Reduction of Electricity Consumption and Electricity Demand Peak in Home Environments

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***Abstract*—There is an increase need to become more energy efficient and to reduce peak electricity demands to move towards the so called Smart Grid. In order to succeed, Home Energy Management Systems need to be developed to seamlessly provide the users with the tools to control the household electricity consumption. The Home Energy Management System developed includes a Home Gateway that provides rules to reduce the household consumption and a scheduling algorithm to reduce the peak demands. In addition, web services are used to provide remote access, communicate with the Smart Meter and the Energy Rules Server. Users will be able to donwload/update rules to reduce the electricity consumption and configure their Home Energy Management System remotely by using the JAVA based pilot-application developed. In this article the Home Energy Management System and its components are presented. The results show that the energy management system based on rules reduces the total househapld consumption. The scheduling algorithm results show that it is possible to distribute the consumption with some delays on the appliances tasks.**

***Index Terms*—Smart Grid, Home Energy Management, Home Gateway, Demand Response (DR), Demand Peaks**

I. Introduction

A Home Energy Management System (HEMS) is a system from which the user can control the devices in the home network through an Graphical User Interface (GUI) and apply energy management strategies to reduce and optimize their consumption. This article presents a HEMS, which helps reduce the household electricity consumption, and which includes a scheduling algorithm that spreads electricity consumption over time reducing demand peaks. Demand peaks are high points on power consumption caused by customers using electricity concurrently during the same period of time. From the utilities and electricity production perspective, demand peaks should be reduced or avoided as it is more efficient to have the power consumption distributed over time. Utility companies are forced to develop costly methods to generate enough power to meet the demand peaks. If the utilities cannot meet this demand, this could result in electricity shortages or even blackouts in certain areas.

The appliances found in users premises are usually manufactured by different producers and may use different communication technologies which can lead to interoperability issues between devices. Therefore, the main challenge in home networks is the variety of technologies, providing different communication methods, as well as the diversity of producers, providing different types of devices and services. The herein proposed Home Gateway is technology and device type independent, in order to offer a common pluggable platform to different devices in the home network, which makes them interoperable at the service level.

The HEMS main elements is the Home Gateway. The system can be accessed remotely and communicate with other components using web services:

- Remote access: users can connect to their Home Gateway, change the home appliances status and the energy management system settings among others.
- Communicate with other components of the HEMS: the HEMS can include other components beside the Home Gateway, such as the Smart Meter and bridges to communicate with other devices. Web services are used to handle this communication.
- Energy Rules Server: the Energy Rules Server will contain rules for reducing the electricity consumption. The user can donwload/update the energy rules in their HEMS through web services.

The Home Gateway presented in [1], [2], [3] has been extended to include a scheduling algorithm and the performance on terms of energy savings and energy reduction has been tested in this article. The scheduling algorithm which will distribute the electricity consumption over time. Different appliances are scheduled to consume based on their priority type, which can be changed by using the remote access. The overall goal of this method is to guarantee that a defined electricity consumption limit, provided by the utility and approved by the user, will not be exceeded. This technique could result in a more distributed consumption and lower demand peaks, which can lead to a reduction of greenhouse gasses. Additionally, the system presented can also ease the task of forecasting consumption as the customers will guarantee that they will not consume more than a determined amount of power.

In the past years, research has centered in home gateways for home automation and home energy management. An example of a home gateway using OSGi and ontologies is Domotic OSGi Gateway (DOG) [4] by Politecnico di Torino. The main difference between DOG and the home gateway herein presented is the fact that DOG is focused on domotics, while the home gateway herein is mainly concerned with energy management. The user can use it to define their own energy management system by creating, modifying and deleting rules, which may reduce the total electricity consumption. In [5], a HEMS has been implemented to reduce stand-by consumption by setting a power line network. Similarly, in [6], a HEMS implementation using ZigBee and infrared communication

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to reduce stand-by consumption of power outlets and lights is presented. The HEMS proposed in article paper has two main advantages over [5] and [6]: 1-the energy management strategy can help reduce the consumption and not only stand-by consumption; 2-the HEMS may communicate using different technologies and not only power line communication or ZigBee. SESAME-S [7] has developed a Home Gateway very similar to the one presented here. They have also used OSGi and have developed their own ontology for energy management. However, SESAME-S does not produce any results on the home gateway related to energy management. Their focus is in the user's acceptance of their system.

