Component-Based Modelling for Sustainable and Scalable Smart Meter Networks

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***Abstract*—It is expected that the Internet of Things (IoT) provides the foundational infrastructure for smart cities, and making ICT an enabling technology to meet major challenges associated with climate change, energy efficiency, mobility and future services. On the other hand a smart city with these requirements is usually evolving through incremental automation and integration of new components, that are digital or physical components or smart devices. To handle the growing scale and complexity of a system, an adaptive modelling method is needed for dynamic analysis and verification and/or validation, and integration. In this paper, we consider the case study of a *Demand Response* (DR) Programme that is to be realized by the deployment of a network of smart meters. Through this case study, we propose a component-based modelling approach and demonstrate how it deals with the growing complex architecture.**

I. Introduction

A. Properties for a Sustainable Energy Value Chain

The recently introduced concepts of smart metering and Advance Metering Infrastructure (AMI) provide intriguing opportunities to embrace new sustainable services for the whole energy value chain [1], [2]. Around the world, electric meters are leading the way in smart meter deployments. Success of these opportunities relies on three key imperatives, as follows.

Firstly, novel technologies envisioned as part of the energy value chain aim at enabling two-way flow of information to help consumers contribute to achieving broader energy goals [3]. Indeed, within the IoT, interoperability of devices across a variety of industries, manufacturers and utility providers will enable more information and connectivity throughout the infrastructure and to homes, and ultimately consumers. Moreover, context-aware analytical computation using the different network resources is an indispensable part of IoT and will help new energy services develop [4].

Secondly, current smart meters provide real-time pricing for all types of users and so, in some way, encourage consumers to reduce their power consumption at peak times individually [5]. Thus, consumers can adjust their own individual load according to the time-differentiated prices (and also taking into account their own willingness to pay for their preferred quality of service) [6]. However, these approaches to user adaptation like some others [7], [8] mainly meet individual requirements on the resource sharing and allocation, and may not always achieve the best solution to the energy consumption problem. It is in this context that demand-side management (DSM), demand response (DR) and Direct Load Control (DLC) programmes (e.g., *residential load management*) emerge mainly focused on the following two objectives: reducing consumption and shifting consumption [9], [10]. In our work, consumers are required to cooperate aiming at achieving energy-aware consumption patterns. For illustration, imagine a smart community that autonomously adapts its energy consumption by means of enabling a limited amount of household smart meters to share real-time neighbourhood information cooperatively. Users therefore cooperate with other users or with data collectors, thus facilitating the integration of energy consumption information into a common view. Note that the interactions between users do not have to be manual, but can be automated through the IoT and two-way communication.

Finally, a smarter energy system should aim at inducing sustainable behaviours, from the generation and supply of renewable energy to its efficient consumption. Our proposal embraces consumers cooperation in response to supply conditions, in particular targeting renewable sources [11]. Utilities through the AMI are allowed to perform real-time billing, profiling and fault detection as well as to create incentives for users consuming renewable sources (e.g., guaranteeing the lowest price if the load demand does not exceed a certain threshold). On the other hand, consumers, empowered to have better access to their consumption and appliance interconnection [10], are provided with sufficient incentives to coordinate their energy demands, thus distributing the total daily load of the community to avoid overloading the utility companies. Proportional share scheduling, dispatching, fair resource allocation, and bargaining algorithms [12], [13], [14] appear to be the common approach to reach an optimal energy consumption agreement within a community in an automatic and dynamic way. The application of distributed algorithms will be even more decisive once plug-in hybrid electric vehicles become widespread [15], [16].

