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Asset Monitoring in the Service Oriented Internet of Things empowered SmartGrid

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Abstract The smartgrid envisions several sophisticated services, which heavily depend on almost real time monitoring of the assets and the functionality they provide. High performance smart metering is the flagship of ongoing projects worldwide. In order to succeed, a service oriented approach must be adopted, tools for simulation and pre-deployment evaluation will need to be created and finally adaptive systems targeting self-X behaviour (e.g. self-management, self-optimization, self-monitoring, self-healing, and self-protection) may raise the level of sophistication once the infrastructure is operational. In all of the above the constraints set by enterprise services need to be respected and collaboratively tune infrastructure's layers via active monitoring and control in order to enable the best overall system performance. We discuss on considerations and propose directions that could be followed.

Keywords smart metering · web services · networked embedded systems · enterprise services · performance assessment

1 The SmartGrid emergence

The early stages of large scale electrical distribution at the end of 19^{th} century, found several cities being powered with DC from a number of distributed power generators, which due to the nature of DC were located near the loads (economically feasible distance to the furthest client was a few kilometres). With the emergence of Teslas AC, electricity generation could be done in remote locations and be transferred more efficiently over long distances. This led to the grids of today where power transmission networks provide redundant paths eventually routing electricity from any power plant to any load

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centre driven by market criteria e.g. the economics of the transmission path, the cost of power etc. Today the vision of smartgrids [2, 19] moves again towards a distributed infrastructure (like in the DC era); however the things are fundamentally different since modern Information and Communication Technologies (ICT) empower the new concepts and enable us to achieve even better efficiency while providing a new generation of services to all involved parties.

The smartgrid is a system of systems i.e. a complex ecosystem of heterogeneous cooperating entities that interact in order to provide the envisioned functionality. Advanced business services are envisaged that will take advantage of the near real-time information flows among all participants. These real-world energy services will go way beyond the existing ones and enable us not only to become more energy aware, but also to optimally manage it. Such an infrastructure is expected to be pervasive, ubiquitous and service-oriented.

The smartgrid era envisions energy monitoring and control at large scale; which has profound implications for its engaging actors. The smartgrid vision aims at evolving the grid towards advanced configurability, reactiveness, and self-X features i.e. self-management, self-optimization, self-monitoring, self-healing, and self-protection. It is expected to be the key part in a global ecosystem of interacting entities, whose cooperation will give birth to innovative cross-domain services [7]. One of the key driving forces behind these efforts is energy efficiency and better management of the available resources. In order to achieve this, better visibility via fine-grained monitoring of energy consumption and/or production is essential. Additionally the enforcement of decisions taken based on the monitoring will need to be enforced on the infrastructure hence control must also be available via open ways. Since smartgrids will heavily depend on IT, it would be beneficial to consider the lessons learned from the Internet, especially when it comes to complex large scale system-of-systems infrastructure.

2 The Internet of Things promise

The smartgrid will be mainly driven by an amalgamation of the Internet of Services and Internet of Things [4]. Networked Embedded Devices (Internet of Things) will be integrated ubiquitously in the fabric of the smartgrid (ranging from smart meters, to smart appliances, electric cars, energy management systems etc.) and provide in an open way detailed information about the physical world they monitor or actuate. In the mid and long term any kind of device with processing and communication capabilities may be able to measure the energy it consumes or produces and provide that information via open interfaces to the world (as depicted in right side of figure 1); effectively acting as a smart meter. Most of the Internet of Things devices will be mobile, acting alone or in communities representing their users [5], and will offer new capabilities for monitoring and controlling the energy infrastructure.

Connectivity is a key issue. According to Håkan Djuphammar, VP of systems architecture at Ericsson, "[In 10 years' time], everything has connectivity.

