifies the tracking station about its current location and state.

Community service parcel service: The SMF of parcel service provider and the customer exchange information about presence at delivery location. The provider subscribes for packet delivery and the customer notifies if at home or not. Advantage of that service is that unnecessary drives are avoided (in consequence preserve of environment and avoidance of costs and time).

Community service for relocation/cold transport companies: The relocation/cold transport companies communicate with other relocation/cold companies to inform about location and additional available transport capacity. The other company can use this capacity. This reduces drives on same route (saves money, time, and environment). The relocation/cold transport company can also offer free transport capacity (location-based) to other customers. The customer can subscribe for short-term transport options. The driver of the truck notifies customer for acceptance.

D. Ambient Assisted Living (AAL) and surveillance community

Community service Ambient Assisted Living: The parented person (e.g. senior citizen), the residential monitoring platform (as part of Smart Home), relatives, nursing service, emergency service, friends and other service providers act as peers. They exchange information according to the current state of the parented person (location information, medical status etc.). As service composition the residential monitoring platform can coordinate the order to inform the assistants of the parented persons (in case of emergency e.g. the senior citizen fall down) regarding to their location information. The SMF of the parented person therefor subscribes at the mobile SMF of the assistants. The assistants can notify and confirm the request, can directly communicate with the parented person (e.g. for call backs) or can contact the other assistants using the communication services of the SMF (IM, audio/video call).

Community services for senior citizens: Senior citizens, relatives, friends and other service provider (e.g. shopping service) act as peers. They exchange information according to the current needs of the senior citizen (availability of food, wishes for walks, support for public authorities, talks etc.) and current service offers (e.g. shopping, read outs, walks etc.). The senior citizen subscribes for service and the peer providing the service notifies if the service can be performed currently or reschedules the time/date.

Community service residential building security/keeping: households, relatives, friends, neighbours, police, fire fighters, security service, facility manager act as peers. They send their current position (location information) continuously to the observed peer and will react on exceptional events in the household (e.g. temperature, water level, door/window contacts etc.). They provide the service to react in case of an alarm. As service composition, while alarm situation, the platform (home surveillance system, connected to SMF) generates an optimised subscription schedule with respect to the current location information of the observing peers (or triggers pre-configured alarm chains, consisting of own mobile SMF and other peers in the same community). The observing peers have subscribed for the behaviour of all other observing peers, thus they stay informed how the other peers will react. This offers the possibility to implement a decentralised monitoring and alarm system. The communication solution of the SMF (sending IMs, establish audio/video calls) can also be used to inform the closed user group (e.g. neighbourhood) about irregular activities during absence of house owners.

VI. Conclusion

This publication presents a novel solution for service provisioning and service usage in different application fields. The presented platform forms the main part of the solution in provision and use of M2M services by connecting service providers and service users, using an overall solution for information exchange. The concept of a P2P-connected Energy-Community became more generalised and the advantages of the solution are no more limited to the energy sector, but can also be applied in various sectors of M2M. The P2P networked community concept offers advantages in all application fields where decentralised challenges exist and central solutions for service provisioning or optimisation are not realisable. The novel concept provides a great possibility to form Smart Villages and the community-based approach is a new comfortable way to join a network of numerous participants, whereby the connection of peers is done by joining the users to a social network. Existing infrastructure can be used to provide different kind of services in different application field with same and cost efficient hardware (e.g. mobile Smartphone). The joint optimisation is based on information exchange between the peers which creates maximal benefit for all participants.

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