B. Component-based Architectural Modelling

All the above three key imperatives determine the *evolving* nature of the development of smart meters, their deployment, and incremental integration into larger networks [17]. For example, future smarter meters will be integrated into the smartphone networks for people to plan and control their appliances at home remotely. One of the greatest changes that arises from this dynamically developing situation is to deal with growing scale and functional/architectural complexity. This challenge becomes profound with the growing demand on the trustworthiness of the platforms and processes, access control, security protocols for safe transfer of large datasets over the Internet, data anonymization, privacy-preservation during data mining, and also ensuring that the entire infrastructure is resilient to cyber attacks, are of primary importance when designing such novel services [18], [19], [20]. We propose a model-driven integrated engineering approach to tackle this challenge. In this approach, abstract evolving modelling of system architectures is essential for development and the application of techniques/tools to support design and deployment of integration of new components, and for analysis, verification, simulation and testing to ensure trustworthiness. This paper presents initial findings and its main contribution is twofold:

- We describe a cooperative DR framework designed to create more sustainable energy systems. The framework is envisioned to promote behavioural changes in small or large communities with common interests that create the need for involved entities to reach binding agreements and coordinated behaviour. A fair resource allocation process, initially conceived in a centralized way by means of a Data Collector, will provide the community with the appropriate scheduling of its total demand taking into account both the renewable and fossil supply from the utility providers.
- A cyber-physical component-based modelling method is introduced to support the development of the framework described. This methodology captures the evolving nature of the system architecture and will help in dealing with the dynamically growing functional complexity of our framework, which comprises a number of distributed, dynamic components deployed over large networks of heterogeneous platforms. Thus, the interoperability of the distributed components becomes important as well as the aspects concerning organizational structure (i.e., system topology), distribution, interactions, security, fault-tolerance and real-time. To deal with these attributes of complexity, we show the importance of abstraction in reusing models and showing equivalence between different designs (e.g., distributed and centralized design).

The rest of the paper is organized as follows. Section II describes our cooperative DR framework, including roles and main phases. We introduce cyber-physical component-based modelling in Section III. Finally, we discuss future directions for this work and conclude in Section IV.

II. System Description

The system in our case study defines three possible *roles* for participant nodes:

- **Consumer:** A user (or household) equipped with a smart meter (or equivalent retrofitted electricity meter, normally with an energy consumption scheduler or home energy manager) that is connected to not only the power line, but also to a communication network.
- **Data Collector:** Also treated as a consumer, but in charge of the data aggregation process. According to the resource allocation algorithm used for DSM, this process has a centralized form. This role will, however, rotate amongst the community members. A distributed approach can be implemented securely and privately as shown in [21].
- **Utility:** A set of energy suppliers shared by customers. We assume utilities implement distributed generation that allows collection of energy from many sources, primarily renewable, aimed at giving lower environmental impacts and improved security of supply.

Furthermore, the framework comprises three different phases, demand commitment, supply commitment, and fair reallocation of demand.

A. Demand Commitment

Let $\mathcal{N}$ denote an ordered set of Consumers that are willing to cooperate in the pursuit of global community targets (i.e., become greener), sending their data to the Data Collector.

Assumption 1 (Data Aggregation)**.** *Each Consumer within the community will carry out aggregation tasks in turns and order.*

Each consumer $i \in \mathcal{N}$ has a set of household appliances $\mathcal{A}_i = \{$washer, dryer, coffee makers, cooker, alarm, light controller, water heating,$\ldots\}$.

Assumption 2 (Consumer's Habits)**.** *Consumer's habits, behaviours and use of appliances commonly demand a fixed energy load (e.g., refrigerator, alarm-controller, meters, standby televisions, water heater, etc.) as well as a variable load resulting from the utilization of such appliances and other equipment or facilities.*

Assumption 3 (Home Energy Scheduler)**.** *We assume that an energy consumption scheduler (or home energy manager) connects via a home area network (HAN) and lower power wireless such as ZigBee, connecting all the appliances in the home. This scheduler is further connected to the grid, the Utility and other Consumers within the community via either wired or wireless links.*

The scheduler also provides the user with an interface to control, monitor and program the functioning of appliances.

Definition 1 (Fixed/Variable Energy Demand)**.** *We define a fixed energy demand for Consumer i as $f\mathcal{D}_i^t$ at a time $t \in \{0, \ldots, 23\}$ as the aggregated load of non-shiftable local consumption of their appliances and regarding frequent behaviours. Similarly, a variable energy demand for Consumer i is denoted by $v\mathcal{D}_i^t$ and represents the aggregated load of shiftable consumption at a time $t \in \{0, \ldots, 23\}$.*

We consider a discrete time slot system. Without loss of generality, we assume that time granularity is one hour of the day. Each consumer then pre-allocates a certain amount of fixed demand as well as variable consumption planned for the upcoming 24 hours [22].