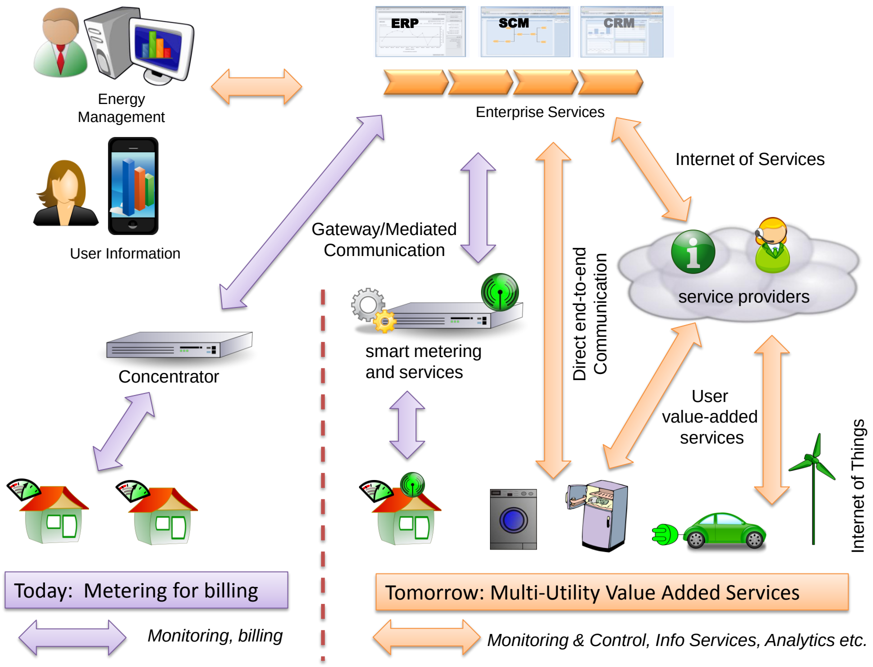

Fig. 1 Envisioned Multi-Utility Service Driven smartgrid

We're talking about 50 billion connections, all devices will have connectivity..." [12]. This was reinforced by the Ericsson President and CEO Hans Vestberg who mentioned that 50 billion devices will be connected to the web by 2020. Intel's John Woodget, global director, telecom sector has a more moderate prediction, in the range of 20 billion connected devices by 2020 [12]. The world market for technologies, products, and applications alone that are related to the "Internet of Things" will increase significantly from 1.35 € billion to more than 7.76 € billion in 2012, with average annual growths rates of almost 50% [18].

Getting down to the smartgrid specific statements, Marie Hattar, vice president of marketing in Cisco's network systems solutions group, estimated in 2009 that the smart-grid network will be "100 or 1000 times larger than the Internet" [11]. Similarly Vishal Sikka, CTO of SAP, stated in 2009 that "The next billion SAP users will be smart meters" [13]. Only for installing smart meters in homes an estimated $4.8 billion will be spent according to ABI Research [1]. According to Pike Research the market for energy management systems (including wireless sensor networks, lighting controls, heating and cooling management in buildings) will turn into a $6.8 billion a year market by 2020 and will generate investment of $67.6 billion between 2010 and 2020 [15]. They also note that a total of $4.3 billion will be spent on the installation, maintenance, and management services for smart grids by 2015 [17]. Being able to process and do analytics on the huge amount of collected data is also a multi-billion industry. Smart-grid data analytics services will generate $4.2 billion in annual revenue by 2015, according to a report released in by Pike Research [16].

Now coupling all predictions about the Internet of Things and the smart-grid with the fine grained information that can be provided in a very timely manner, one can understand the large scale and amount of information that can be acquired in very short time. This information is today usually not available at all or in the best case only acquired by local systems (e.g. a building energy management system), but over dedicated channels and proprietary interfaces that hinder further dissemination of it from 3^{rd} parties. However the adoption of standardized information models and networking capabilities, make this information now available to any kind of device that roams nearby (e.g. a smart phone, tablet) and its propagation over gateways e.g. to the Google power meter project (`www.google.com/powermeter`) enable large scale monitoring (e.g. consumption patterns). It is however fundamental that this happens via open standardised services where different stakeholders can be independently involved (no vendor lock-in, no dedicated devices or proprietary solutions) e.g. by providing the hardware, the metering and data processing software or value-added services on top of it.

