A Self-Organising Approach for Smart Meter Communication Systems

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Abstract. Future energy grids will need to cope with a multitude of new, dynamic situations. Having sufficient information about energy usage patterns is of paramount importance for the grid to react to changing situations and to make the grid 'smart'. We present preliminary results from an investigation on whether autonomic adaptation of intervals with which individual smart meters report their meter readings can be more effective than commonly used static configurations. A small reporting interval provides close to real-time knowledge about load changes and thus gives the opportunity to balance the energy demand amongst consumers rather than 'burning' surplus capacities. On the other hand, a small interval results in a waste of processing power and bandwidth in case of customers that have rather static energy usage behaviour. Hence, an ideal interval cannot be predicted *a priori*, but needs to be adapted dynamically. We provide an analytical investigation of the effects of autonomic management of smart meter reading intervals, and we make some recommendations on how this scheme can be implemented.

1 Introduction

Emerging alternative forms of energy are increasingly allowing consumers to produce electricity and to feed surplus capacities back into the power grid. This will turn them from consumers into producers. Additionally, power grids will become more important for mobility as electric cars will be connected to the grid for charging their batteries. These aspects will turn traditional customers into prosumers. If, for instance, a customer, produces surplus energy via solar panels during the day, (s)he would be in the producer role. When however charging her or his car over night, (s)he would become a (heavy) consumer. Such emerging scenarios will contribute to a highly dynamic overall power grid usage which requires the traditional power grid to become smarter by adding more control – the *Smart Grid*. A smart grid utility provider needs to be able to detect over-usage or under-provision in (real-)time to manage demand by, for instance, scheduling the charging time of consumers' e-cars. This would avoid 'burning off'[3] surplus capacities and hence increase sustainability of energy usage.

Motivation. Fine-grained information about energy consumption patterns is of paramount importance for grid providers to react to a changing environment and to maintain high sustainability by, for instance, managing demands flexibly. Today's smart meters send consumption values to the grid provider at constant intervals [5, 7]. A small interval is beneficial for energy sustainability and a power grid's efficiency, as it allows fine-grained demand management [1]. This can also be directly beneficial for the customer if the provider's ability to control charging periods of her/his heavy usage appliances (e.g. an electric car battery charger), is incentivised by reduced energy prices for the consumer. However, if consumers without heavy usage appliances (i.e. those who do not exhibit a high degree of variability in energy consumption), frequently report their energy usage, they reduce the benefit of small intervals as unnecessarily gathered monitoring data increases the overall operational load on the grid's ICT infrastructure. Uniformly applied intervals may not be sufficient as energy usage patterns and energy requirements vary from household to household, and over time.

Secondary Effects: Sustainability vs. Privacy Trade-off. Furthermore, a small interval threatens individual customer's privacy – especially if it allows the derivation of behaviour patterns [5] from energy consumption readings. Thus, depending on the situation, a small interval may require privacy to be traded off against sustainable energy usage. We are able to provide some information to prepare further investigations even though this concern is outside the scope of this paper.

Research Contributions. As outlined above, different situations can be identified in which various grid aspects depend on the flexible usage patterns determined by the user base. We pick the reporting interval as first representative example to investigate how to apply more self-* properties to the smart-grid. For the considered case we identify situations where small reporting intervals are beneficial with respect to sustainability whereas large intervals can be disadvantageous. The contrary view applies with respect to efficiency in processing the reported data. Thus an ideal interval cannot be predicted *a priori* as it depends on the variability of an individual's energy usage over time. Autonomic management [2] is a (policy-driven) approach to adapt the metering report interval for *individual smart meters* in response to different usage patterns and requirements, in order to improve the grid's *overall efficiency*, in contrast to contemporary statically configured systems. Eventually, this will turn the smart grid into a self-organising system. As a direct effect, complexity is moved from a central point of computation (at the utility provider) to the individual smart meters, which increases efficiency in data processing and makes the system as a whole more scalable, more resilient and has a positive impact on the above mentioned secondary effects.

[3]Where the term 'burning off' energy in this case refers to the losses due to reduced degree of efficiency when employing battery buffers or pumped storage hydro power stations. See: Energy storage - Packing some power. The Economist. 2011-03-03

Structure of this paper. We provide some information on background and related work in Section 2, followed by an analysis of the problem and our approach towards autonomic management in Section 3. We report on a preliminary evaluation of our approach in Section 4, and provide some concluding remarks and outlook on future work in Section 5.

