# Heating Schedule Management Approach through Decentralized Knowledge Diffusion in the Context of Social Internet of Things


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## ABSTRACT

In the forefront of efforts to curb energy consumption and as a consequence decrease greenhouse emissions, cities as well as individuals, turn to the field of Smart Homes to optimize their heating schedules through IoT-enabled solutions. However in many cases efforts are focusing on algorithms and systems requiring large amounts of processing power and constant data availability to be effective. In this paper, an approach tailored to the constrained resources in the IoT domain is introduced that is based on the Social IoT paradigm, instead of centralized computational nodes. The framework enables Smart Home Gateways to seek solutions to their heating schedule needs through communication of actual observations with fellow homes rather than brute force calculations based on probabilistic models that may require centralized approaches. Using the provided IoT components of the COSMOS ecosystem, Smart Homes may run purpose-built applications that use stored Knowledge, communicate it throughout the Network of Things and act on it in ways which aid the end users in retrieving relevant solutions. Raspberry-based simulations indicate that this diffusion of Knowledge as well as the improvements and evaluations through feedback performed on it, allow for the creation of a lightweight and resource effective approach, on the problem of Heating Management.



## Categories and Subject Descriptors

C.2.4 [**Computer – Communication Networks**]: Distributed Systems – *Distributed Applications;* C.4 [**Performance of Systems**]: *Performance attributes;* I.2.6 [**Artificial Intelligence**]: Learning – *Knowledge acquisition;* I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence – *Intelligent Agents.*





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## General Terms

Algorithms, Measurement, Performance, Design.

## Keywords

Internet of Things, Knowledge Diffusion, Social Internet of Things.


## 1. INTRODUCTION

In the current spread of effort between minimizing energy demands in households and decreasing greenhouse emissions to an environmentally sound level, cities are seeking to invest in opportunities of End User engagement through smart meters and sustainable energy programs [1]. Countries facing a dwindling supply of fossil fuel derived energy, have an interest in monitoring and if possible shift public energy consumption habits in more efficient directions. Especially in the UK, effort is underway to proceed with the installation of smart meters on every household by 2020 [2].

While the efficiency of this approach, given wide enough adoption, is deemed cost effective, consumers have yet to see tangible benefits mainly because of the slow pace of implementation [3].

In this paper, an alternate novel approach to heating management is proposed that makes use of the effect social norms have on heating schedules, considering, as stated in [4], that Users tend to direct their behavior towards specific patterns. The implementation is based on a pluggable decentralized Smart Homes application, provided that there is an existing platform recording data such as temperature and consumption. End Users of the application will be able to receive a heating schedule based on their personalized heating needs and their available budget. This is achieved by using existing heating and consumption patterns stored from previous time periods, both in individual and remote households, in the context of the COSMOS [7] platform, that also offers anonymization and privacy features. . By allowing homes to share and diffuse their patterns, engaging in what is described as Decentralized Knowledge Discovery, we take advantage of socializing between the Smart Home entities, in an IoT ecosystem and can provide schedules that are relevant to End User satisfaction but also efficient on how they act on the overall energy consumption and therefore carbon emissions. Communication is handled in an anonymized and privacy sensitive manner, using the concept of Virtual IP addresses and tunneling.

Additional considerations include the fact that End Users, display a certain short sightedness when efficiency investments are concerned, giving greater weight to immediate costs than future gains which could in long term offset those costs [4, 5]. This includes the willingness to participate in programs which demand a very low, or even nonexistent monetary commitment. In that light, it is also important to offer a solution which requires minimal extra costs of installation and maintenance, thereby precluding the use of computationally powerful Gateways as described as a requirement in [6]. This can be achieved by limiting the need for complex calculations, on the side of the Gateway and merely containing its computational needs into locating and retrieving relative Knowledge, which it has stored beforehand, in a structured manner, either locally or remotely in other Smart Homes.

The remainder of this paper is organized as follows. In Section 2 the specific steps the approach entails and the differences between existing approaches of heating management are described. In Section 3 lies the description of the Application and its demands in Platform centric and home specific Services. In Section 4 the outline of the implementation specific details and experiments are presented. In Section 5 the paper concludes.