3 SOA-ready assets and monitoring as key driving forces

The Internet of Things due to its huge size, will inevitably be dominated by heterogeneous in hardware and software devices. For Enterprise application developers, this will be an integration nightmare when trying to create applications and services that rely on data coming from them. Thus, open interoperable [14] approaches are needed in order to be able to discover the devices, interact with them in a standardized way and process the data exchanged. A key service that the majority of such real world applications will rely on, is almost real-time monitoring, that will enable consumption of data coming from the real world and that can be fed to the respective business processes. To take this one step further, most of the devices might expose a management interface that controls real-world processes, which will close the loop monitor-assessment-control.

The major monitoring use-case in the smartgrid domain is that of smart metering. Today several approaches target high density metering i.e. with 15 minute resolution, and with a trend to increase the resolution further. By being able to have detailed information on energy consumption or production, one can better manage the energy within a network. Additionally significant use cases such as demand-response (DR) and demand-side-management (DSM) can be better addressed, which results into high monetary returns for the utilities. However the monitoring goes beyond smart metering as now other use-cases can be supported (depicted in figure 1) such as preventive asset maintenance, infrastructure analytics, better user energy signature assessment etc.

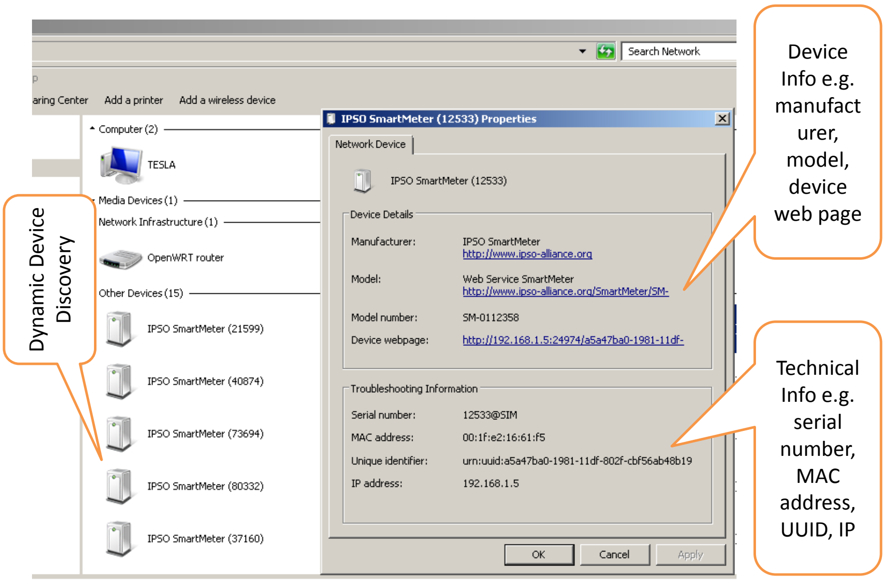

Fig. 2 Information provided by a web service enabled device

To be able to do large scale discovery and monitoring in an IP-dominated [10] infrastructure, and easily integrate devices at functional level with business processes, several challenges need to be tackled [3]. Thankfully existing approaches such as REST and web services on devices (DPWS) assist towards partially realizing the goals. For instance DPWS supports Web Services Dynamic Discovery (WS-Discovery) that defines a multicast discovery protocol to locate services on the local network. The communication is based on WS and more specifically on SOAP/XML and UDP multicast. Existing systems already implement WS-Discovery and many prototypes already demonstrate that web services can be implemented at industrial devices, wireless sensors and that benefits arise from doing so [8].

As an example on how information can be provided, we have experimented with DPWS for realizing smart meter behavior. In Fig. 2 we can see an example of a web service enabled device i.e. a DPWS-enabled smart meter. The device depicts its functionalities as a collection of web services. As we can see widespread existing operating systems such as Windows can dynamically discover it and depict the information provided. Furthermore specific info such as manufacturer, model, the on-device web page, serial number, IP address etc. can be acquired and displayed. Being able to acquire, process and interact in a service driven way is crucial, especially if we consider the billions of heterogeneous devices that will be active in the future smart grid.