Assumption 4 (Appliance's Consumption)**.** *For each i's appliance $a \in \mathcal{A}_i$, we assume both daily fixed and variable energy consumption scheduling vectors, at each time slot $t \in \{0, \ldots, 23\}$, to control its non-shiftable and shiftable consumption. Hence, $fx_{i,a}^t$ and $vx_{i,a}^t$ denote the corresponding one-hour fixed and variable energy consumptions, respectively, that are scheduled for appliance a by user i at hour t.*

The daily fixed and variable demand for consumer $i \in \mathcal{N}$ is denoted by the aggregated demand $f\mathcal{D}_i = \sum_{t=0}^{23} \sum_{a \in \mathcal{A}} fx_{i,a}^t$ and $v\mathcal{D}_i = \sum_{t=0}^{23} \sum_{a \in \mathcal{A}} vx_{i,a}^t$, respectively. Thus, the daily load/demand for the whole community at a time t is then given by $\mathcal{D}^t = \sum_i^N (f\mathcal{D}_i^t + v\mathcal{D}_i^t)$.

B. Supply Commitment

Now, aiming at making the best use of renewable sources, thus replacing carbon-intensive energy sources, the Utility makes essential information available to the consumers about both the reliable renewable and fossil, energy supply planned for the upcoming 24 hours.

Definition 2 (Renewable and Fossil Energy Supply)**.** *We denote by $r\mathcal{U}^t$ the energy supply generated from a set of renewable sources at a time slot $t \in \{0, \dots, 23\}$. Similarly, $f\mathcal{U}^t$ represents the energy supply at time t generated from a set of fossil sources.*

The Utility centralizes the distribution of the energy, the notification to the Data Collector, and the billing process.

On a daily basis, the Data Collector verifies that the total energy consumed by all appliances in the system fulfil the daily utility service provided by the Utility. In particular, it is critical that the community reaches the point such that:

$$\forall t \in \{0, \dots, 23\}, \sum_{i}^{N} f\mathcal{D}_i^t \ll r\mathcal{U}^t$$

In the best case, the inequality below should apply:

$$\sum_{i}^{N} \sum_{t=0}^{23} (f\mathcal{D}_i^t + v\mathcal{D}_i^t) \leq \sum_{t=0}^{23} r\mathcal{U}^t$$

C. Fair Reallocation of Demand

In this phase, a fair-share re-scheduling of the requested demand per hour is executed by the Data Collector. If, however, the aforementioned best case applies such that $\forall t \in \{0, \dots, 23\}, \sum_{i}^{N} (f\mathcal{D}_i^t + v\mathcal{D}_i^t) \leq r\mathcal{U}^t$, the Data Collector will notify the Consumers that an agreement has been reached without the need of reallocation.

At worst, $\sum_{t=0}^{23} \mathcal{D}^t > \sum_{t=0}^{23} (r\mathcal{U}^t + f\mathcal{U}^t)$, so the Data Collector will have to inform the Utility for the appropriate contingency plan.

Otherwise, the Data Collector is in charge of performing a reallocation of the community's total demand, which is fair to all the consumers while at the same time targeting the renewable supply available for each time slot. In this regard, several optimization *Pareto-efficient* approaches to the resource allocation problem have been the focus of much attention in wireless sensor networks [13], broadband networks [7], and smart grids [15]. For a comprehensive description of the many algorithms that can be used to solve the resource allocation problem (see [12]).