The remainder of this article is organized as follows: in Section II, an overview of developed HEMS is provided. Section III describes the rules used to reduce the household consumption and the electricity savings results are provided. The scheduling system and the results obtained are presented in Section IV. Finally, the conclusions are found in Section V.

II. Home Energy Management System

The aim of the HEMS developed is to reduce and schedule electricity consumption of the household. The Home Gateway developed offers the user a variety of basic functionalities:

- Monitor: The user can obtain the current status of any device connected to the home network through the user interface, locally or remotely.
- Control: The user can send basic commands, such as On/Off and parametric commands, such as *Start Program 3* to any home appliance, locally or remotely.
- Data Validation: The systems checks that the commands to be send to a device are actually valid for that device. For instance, if *Start Program 3* is send to a lamp the Home Gateway will detect the error and notify the user.

To build a HEMS and not only a home automation system more advanced and energy related functionalities are provided:

- Power Consumption History: in order to reduce electricity consumption it is important to know how much electricity each appliance consumes. The HEMS herein presented gathers this information.
- Energy Management System: the developed Home Gateway uses energy rules to help reduce the electricity consumption. The rules can be edited, deleted or created at any time and will be effective immediately without having to restart the system. The rules can be introduced into the system by the user. However, this requires that the user has advanced knowledge about the system, which is, in many case, unrealistic. Therefore, the Home Gateway communicates with a Energy Rules Server through web services. The user can connect to this server to browse the rules and an obtain a brief description of each rule so the most suitable rules, according to user's preferences, can be downloaded.
- Scheduling Algorithm: besides reducing the consumption, in order to be more energy efficient the electricity consumption should be distributed over time instead of creating demand peaks. This algorithm guarantees that the total electricity consumption in the household does not exceed a certain limit.

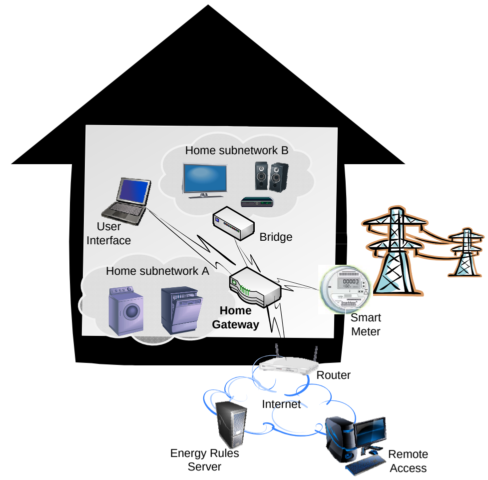

Fig. 1. System Architecture

The following subsections provide more details about the above functionalities and an overview of the system architecture and its implementation.

A. System Architecture

In the HEMS herein designed, the central element is the Home Gateway which can directly communicate with all the home devices or can use a bridge to interconnect with them. Besides being able to communicate with the home devices the Home Gateway can also communicate with the Smart Meter and will enable remote access through the internet. All the elements of this HEMS are depicted in Fig. 1.

B. Implementation

A Home Gateway that manages the home appliances to fulfill the reduction of overall consumption and reduction of peak demands has been developed using OSGi Equinox Framework [8]. The OSGi Framework is an open service platform for the delivery and control of different JAVA-based applications, called bundles. Each bundle has a specific functionality and can interact with other bundles in the same component of with other bundles in another component through web services. Web services are incorporated into the Home Gateway developed to offer modularity as some of the HEMS functionalities are external to the Home Gateway, such as Smart Meter or Energy Rules Server. To incorporate web services into the Home Gateway developed, Apache CXF Distributed OSGi [9] is used. This distribution enables an easy integration of web services into OSGi platform. Furthermore, CXF-DOSGi will auto-generate the Web Services Description Language (WSDL) from the java interface, at the deployment time. Further information of this implementation can be found in [3].