## 2. SCENARIO DESCRIPTION; DIFFERENCES WITH ALTERNATE APPROACHES

The main objectives of the COSMOS platform and ecosystem is the implementation of a Smart Network of Things capable of acting independently of centralized orchestration methods by dynamically cultivating connections and exchanging Knowledge in the form of Experience [7]. Following the IoT-A reference model [8], the Smart Home Use Case entails the use of IoT enabled flats, which can be abstractly represented by the concept of the Virtual Entity. These Virtual Entities are able to acquire and expose IoT-Services that are divided into both readings and actuations. Additionally VE Services are offered which can be a grouping of actions or acquisitions based on the IoT-Services and can be manipulated by the level of applications, into offering complete solutions to End Users.

The proposed scenario takes into account that the End User desires an increased amount of cost efficiency, without having to be manually acting in order to provide feedback or actuation to a heating schedule of their flat, as is the case with Smart Meters that imply the monitoring of their readings by the End User and the need for continuous modification of settings [20]. Such an approach is time consuming and will eventually alienate users even if the data is provided in understandable monetary terms and not in consumption metrics.

For the purposes of the scenario, each flat possesses a management and monitoring tablet which can act as the Gateway to the entire network. The VE code will be located on this tablet, as well as all COSMOS applications the End User may choose to install. The Heating Scheduling application will provide a Graphical User Interface for ease of access with a minimal of complexity and required options. The End User is only to be engaged during the early phase of the scenario actions. The first step is to plan a program, stating the desired temperature value for their flat, for specific time intervals of the planning period. Additionally the End User must input their desired budget. The application will then form the Problem by combining user input with the predicted temperatures during the programming period (provided by the Platform or third party Apps) and will use the VE Services offered by COSMOS implementation of VE functionality, in order to locate a similar Problem as the one described by the End User and return its Solution. The Solution is structured as the actuation to be undertaken and the consumption per time period. This process involves the use of Case Base Reasoning [9] on the internal VE Knowledge Base (Case Base). Given the possibility that the VE itself may not possess suitable Knowledge (Experience), it will initiate its own Experience Sharing mechanism, which targets suitable remote VEs the flat VE has knowledge of. These VEs will, in turn, search their own Case Bases for a suitable Solution and return their answers to the original VE. At this point the application will evaluate the monetary requirements of the returned Solution and actuate the Schedule or modify the input if the End User's budget is overshot.

The approach is different from existing suggestions on Heating Scheduling as it does not require, for example, constant End User monitoring to provide optimization, demand exceeding calculating power or great amounts of extra hardware installation [2], [6], [22]. Additionally use of Social Networking techniques in the context of IoT (SIoT [10]) is made, in order to simulate relations between Social Nodes, which can aid the process of Knowledge diffusion, through Social associations of similarity. Therefore our Experience Sharing mechanism, which is enabled by the Network of Socially active Things, can act efficiently in locating suitable answers, irrelevant of location [11]. The VEs themselves are creating associations in a decentralized manner, in order to avoid centralized approaches with limited scalability.

Additionally, the reasoning approach is based on the Case Based Reasoning Paradigm, in a way which makes use of accumulated VE Knowledge and can be enhanced by implementing the CBR cycle [9] and especially the revising and retaining steps. This approach requires minimal computational resources from the actual Gateways implementing the VE logic, as it is based on queries and retrievals of suitable similar Cases and no extensive Problem-Solution modelling methods.

## 3. APPLICATION DESIGN

The Application makes use of the CBR technique, which includes the actions of **retrieving, reusing, revising and retaining** Cases. The required End User inputs are the desired temperature, the time periods for which the schedule must be in effect (these can be discontinuous) and the desired budget the End User is willing to commit.

The creation of the Problem part of the Case is described as a process which takes part every half hour sub interval and creates a vector with the values of:

- Inside temperature
- Desired temperature inside (provided by the End User)
- Temperature outside (predicted by a weather website)

After the chronological series of Problems creation the Application begins making use of the CBR technique by aiming at the retrieval of similar Cases from the local CB, by using the Planner component capabilities of the VE. Aiding this process is the use of the Experience Sharing component, which is activated on the condition that the local CB has no suitable Cases for Solution retrieval.

A Solution has as properties:

- The URI of the IoT-service for setting the valve.
- The energy consumption that corresponds to the problem.