In this paper, we restrict ourselves to the description of the global centralized optimization problem to which there exists a unique *Nash bargaining solution* such that: $\forall i \in \{1 \dots \mathcal{N}\}, \forall i \in \{1 \dots \mathcal{N}\}, \mu_i^t = f\mathcal{D}_i^t + min\{\mathcal{F}(v\mathcal{D}_i^t)\} \leq r\mathcal{U}^t$, where $\mathcal{F}(\cdot)$ is in charge of the shifting for the variable demand according to the time interval for which appliance can be scheduled. Perhaps the simplest way to give each consumer an equal chance against all other is to recursively apply a round-robin strategy in the allocation of each Consumer's needs. This is both possible and simple, due to 1) the number of participants is known and fixed, and 2) the reallocation process is centralized by the Data Collector who, starting on their own, will satisfy the demand of other Consumers demand in the appropriate order. As a result, the Data Collector will send the reallocated vector $\forall i \in \mathcal{N}, \overrightarrow{\mu}_i$.

Note that, if the consumers were to misbehave, e.g., by deviating from the reallocated vectors or switching off the home scheduler, the Data Collector may still have a way of isolating the misbehaving user from the coalition formed for upcoming days. Cooperative game theoretic frameworks and proofs such as in [23] can be applied to the validation of the incentives that encourage users to behave in a desired way when there is a shared objective.

III. Cyber-Physical Component-Based Modelling

This section shows how an extension of the rCOS component-based modelling method [24], [25] can be used to support the development of the system in different ways[1].

A. Cyber-Physical Components Modelling – rCPCS

The models of software components in rCOS are extended with physical components, that may be controlled by digital controllers. We call the extended version of rCOS "Refinement of Cyber-Physical Component Systems", rCPCS for short. In general, *cyber-physical component*, or simply "component" when there is no confusion, has *discrete state variables* that are directly changed by control programs, and *continuous state variables* whose changes follow differential equations, depending on states of the discrete variables.

a) State variables: The state variables of a component C, denoted by αC, called the alphabet of C, is divided into two subsets, $\alpha C = \langle \beta C, \gamma C \rangle$ of private discrete state variables and continuous state variables. For example, an appliance $A \in \mathcal{A}$ of the appliances of a household is a component. Its state variables can be $\alpha A = \langle \{s : \{on, \mathit{off}\}\}, \{rate : \mathit{Real}\} \rangle$, where $rate$ is the rate in which energy is consumed by the appliance when it in operation.

b) Interfaces: A component model specifies the interfaces through which the component interact with its environment (i.e., other possible cyber-physical components including human actors). A component C can have a *provided interface* (or *input interface*), *C.pIF*, and or a *required interface* (or *output interface*), *C.rIF*; but a component must have an interface. Each of the interfaces contains two sets, $C.pIF = \langle pO, pW \rangle$ of *provided operations* and *provided signals* or *wires*, or $C.rIF = \langle rO, rW \rangle$ of *required operations* and *required signals*. It is required that the set of provided signals is a subset of the set continuous variables of the component (i.e., $pW \subseteq \gamma C$). The variables $\gamma C - pW$ are the *private continuous variables* of C. For example, the appliance A in the above paragraph can have a provided interface $A.IF = \langle \{switch()\}, \{rate\} \rangle$ (i.e., one provided operation $switch()$).

The interfaces provide the means for the component to interact with its environment. Interactions can be with other digital or physical components. For example, a digital controller can be designed to interact with A to switch "on" and "off" of the appliance, and a meter to record the energy consumption by using the $rate$. On the other hand, interactions A can be with human actors, for example the householder

[1]The modelling method supports different implementations of coordination and control of components on different hardware platforms.

can "observe" or use the $rate$ to "calculate" the energy consumption, and "switch" the appliance "on" and "off". One can imagine the evolution from interactions of the appliance with human operators to interactions of digital controllers and meters would be one step of increase in automation, but the model of the functionality, behaviour, including interactions behaviour, of the appliance remains unchanged.

c) Local functionality and behaviour: The local functionality of a component is defined by the change of the state of the discrete variables when an operation in the interfaces is performed. This is specified as a *design* in Unifying Theories of Programming (UTP) [26], [25]. A design of a component is a predicate of the discrete state variables and their primed versions in the form $p(v) \vdash R(v, v')$. For example, the functionality of $switch()$ of appliance a is defined as:

$$(state = on \vee state = off) \vdash$$
$$(state = on \wedge state' = off) \vee (state = off \wedge state' = on)$$