2 Background and Related Work

Smart Grids in general represent a popular research topic; however, neither our primary focus, which is to improve efficiency by autonomic interval adaptation nor our secondary topic of interest, which is the (autonomic) management of the trade-off between sustainability and privacy via reporting interval adaptation, is well investigated. For instance, current state of the art regarding meter reading reporting involves a static configuration and only mentions different statically configured intervals [5], but no autonomic adaptation of those is being discussed. [5] mentions that *Canada supports meter readings at 5 to 60 minute intervals* and that *the next generation of smart meters will reduce these time intervals to one minute or less.* [7]. Other existing work [9] has been conducted to apply autonomic management to multiple domains. This also includes the adaptation of house keeping intervals in order to improve routing overlays efficiency. Despite being in a different field it shares some similarities to the approach we propose.

With respect to secondary effects of our approach, threats to and vulnerabilities of smart metering systems are widely discussed topics [4, 3, 10]. While communication security [3] is widely studied, the aspects of privacy and potential threats [5] to customers through smart meter data exploitation are not fully covered up till now [8]. An important first step towards a privacy-enabled smart grid has been made by NIST [6], when defining problems related to privacy protection and legal constraints.

3 Problem Analysis and Approach

3.1 Scenario

Based on the demand management use case introduced in Section 1, we model the ideal frequency with which meter readings are being reported in terms of the dependency of the fluctuation of power usage over time, (i.e. in energy usage). If the power consumption and its fluctuation over time are high it is beneficial for the provider if meter readings are sent at small intervals. This is, however, only applicable if power usage of the individual customer exhibits some degree of fluctuation and intensity. Autonomic management is an approach to control systems in the presence of changing situations and requirements.

3.2 Approach

Autonomic management approaches in general are based on the autonomic management cycle. This comprises a monitoring, analysis, planning and execution phase. During a monitoring phase relevant events are captured, of which metrics are derived in an analysis phase. Based on these metrics a policy determines how the system is modified in a planning and an execution phase.

At a high level: Our autonomic management mechanism is intended to operate on each smart meter in a grid individually, requiring local data only in order to achieve an overall benefit. It is designed to detect cases when reporting effort is being wasted, and to increase the current reporting interval accordingly. Conversely, it decreases the interval in situations when a higher reporting rate is appropriate. A high variability within reported (aggregated) values suggests a decrease of the interval which other wise could be increased, to reduce unnecessary reporting activities. The magnitude of change for each of these interval adaptations (increase/decrease) is determined by our autonomic manager's policy. During each planning phase, the policy considers metric values derived from events received during the current autonomic cycle. These events are based solely on locally gathered data, thus no additional network traffic is generated by the autonomic manager.

In detail this means that: In the monitoring phase energy consumption is measured in (close to) real-time, and such an individual measurement is referred to as *Raw Energy Measurement (REM)*. A number of such REM values will be measured, maintained and aggregated. We refer to the aggregate values as *Aggregated Raw Measurements (ARM)*; the latter values are sent in smart meter reports. The metric we consider as an appropriate measure for variability is the standard deviation of ARM values (σ_{ARM}). Based on σ_{ARM} the policy determines the proportion P by which the current interval should be decreased. In our preliminary investigation here we define a threshold t after which we consider the variability (i.e. σ_{ARM}) as high enough for decreasing the reporting interval. The new interval is then calculated as:

$$new\ interval = current\ interval \times (1 - P) \tag{1}$$

The proportion of change P lies between zero and one, and is calculated as:

$$P = 1 - \frac{1}{\frac{metric - ideal}{k} + 1} \tag{2}$$

where *metric* denotes σ_{ARM} and *ideal* is zero in our case. k is a positive constant that controls the rate of change of P with respect to the difference between the metric value and its ideal value. The higher the value of k, the lower the resulting proportion of change, and hence the slower the resulting response by the manager. k can be used to consider consumers' reporting preferences in the smart meter configuration. Further, we define that, if σ_{ARM} is smaller than the variability threshold we increment the current value by 10 (arbitrarily chosen). We constrain ourselves here to values between 1 seconds (the lowest possible reporting interval) and 1 hour (the maximum interval [7] – see Section 2).