By executing the URIs at the corresponding time intervals, the heating schedule is executed.

From the sum of the energy consumption of each individual Solution, we can find the total (predicted) energy consumption. This leads the Application to extract the actual cost (budget) of the returned Case based on charge rates of the kWh (retrieved by external websites). The resulting value will be compared to the user's budget and must be strictly less or equal.

The End User may decide to accept the Solution and store the new Cases, which leads the Application into the reuse of the CBR cycle. Regardless, the evaluation of the Solution will follow which can be system based, End User based, or both.

The system facet of the evaluation of the Solution can be achieved by finding the optimal theoretical energy consumption using the Heating Degree Days [21] calculation and comparing it to the Case consumption. The End User may also state his satisfaction through the Application GUI. This is the retain/revise part of the CBR cycle.

The Application can also offer a mechanism for Case aggregation on the half hour intervals, in that a more flexible means of Case retrieval, with more accurate time series similarity of the Cases, may lead to better query times as the volume of existing Knowledge.

Given the assumption of aggregation in a continuous time interval, the Problem part is:

- Initial inside temperature before the aggregated time period
- Set of inside temperatures of the flat
- Set of outside temperatures of the flat

The Solution part thus is modified as:

- Set of URIs representing the setting or not of the valve actuator
- Aggregated time period consumption.

## 3.1 Interaction with the COSMOS Platform

The COSMOS platform itself must provide Services to aid the actual running of the Application. The COSMOS platform will have to provide the COSMOS Cloud storage for the historical data. This connection will be used for the initial population of the CB with Cases. The initial Case Base will be extracted from historical data derived from tracking the energy behavior of the End User.

Over a period of time (e.g. six months) the COSMOS Cloud will accumulate readings for **Tin**, **Tout**, **consumption** and **flow rates** (for fixed intervals). Further on, data retrieval may be performed and extract the relevant information which can be used in Case creation. This process is used strictly for the initial creation of Cases in a VE which possesses none. Later acquisition of Knowledge will be through the mechanism of Experience Sharing.

In order to ensure VE access to remote VEs containing relevant Cases, the platform also offers Social connectivity Services. By making use of the platform based Social Analysis component, a VE can receive a recommended list of Followees, based on similarity parameters and Trust and Reputation mechanisms used.

By offering a social community to the VEs, COSMOS makes sure that, if a good solution is available, it can be found.

## 3.2 Interactions Between VEs

In the case of VE to VE interactions and communications, the Application will be making use of the Experience Sharing component.

The concept of Experience Sharing as touched in Section 2, is a major driving force behind the innovation of the Scheduling creation application. The Internet of Things enabled devices, are expected to be heavily resource constrained for the most part [12], leading to severe limitations on the amount of processing that can be done locally for the implementation of optimal problem solutions to specified problems.

Therefore the preferred approach is the enabling of VEs in creating Knowledge through monitoring their own actuations and data in a way that is described in the application logic. This leads to a decentralized way of accumulating Knowledge through the flow of Experience between VEs on demand. Each VE is responsible for maintaining its own Case Base which contains Cases relative to its running COSMOS applications. These Cases can be user designated as sharable or not, depending on preference, with the Social ranking VE components creating a reward mechanism for VEs that tend to share their Experience more. In effect the VEs are encouraged to share, by connecting their access to others Experience with the evaluation they have received by their Followers as providers of Knowledge [13]. Restrictions of this kind are to take effect during periods of great device load with default VE behavior leaning on the side of free Experience Sharing given appropriate user settings. Privacy and anonymization techniques are also applied in the context of COSMOS that are not described here.

Continuing on this path, a VE will have, in optimal conditions, a group of Followee VEs which it can query at any given time for a Case-Solution (mentioned as Solution) to a given Case-Problem (mentioned as Problem). This in effect multiplies the opportunities a VE has to actually retrieve relative Solutions to its Problems, as Knowledge is stored in a decentralized manner throughout the Network of Things. This decision was taken in order to nullify the need for a dedicated Experience Repository, situated centrally on the platform, which would inevitably create scalability problems with IoT expansion predictions for the expected networking of future IoT-enabled devices. The paradigm of decentralized M2M communication in propagating Knowledge has already been considered as advantageous in [14] concerning vehicle-to-vehicle communication. Experience Sharing thus acts as supplementary to the concept of Case Based Reasoning as it provides a faster diffusion of Knowledge through exchange, creating Experienced and Knowledgeable VEs, while at the same way using the methodologies of CBR in refining acquired Knowledge.