The Home Gateway accesses a knowledge base data repository from where the capabilities of the devices can be obtained. This knowledge base data repository is implemented by an ontology, where the home devices are classified according to their functionalities and capabilities. Using this knowledge

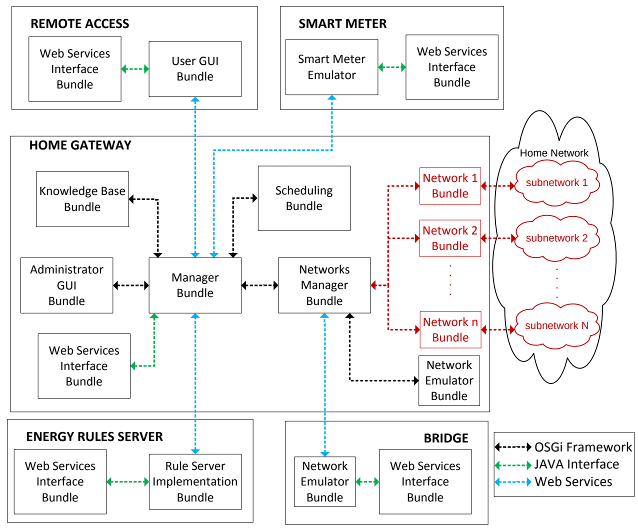

Fig. 2. OSGi Implementation

base data repository, energy management strategies can be performed by applying a set of rules, which are based on the energy consumption of the home devices, information from the electrical grid and users' preferences. The ontology has been included into the JAVA implementation by using Protégé-OWL API 3.4.4 [10]. The rules in this system have been written in SWRL which can be used to reason about the home devices in ontology terms. In order to run this rules from the JAVA platform Jess Rule Engine are used.

The components and its bundles are depicted in Fig. 2. In order to test the Home Gateway, some of the components, such as the Smart Meter, Energy Rules Server, bridges and home appliances have been emulated to test the Home Gateway capabilities.

A brief description of the Home Gateway bundles is provided below:

- Scheduling Bundle This bundle implements the scheduling algorithm and ensures that the maximum consumption is not pass a certain limit set by the user.
- Knowledge Base Bundle This bundle handles the interactions with the knowledge base data repository and rule engine. To implement the Home Gateway knowledge base data repository DogOnt [11] ontology is used. In addition, this bundle contains the means to apply energy management strategies by using rules.
- User Interface Bundle The Home Gateway developed provides a GUI which is contained in this bundle. This interface is used to communicate to the devices, obtain information about them and manage the energy management rules and the scheduling algorithm.
- Network n Bundle The home network found in the users' premises can contain devices using different communication technology, for example power line or wireless. Each of these *Network n* bundles will handle the communication with the devices in the subnetwork n in the home network which use different communication technologies. These bundles will send messages and forward notification messages to/from the devices contained in the n subnetwork.
- Network Emulator Bundle The focus of this article is not on the enabling technologies in the physical layer and their interoperation, but on the software mechanisms that allow use of the different elements, regardless of the connectivity mechanisms towards the Home Gateway. The home network is therefore emulated and an interface is provided to emulate changes in the devices status.
- Networks Manager Bundle Due to the fact that various Network n Bundles may exist, inside the Home Gateway and also in bridges, this bundle is created to handle the communication with these Network n bundles.
- Manager Bundle This is the central bundle which handles the interaction between the different bundles and contains the web services implementation and therefore acts as the server. It uses web services to communicate with bundles found outside the Home Gateway, such as the Smart Meter or the Energy Rules Server and OSGi framework to communicate within the Home Gateway.
- Web Services Interface Bundle It provides the JAVA interface needed to implement the web services.

In addition to the Home Gateway, other components have been developed to test the energy management system and the scheduling algorithm: a *Remote Access*, a *Bridge*, the *Energy Rules Server* and the *Smart Meter*. In order to emulate the remote access, a User Interface has been deployed in another computer, which communicates with the Home Gateway using web services.

The Home Gateway may not provide all the communication technologies found in the home network and the possibility of using bridges to communicate to some of the home appliances is a probable scenario. For this reason and to test the developed Home Gateway, a bridge has been implemented.

Energy Rules Server is used as a rules provider for the energy management system of the implemented Home Gateway. This bundle emulates a rules server that can be found in the internet.