The informal meaning is that if the current state of A is either "on" or "off" (i.e., working normally), the performing $switch()$ will change the state from "on" to "off" or from "off" to "on". The predicate p before "$\vdash$" is called the *precondition* of the design and the predicate R after "$\vdash$" is called the *postcondition* of the design. When the operation is performed in a state in which the precondition does not hold, the execution is not specified (i.e., it can be *chaos*). Therefore, the formal meaning of a design $p \vdash R$ is defined as the implication $p \Rightarrow R$ for program partial correctness (i.e., if the precondition holds and the execution terminates), the final state is related to the initial state by R. Thus, the initial state is represented by variables and the post-state of the execution is represented by the primed versions of the variables. The *total correctness semantics* of designs is defined in the definitive UTP book [26].

Besides discrete functionality, cyber-physical system (CPS) components can also have continuous evolution for its continuous variables, defined in time-dependent functions, often differential equations. For example, the continuous evolution for the appliance A can be defined by $rate$ as the rate in which energy is consumed by the appliance when it is on, and the rate is assumed to 0 when the appliance is off. We believe the definition of $rate$ is usually provided by the manufacture of the appliance. Thus, the *behaviour* of A is that the $rate$ evolves along with the switches on and off of the component A.

Now we can consider an electronic meter M that records the accumulated consumption of energy of appliance A. Its provided interface *M.pIF* provides a signal $read$ and its required interface *M.rIF* consists of a single signal $rate$. The behaviour of M (i.e., the evolution of $read$) is a timed function of the required signal $rate$. For example, it can be defined as $read(t) = \int_0^t rate$. Therefore, in general, the behaviour of the continuous variables are defined by timed functions of the discrete variables and the required signals. In general, the continuous behaviour (or the trajectories) of the continuous variables of a component C is specified as timed functions of the following form, where feedbacks loops are possible

$$\gamma C = F(\beta C, \gamma C, rW)$$

The above model of the meter does not include a sensor in the meter; a sensor is implicitly modelled by the observer of $read$. If a sensor is modelled, $read$ would be discretized and represented as a step function. Also, a sensor can be modelled as a separate component S that "senses" $rate$ through its required signal and translate it into a step function that feeds in the meter M', accumulatig the energy consumption. We can prove that the meter M modelled is equivalent to the composition $S \parallel M'$.

The extension of the rCOS interfaces to include signals is significant for the composition of physical components. For example, consider the design of an energy-aware building or renovation of a building for energy saving. A room *Room* in the building can be divided into a number of sections, Sec_i, $i = 1, \ldots, n$, as components. Each is interfaced, say through a "window", or a "wall", that connects the temperature sT_i in a section Sec_i to the temperature T outside the building by a function $sT_i = f_i(T)$. Notice that different windows or walls hae varying heat transmission. Different sections are then interfaced through 'airflow', such that temperature of the whole room can be defined in terms of the sections. Then the room can be modelled as $Room = \|_{i=1}^{n} Sec_1$, which interacts with the outside environment of the building. The analysis of the sections, windows, and walls, together with the simulation of the model will be useful in deciding if a energy saving target is feasible, and will provide a design or renovation plan to reach the energy-saving target if feasible.

This example shows another significance of the notion of interfaces. That is they also interface the interdisciplinary collaborations among modelling in material science, electronics, control engineering, and software engineering. Therefore, interfaces also bridge different technologies.

B. Component Composition

Components are composed through their interfaces. When composing two or more components, it is often necessary to design connector components, modelled in the same notation, for linking the components together. Different ways of composing components represent different design approaches (see Fig. 1).