Additionally the implementation of Experience Sharing takes on a recursive approach to Solution retrieval as queried VEs may act as brokers for their own subgroups of Followee VEs. This translates as a transparent mode of Experience Sharing, as the original VE is merely notified of the broker's inability to locate a suitable Case in its own Case Base and that the provided Experience, if any, belongs to an unknown third-party VE, which is not necessarily connected to the original VE. In order to avoid infinite loops of requests inside the Network of Things, each Experience Sharing request is provided with a ttl (time-to-live) variable which decrements on each subsequent recursive call of the Experience Sharing component. The calculation of the maximum ttl value per VE is done by taking into account the number of Followees of the specific VE, the Modelling and Visualization of the Network which is provided by the COSMOS platform and the theory of "six degrees of separation" [15] with the purpose of maximizing the coverage of any given request. Therefore the maximum ttl setting of any VE will be a number between one and six and any incoming requests for Experience will have to be properly monitored for their ttl setting not exceeding the VE maximum used. If so the ttl is appropriately modified to this upper limit and not merely decremented [16].

On a successful completion of the Experience Sharing request, the original VE receives a Solution which is returned as most similar to the requested Problem and will proceed to evaluate it. Evaluation is done on a per application basis and can be a combination of End User or System evaluation. At this point the VE which provided the Experience either as a broker or actual Experience holder, will be ranked by the Social Monitoring component of the original VE in an appropriate fashion [17]. The process flow is described in Figure 1.

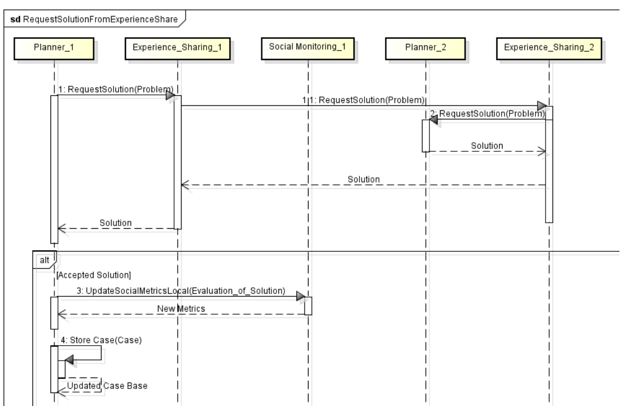


**Figure 1. Social Monitoring in Experience Sharing**

# 4. IMPLEMENTATION DETAILS/SIMULATIONS

## 4.1 Testbed Description

Development of VE specific code has been performed in the context of the COSMOS Project and is based on the Java programming language, in order to ensure that the VE code will be cross platform compatible. Java was also selected since it represents a tradeoff between intermediate computational requirements a gateway should possess and availability of frameworks and technologies for the implementation. As a deployment Testbed, Raspberry Pi 2 was selected since it also represents a tradeoff between reasonable cost and satisfactory gateway capabilities. Running on that is the Raspbian OS which is a Linux version for Raspberry based on the ARM hard-float Debian 7 'Wheezy' architecture port. The latest image of the Raspbian OS comes bundled with Java version 1.8. This part of the Testbed will act as the Hardware Gateway of the Flat on which the Application is running and is being operated on by the End User. Following that we are simulating 2 additional interconnected VEs through two remote Virtual Machines which have been retrofitted with the required code (application and VE code) and have possible Knowledge pertaining to the initial VE's needs.