4 Smart Metering Infrastructure Considerations

4.1 Goals

For the smart metering to be able to realize the vision of the smartgrid, we need to be able to:

- *Goal 1*: design, simulate, test and assess the infrastructure prior to deployment
- *Goal 2*: be able to monitor in real-time a running system and detect deviations from expected behaviour
- *Goal 3*: be able to manage and adjust in real-time a running infrastructure

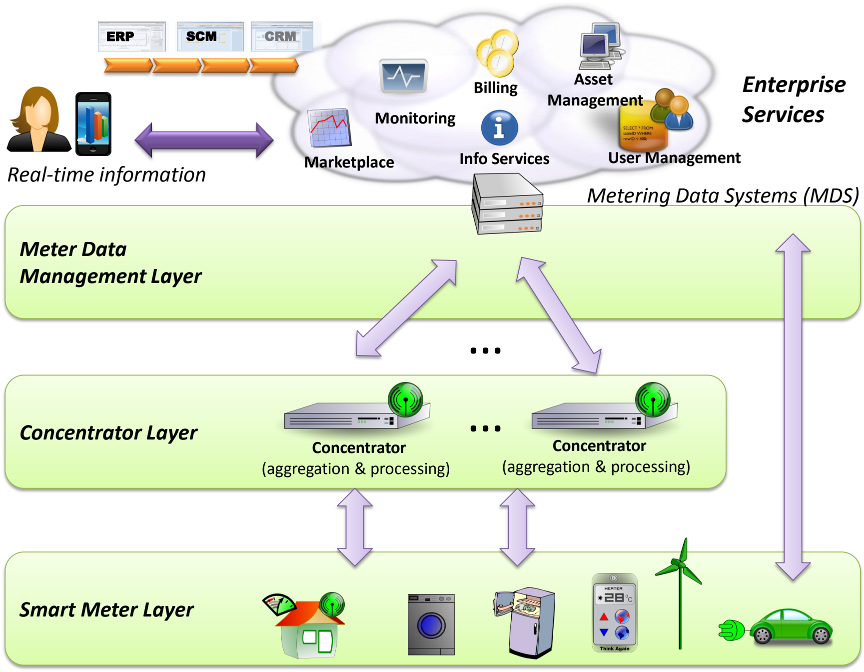

Fig. 3 Smart Metering Infrastructure Overview.

A typical set-up for a smart metering infrastructure is a three-layered hierarchical architecture, similar to what is depicted in Fig. 3. However please note that a meter may report its readings either to a concentrator (common case today) or even directly to the metering data system. Bottom-up we can clearly distinguish:

- *Meter Layer*: the last mile, where the (residential) meters are passively tapping in and measuring the energy consumption or production of the attached devices. In the future this can refer to the energy consuming/producing device directly.

- *Concentrator Layer*: the meters connect to this layer via various (often proprietary) protocols to report their measurements. The reported data is aggregated and submitted to the metering data system (MDS). In a future interoperable infrastructure this may be an information acquisition and processing point e.g. for performance reasons.
- *Metering Data Management Layer*: here usage data and events with respect to the infrastructure are collected for long-term data storage, analysis and management. This is typically used by enterprise services in order to empower applications such as billing, forecasting, etc.

4.2 Assessment Considerations

Goal 1 (as depicted in section 4.1) would imply possibly an offline simulator that is able to consider the specific key performance indicators required by the smart metering infrastructure owner. Here different near real world conditions and configurations can be tried-out and assessed prior to any actual real world deployment. Business Process modelling tools may integrate functionality exposed by the simulator and use it to test their behaviour. To our knowledge today we do not have any simulator addressing the majority of the issues needed by smartgrids, despite of the fact that heavy investments are made in the domain.

Goal 2 (as depicted in section 4.1) would indicate the need to actively monitor in real-time a wide variety of aspects and possibly raise events in case of malfunction or failure to satisfy specific performance indicators. A large scale distributed monitoring framework is needed that can integrate in a timely fashion monitoring of all assets. In-network processing depending on the business requirements is a must, especially when considering the vast information to be generated. Distributed processing (e.g. aggregation, filtering, computation) of data on-device, in-network and the enterprise systems in a collaborative form may enable us to extract optimally the information needed without propagating it from the device layer directly to the business systems; a usual practice today which is not feasible in a full-blown Internet of Things infrastructure.