d) Household with distributed meters: Compose the alliance A and meter M, we a composite component $C = A \parallel M$, that can be written in more readable format such as:

```
Component C {
  attributes state: {on,off};
  signals rate, read: Real;
  provided interface: switch(), read;

  functionality: switch(){/**as defined};
  behaviour: rate = .../*as defined;
             read = .../*as defined }
```

e) Household with decentralized meters: Consider an arbitrary number m of appliances in a household, each modelled by A_i with meter M_i for $i = 1, \ldots, m$. Then, for each i, we can obtain $C_i = A_i \parallel M_i$, with a different $switch_i$, $rate_i$, and $read_i$. Then a household is modelled by the composite component $H = \|_{i=1}^{m} C_i$. It only has a provided interface consisting of operations $\{switch_i \mid i = 1, \ldots, m\}$ and signals $\{read_i \mid i = 1, \ldots, m\}$. In this design, we assume the householder reads the meters, plans their daily use of energy, and operates the appliance with the switches.

f) Household with a centralized meter: In a more general household, there is usually a centralised meter installed. In this there is a main switch connector, denoted by G. This G has a continuous variable $rate$ as its provided interface and

$\{rate_i \mid i = 1, \ldots, m\}$ as provided interfaces. The behaviour of G is $rate = \sum_{i=1}^{m} rate_i$. Then the household can be modelled by $H_1 = ((\|_{i=1}^{m} A_i) \parallel G) \parallel M$.

The difference between H_1 and H from an external observer's perspective is that H_1 has only one provided signal $read$ while H has m provided signals $read_i$, $i = 1, \ldots, m$. However, we can add the connector G_1 to the whole H, which receives input signals $read_i$ and outputs signal $read$, so that $H \parallel G_1 = H_1$.

C. Making the Home Smarter – System Evolution

Both designs H and H_1 of the household assume that the householder does the planning and control. Either can be made smarter by increasing automation in planning, scheduling and control on the operations of the appliances. For example, with the distributed meters in H, Assumption 4 can be realized with a scheduler that reads $read_i$ to decide when appliance A_i can be switched on to operation according to the energy combustion budget fx_i and vx_i. We can have a separated scheduling/managing component *HM* that controls all the appliances in a centralized manner. Component HM allows the householder to set up the budgets fx_i and vx_i for each appliance A_i; it then controls the operations of the appliance to meet the budgets of the appliances. It is also possible to have a distributed scheduling solution in which the control on A_i according to fx_i and vx_i cam be embedded in meter M_i to make M_i smarter. In this case M_i needs to provide an operation (to a control panel) for setting the daily budgets. From the external point of view, a new household with "smarter" meters that operate the appliances (possibly through wireless control or any other networking mechanisms) behaves exactly the same as the "simple" meters. But the latter is with dedicated planning and control by the householder (who is seen as a component of the household).

Consider the solution with a centralized meter M. The amounts of consumption for individual appliances cannot be directly observed or read. Therefore, the home manager HM has to be design to calculate the consumption $read_i$ of an appliance A_i from its $rate_i$. After that, the control strategy would be same as in the previous case. Obviously, HM can be embedded into the centralized meter, M, and in this case M becomes a smarter meter.

D. Energy Reallocation

The designs of a household in subsections III-C and III-B are all equivalent to the following component:

```
Component H {
 attributes: fD, vD: Real;
 signal: read: Real;
 provided interface:
   Rf(;x:Real), Rv(;y:Real);
   Wf(x:Real), Wv(y:Real);
           /** x, y - return parameters
   setUp() /** set up budget and policy
           /** by householder;
   read;
 functionality:
   Rf(;x){x:=fD}; Rv(; y){y:=vD};
   Wf(x){fD:=x}; Wv(y){vD:=y}
     ----
 }
```

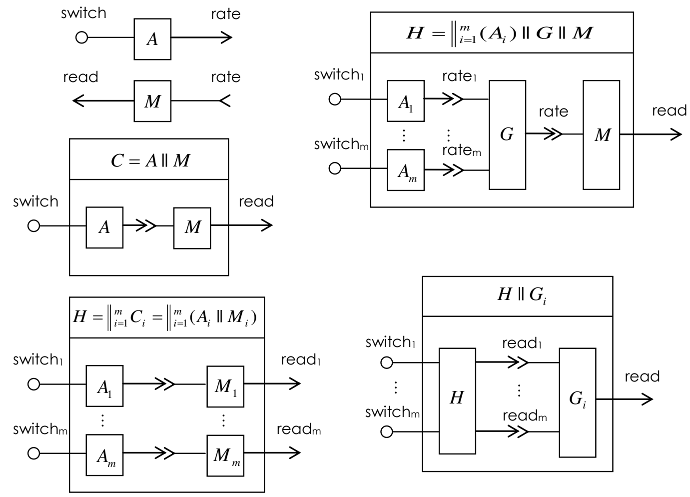

Fig. 1. Different ways of composing components represent different design approaches.