4 Evaluation and Results

We have evaluated our autonomic management approach based on usage patterns derived from [6]. These show the energy consumption of a number of appliances over a normal day. We reproduce this as shown in Figure 1, which also represents measurements at the smallest possible interval (i.e. 1 sec.). The exhibited usage pattern represents an *average user* into which we factor in an e-car battery[4] to represent a regular use case with phases of *heavy usage* (afternoon/evening) and *light usage* (nights). Figure 1 shows the energy usage over the elapsed time during a day when a static energy reading interval (1 sec) is defined and also shows how the reporting interval is autonomically adapted, based on our approach (as outlined in Section 3). We choose a number of values for the policy parameters t (threshold) and k (adaptation rate control), the parameter values are given in the individual plots. We also configure our policy

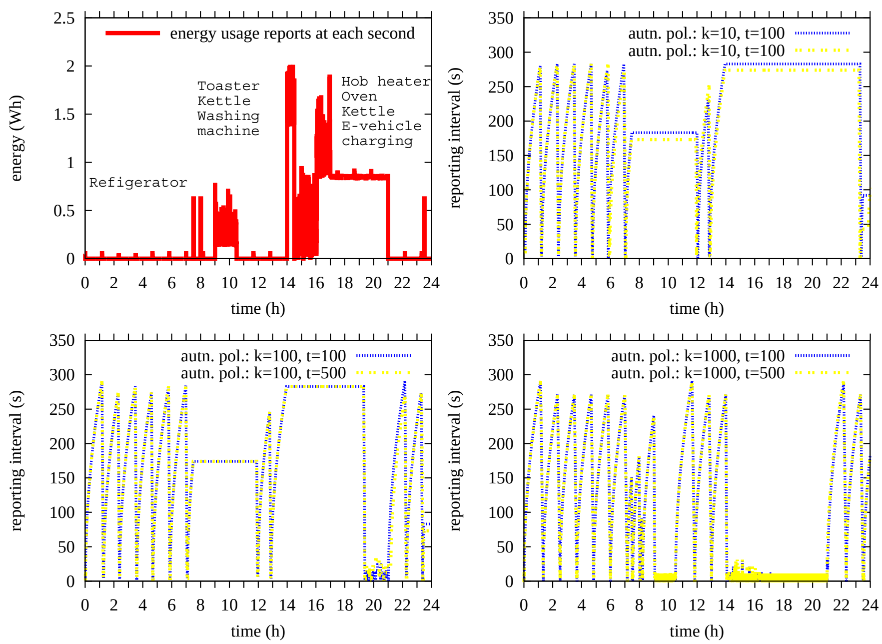

Fig. 1. Raw energy usage over time, at the left top and autonomically adapted intervals.

to only consider a sample size of the latest 30 ARM values to compute σ_{ARM}. The number of values determines how much outliers may be compensated for and the semi-arbitrarily chosen number (based on test runs of our harness) was considered sufficient for this initial demonstration. We leave an investigation on ideal sample sizes for future work as this would be beyond the scope of this work.

The presented results show that our simplistic autonomic manager detects phases of little variability and increases the reporting interval accordingly until

[4] http://www.pluginrecharge.com/p/calculator-how-long-to-charge-ev.html

a peak – this suggests potential for improvement with respect to how aggressively the manager deals with variability and high intervals. We also see that the configuration with high k values (1000) reacted most desirable by keeping the interval low when fluctuations occurred. Only little difference can be observed between the effects due to t. However, an holistic analysis (e.g. gradient decent) for all above mentioned policy parameters is required as next step in future work.

5 Conclusion

As outlined in this paper, the smart-grid will have to be increasingly flexible to cope with varying usage patters and hence the identification of aspects which can be managed in an autonomic manner is an important step to improve the smart-grid further. In a first step to add some self-* properties to the smart grid we have proposed an adaptation of an individual entity of the grid to achieve some overall benefit. We have shown that autonomic adaptation of the reporting interval in individual smart meters will result in significantly fewer reports in phases with very little variability of energy consumption behaviour between the reports that are send to a central control unit. As this represents only an initial investigation, we have limited ourselves to show a rather simplistic policy. A multitude of adaptations of our policy is possible, e.g. reducing the historical data analysed for deriving metrics, or evaluating of different parameters (e.g. k see Equation 2) to consider consumer preferences, and also considering energy generation at the consumer/prosumer side in our policy design. We also plan to implement and experimentally evaluate our approach using available tools, as e.g. [9]. Future work also includes an analysis of other self-* aspects, e.g., the trade-off between privacy vs. sustainability due to interval adaptation (see Section 1). This seems promising as we already see that adapted reporting intervals may make it harder to derive usage patterns and hence to compromise privacy.

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