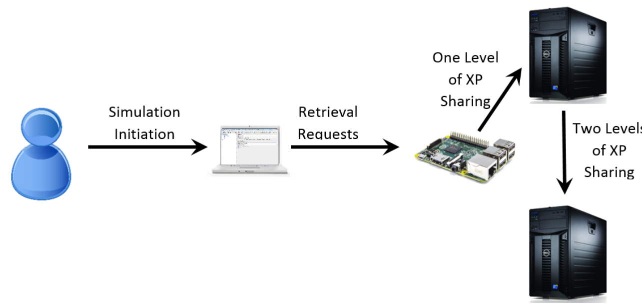


**Figure 2. Testbed Description**

## 4.2 Results

Our simulation approach will focus on the ability of the Testbed at the Raspberry side to provide a consistently stable environment for remote VE components being used by an Application to communicate and Share their Experiences as well as reason on their stored Knowledge, to provide answers to each other's queries. Our tests focused on demonstrating how differentiated workloads of queries may affect VE performance in resource constraint environments. Thus our approach is divided into 4 categories of incoming traffic. The Raspberry running VE Service is contacted and attempts to locate a Solution to the incoming Problem first locally (circular points), if not possible by contacting the first VM (square points) and if needed the second one, through the recursive Experience Sharing mechanism (rhombus points). This description of the simulation workflow directly correlates with the three versions of simulations described in the rest of this Section. This overall delay is considered as the response to the query. The tool used for the simulation is Apache JMeter® [19] that aims to simulate requests from end users and is located in an external workstation, dedicated to the metering process. Our testing plans were divided into four categories, each meant as a representation of possible traffic of the Network of Things. In all categories, differentiations of query values which lead to Experience Sharing were made in order to test the effect Query depth has on the retrieval and answer times.

The first category is the Low Volume category which is characterized by a single Query Thread running infinite loops, with a constant 10 second delay between calls. Results of the three versions of this category of simulation are demonstrated in Figure 3.

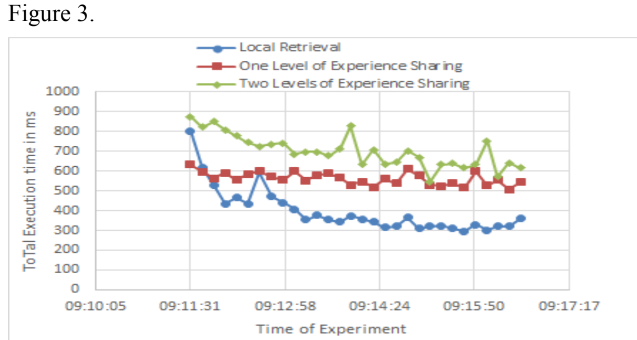


**Figure 3. Low Volume Simulations**

In the Low Volume category results in all three versions demonstrate that the lightweight design of our approach can give times of less than a second since the initiation of the Query until the eventual return of a valid answer.

The second category is the Medium Volume category, which we deem to be the normal volume of communications expected by the COSMOS system. This included the existence of ten Query Threads, starting operation in intervals of two seconds until all operational, with infinite loops for each one and a Poisson timer of query delay of a lambda value of 10000 ms. This leads to an increased load of queries which, due to the nature of Java parallelization in handling incoming HTTP requests, were serviced in less time than the serial arrivals of the Low Volume category. This was true in all three versions of the simulation. Results are demonstrated in Figure 4.

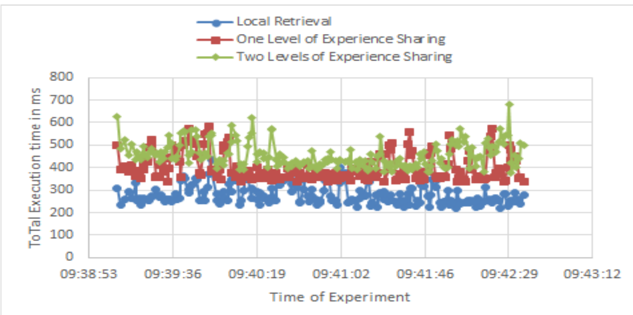


**Figure 4. Medium Volume Simulations**

The third category is the High Volume category which is described by the use of one hundred Query Threads operational in two second intervals, infinite loops and a Poisson timed query delay of 5000 ms lambda. This category initially worked in similar times to the previous two but as more Query Threads came into operation, times increased, especially after fifty concurrently running Threads until stabilizing at averages of 12, 16 and 17 seconds for each version of the simulation. In this category deviation was also increased with results in the third version reaching as high as 28 and as low as 8 seconds. Results are demonstrated in Figure 5.