Goal 3 (as depicted in section 4.1) assumes that once we are able to detect deviations, and we are able to provide a solution, it should be possible to interfere and adjust the infrastructure (e.g. relocate services, remote maintenance, etc.). By applying intelligent monitoring, detection of potential problem areas and automated adjustment/management, we move towards a highly flexible and evolvable infrastructure that could possess the characteristics of self-X systems (e.g. self-management, self-optimization, self-monitoring, self-healing, and self-protection). Integrated monitoring and control is a must for complex system of systems such as the smartgrid.

In order to realize high performance monitoring over the infrastructure depicted in Fig. 3, we need to be ale to ensure that no bottlenecks arise at all layers, and that (mobile) meters reporting their energy readings are able to connect and deliver their data in an optimized way (system-wide view). Considering the layers involved in a smart metering infrastructure of Fig. 3, we need to:

- assess the performance of single concentrator (for each configuration)
- assess the performance of single MDS (for each configuration)
- assess the composite performance of concentrators and MDSs (for the best composite case identification, which might deviate from the best case in standalone tests)
- assess the horizontal scaling (scale out) at all layers and composite impact
- assess the vertical scaling (scale up) at all layers and composite impact

What is pursued is the satisfaction of the minimum level of requirements set for the infrastructure, by trying to investigate a series of key performance indicators (KPI) in the directions mentioned. Any composition of the above managing to satisfy the requirements is acceptable, depending on the significance of each constraint. Typical key performance indicators considered for each "configuration" might be communication, computation, load limits and balancing, network paths, congestion, application logic, etc.

For instance typical considerations with respect to smart metering deployments include:

- impact of security: channel vs. message encryption, firewall inspections etc.
- level of meter reading aggregation
- preprocessing of meter readings at meter, concentrator or network-wide level
- impact of channel communication quality e.g. latency, packet loss, throughput, retransmission
- metering data system performance (application processing, data validation, DB performance etc.)
- load management/balancing
- cost (including lifecycle management of software and hardware)
- risk analysis, resiliency and alternative critical paths
- business process constraints integration
- business process design-phase integration of asset management

As an initial step taking into account the issues raised here, we have implemented and assessed a web service enabled smart metering infrastructure [9]. We have demonstrated an approach that can be used in order to create a rule of thumb when one is designing an smart metering infrastructure with key performance indicator the high meter reading acquisition and storage. In a methodological way we have identified and discussed potential problem areas as well as the line of thought that should be followed in order to find possible inter-dependencies and roadblocks. By investigating each component's limits (as discussed here) we were able to narrow down the operational ranges that could be used to achieve high performance.

4.3 Operational Management

We have argued that integrated monitoring and control should be considered for realizing the core part of smartgrid service functionality. Being able to have high visibility on assets, their status, guarantees of data delivery, potential prediction of pain areas etc. is of key importance to modern utility industry. The monitoring should be done in a cross-layer fashion as depicted in Fig. 4. The enterprise system should be able to configure, depending on a series of key performance indicators, what should be monitored, the quality of expected information as feedback etc. all in a dynamic way, possibly customized per business process.