Operations $Rf()$, $Rv()$, $Wf()$ and $Wv()$ are called by the component *Collector*. The operation $setUp()$ in this example is an abstraction of the setup operations that the householder perform to set up the budget and scheduling constraints. The signal $read$ can be read by the *Collector* and the billing component that is not considered in this paper.

Now let $\mathcal{N} = \{H_i \mid i = 1, \ldots, k\}$ of k households, with their modelling elements indicated by $I = \{i \mid i = 1, \ldots, k\}$. The model of the utility by a component U is simple. It only provides an operation $request(x : Real, y : Real; z : Real)$ for supply of energy. When it is called, it will provide the amount of committed supply for the day through the return parameter. The *Collector* component has an interface (i.e., an active process), through which it periodically call the interface operations $Rf_i()$ and $Rv_i()$ and make a request to utility U through $request()$. After it receives notification from U about the committed supply, it "negotiates" with the households (through communication interfaces that we omit in this paper) and reallocates budgets to the house holds through $Wf_i()$ and $Wv_i()$. Then each household H_i is managed by themselves. This gives us the system $(\|_{i=1}^{k} H_i) \parallel Collector \parallel U$. The requirements for energy allocation for the energy supply can be matched by allocation and supply algorithms of *Collector* and U after coordination of the consumers is completed. rCOS supports the design and verification of these algorithms.

Notice that, except for the "negotiation" of the collector with individual households, the composition $\|_{i=1}^{k} H_i$ of the households behaves exactly the same as one household in a "black box" if a connector is added to summate the fixed and variable demands of the individual households. This shows how abstract modelling deals with complexity. Similarly, we can imagine that a network of utilities works in collaboration to provide a power supply. Once they reach an agreement among themselves on how they share the supply to the request from the collector, they interface with the collector in the same manner as a single utility. Furthermore, the centralized collector can be transformed into a distributed implementation so that the "negotiation" can be performed among households themselves.

In addition to reasoning about equivalent interface behaviour of different designs, the architectural model is also important for identifying and analysing vulnerabilities and weakness in different components due to interaction mechanisms, communication protocols, hardware quality or software bugs. Based on this hazard and risk analysis, architectural decisions can be made for different concerns, such as distribution, use of redundancy, specially designed secure protocols, etc., to improve safety, security, integrity, and availability.

Here, our aim is to show the power, the effectiveness, and the scalability of the modelling method. This extension to rCOS with CPS components is at its early stage. The notation and its formal semantics are still yet to fully developed. Tool support, such as simulation and verification, would be important for its practical adoption.

IV. Conclusion

Within the Internet of Things (IoT) infrastructure, some services are envisioned to be more efficient as users gain autonomy and self-organization. Smart communities, capable of identifying patterns in energy consumption will be able to reduce or shift their use of the resource, making the overall consumption more sustainable and efficient. In this paper, we have used a novel demand response (DR) framework that relies on the cooperation of the consumers targeting the available renewable energy supply to motivate the need of a component-based method for the development of a smart community. Unlike most previous DR strategies that have focussed on pricing and aimed at reducing the energy cost and the peak-to-average ratio, the new DR solution tends to promote a transformation of the whole energy value chain.

Moreover, the rCPCS modelling method provides power means of abstraction so that large and complex composite subsystems, such as the composition of all household, can be treated as as simple component. Future work includes the full development of the modelling notation and its formal semantics. Tools to support analysis and verification are also important for putting the method into practice. Another area of work is to use the model of the system to identify safety weakness and vulnerability components, and points of security threads in order to make architectural decisions to strengthen the system [27]. Furthermore, introduction of intelligent components with learning capabilities is of interest for utilities and storage purposes.

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