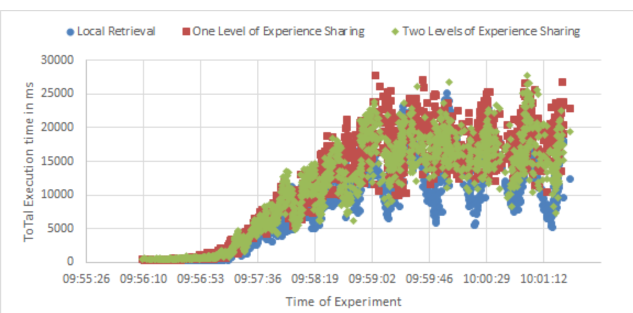


**Figure 5. High Volume Simulations**

Finally we attempted tests in the DoS Volume category, which includes the use of 1000 Query Threads running infinite query loops, starting simultaneously and with no delay between queries. As was expected, times were greatly increased with the VE responding to queries at an average of 200 seconds, but proving that it is robust and reliable enough to sustain such an increased load of operations without denying service. The imaging showcases the denseness by which requests where accepted and serviced. Comparative levels of throughput, between categories as measured by JMeter, indicate that the request service rate was similar to that of the High volume category. Results are demonstrated in Figure 6. Specifically in this category, the query versions implementing Experience sharing where not used because of permission issues pertaining to the use of the VMs under heavy incoming loads. Therefore only the use of the Raspberry running VE and Application code is demonstrated.

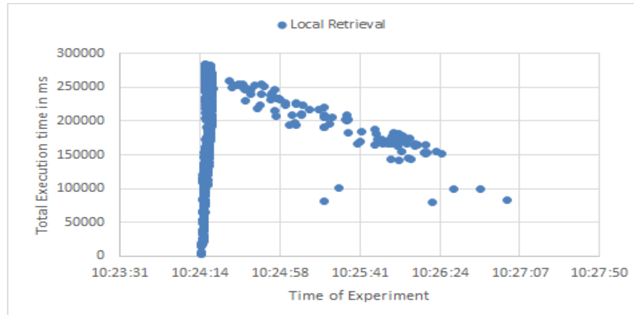


**Figure 6. DoS Volume Simulation**

The issue being presented here is how biased the measurements for XP sharing of one or two levels are, considering the fact that the auxiliary VMs used are not Raspberry Pi 2 themselves. Therefore further simulation is performed in order to clarify the amount of time gained throughout the previous measurements.

The approach taken will be to simulate local search of a Case inside the VM, in order to compare it with the first simulation version of the Low and Medium Volume categories (no XP sharing). Also measured is the actual time the VE spends in searching and retrieving the Case. Results of the simulation are demonstrated in the following table (Table 1):

**Table 1. Raspberry Pi 2 and VM Time Comparisons**

| | RASP2 | VM |
|---|---|---|
| **Request Low(in ms)** | 392 | 201 |
| **Search and Retrieval Low(in ms)** | 378 | 139 |
| **Request Medium(in ms)** | 360 | 212 |
| **Search and Retrieval Medium(in ms)** | 346 | 132 |

These results demonstrate that while the efficiency of the VM is increased by as much as 68% in internal calculations, in comparison to the Raspberry Pi 2, by adding the amount of time the request takes to travel to and from the request originator, the actual simulation gain is a little less than 50% for each VM used. Therefore the results have to be considered under this light.

While these findings, may adversely affect the Application performance under heavier load, the delays in normal and low volume are not greatly affected, considering their low order of magnitude.

## 5. CONCLUSIONS AND FUTURE WORK

In this paper we identified the need for an alternate approach to the concept of Heating Schedule Management through the use of distributed Knowledge acquisition techniques. We approached this issue through the work done in the context of the COSMOS Project and presented a practical application of the research and development being performed. The systems we have developed have also been tested in resource constrained hardware components making the case for their efficient use in real world, cost effective applications. The application itself will be in the future more thoroughly developed as it is currently in its infancy stages.

Next steps include the overall improvement of the Experience Sharing mechanism, in both request handling for delay reductions as well as reversal of its logic, in the sense of offering proactive Experience propagation. Additionally integration with existing research on authentication and privacy, along with greater use of Social IoT mechanisms will provide a better handling of possible mass requests of malicious intent.

## 6. ACKNOWLEDGMENTS

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