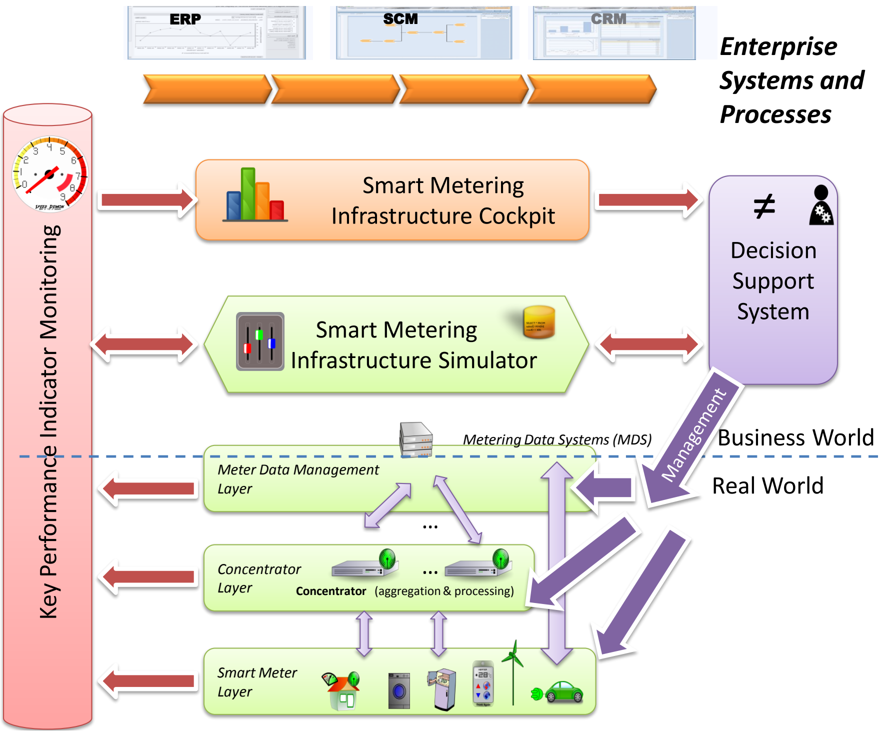

Fig. 4 Smart metering infrastructure monitoring, visualization, simulation, and management

The manager of the infrastructure will be presented with real-time information as well as the assets a management cockpit. This may be a mash-up application customized for each business user depending on his area of interest. For instance an energy provider may want to monitor energy consumption on the network and get an alarm when it exceeds a limit or a device has not reported any meter readings for a specific amount of time. By having direct access to the sources of information (e.g. devices), one can "zoom-in" to the interesting points of action and interact with them (since their functionality is offered as a monitoring & control service). This gives not only to the operators but also to the management fine-grained visibility and new capabilities towards understanding and interacting with the smartgrid.

We have argued that a smart metering simulator could be used in pre-deployment cases (Goal 1 in section 4.1) in order to assess cost, performance and behaviour at that stage. However once build, this could also be used during operational state. We could continue to run simulations, predicting the behaviour of the real infrastructure in advance, subsequently measure it (via the monitoring service) and note any significant deviations between the simulation model and the real world (Goal 2 in section 4.1). Such deviations may for instance imply unforeseen conditions, simulation model inadequacy or misbehaviour at infrastructure level. Typical example might be identifying electricity loss/theft or rogue devices.

Additionally by also coupling the simulator to the monitoring service, we might be able to integrate the current status of the testbed and run "what-if" scenarios. The last are extremely useful if for instance new functionality is to be introduced in the network e.g. experiment with scalability strategies for better overall performance etc. This will be challenging especially as the complexity of the smartgrid increases, which is another reason that simulators must be developed for the various levels that can all interact with each-other (e.g. via interoperable models and communication).

A Decision Support System (DSS) which might detect the deviations between simulation and real-world, may instruct for adjustment in the infrastructure. If the assets support open standardized interfaces e.g. accessible via web services, management re-configurations could be made. By supporting a closed loop of monitoring and control/management, one can foresee the introduction of possible self-X approaches mainly self-healing and self-optimizing, both of which are parts of the smartgrid envisioned infrastructure.

5 Conclusion

Although the smartgrids and the domains that empower it such as the Internet of Things are rapidly emerging towards mainstream, and despite of the fact that hundreds of deployments with significant investments are done worldwide, we still do not have sophisticated integrated tools that would assist us in pre-deployment and during operation of the smart metering infrastructure. Market predictions, even taken with a grain of salt, show that Internet of Things and the services associated with them pose a huge opportunity for innovation especially in the energy domain. We have presented here a vision on what would be needed, mostly from the view of the enterprise and the cross-layer interaction with the smartgrid. We hope that the ideas might spark research interest to deepen the investigation of issues raised and in the mid-term provide implementation of tools that will assist us to assess and possibly even have a self-managed smartgrid. For sure due to the cyber-physical nature of the smartgrid there are several challenges [6] to be tackled both on the energy and the information and communication technologies domain.

Using the operational flexibility of direct communication and real-time interactions (including analytics) coupled with the pre-deployment considerations one can harness the basic benefits of the smart grid. Real-time monitoring, real-time analytics and optimisation on the enterprise side, and real-time control (management) can empower approaches e.g. demand response (DM) and demand side management (DSM). Decisions now can be taken based on very fine-grained data, in very timely fashion and can also be applied in an automatic way. Although this looks promising, it has to be supported by effective tackling of security, privacy and resilience.

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