A Smart Meter has been implemented to emulate the possible communication with the Home Gateway. This communication may involve electricity information, such as kWh price and a request to limit consumption, and user information, such us current electricity consumption and acceptance/rejection of requests.

III. Reduction of Electricity Consumption

To test the electricity savings the HEMS can provide, a set of basic rules, which aim to have no effect on the users' comfort, are implemented into the Home Gateway. All rules will be evaluated every time the knowledge base data repository is changed. For instance, if the Home Gateway receives a statues update, the status of the devices will be change in the knowledge base data repository, and then Jess rule engine will evaluate and trigger the necessary rules. When a rule is triggered and a device in a home network has to change status a message is send to the target device by suing the Manager bundle service and the corresponding Network bundle.

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The energy management strategy for this test is based on a few basic rules in terms of occupancy and irradiance. Therefore, it has been assumed that the home network contains a *presence system*, which by using sensors can indicate the presence of users in the home premises. Light sensors are also used to detect the solar irradiance. The rules used are summarized below:

- Lights and irradiance threshold: If the irradiance detected by the light sensors in a room is higher than the threshold, the lights in that room are turned off. The threshold can be modified according to user preferences through the user interface.
- Lights and no presence: If the sensors detect that there is no one present, all the lights are turned off.
- Standby: Standby power consumption is one of the major energy savings areas as the appliances are consuming without performing any task. Therefore, this rules makes sure that appliances are either turned off or on, but never in standby mode.
- Appliance and no presence: some of the appliances at home can be turned off while the user is away, for instance the printer and Wifi router. A rule for each appliance that the user wants to turn off while away from home has been implemented. This rules can be extended to more or less appliances according to users' preferences.
- Appliance and presence: in the similar way some appliances only have to be turned on when the user is away from the premises, for instance the answering machine or alarm system.

More rules can be added to the HEMS, for instance rules regarding heating, ventilation, and air conditioning (HVAC) systems. However, in other to implement these rules and emulate their consumption, detailed information about the HVAC systems, home architecture and home isolation is necessary. As this information is specific for each home environment and depends on a few factors it has not been included in the simulations presented in the next section.

A. Evaluation

In order to test the HEMS herein described, information about how users interact with the appliances is needed. Most models simulating power consumption in home environments provide time-correlated power consumption for the entire dwelling. However, in order to test the HEMS detail information about, when, for how long, and the instantaneous consumption of each device found in the home environment is needed. The model presented in [12] by Richardson et al. is used. This power consumption model is based on occupant time-use data, where occupant activity is mapped to appliance use. In the same way, detail information about light devices and its usage is also needed. To calculate the light usage, Richardson et al. take into consideration the solar irradiance. This model under-represents the demand during night, as it does not consider users leaving the lights on by mistake. In addition, this models provides time-correlated occupancy data, referred as active occupancy. Active occupancy is defined as the number of people who are at home and awake, this data input is used to model the presence system, which will have status present when active occupancy equals one or more.

TABLE I
HEMS INPUT PARAMETERS AND RESULTS

Cons. 28 days	Cons. w/ HEMS 28 days	Savings 28 days	Estimated Yearly Savings	Savings Percentage
216 kWh	178 kWh	38 kWh	500 kWh	17,72%

Richardson et al. provide an Excel Workbook [13] containing a high-resolution model of domestic whole house electricity demand. This implementation is used to calculate the use of home devices within a single UK dwelling over a 24-hour period at a one-minute time resolution. The simulator incorporates models to calculate the active occupancy and lighting usage. This implementation offers the option to configure the day and month of the year, the total number of users that live in the dwelling and whether a week day or a weekend day is simulated.

To test the work herein described an occupancy of 4 people has been considered. 28 days have been simulated to obtain samples to reproduce the consumption. This 28 days are divided into four weeks (5 week days and 2 weekend days) of each season (Summer, Autumn, Winter and Spring). These data has been used as input into the developed HEMS. A summary of the input parameters used and the results obtained can be found in Table I.

The herein developed HEMS using the rules presented in the previous section can successfully reduce the electricity consumption. Extrapolating the consumption of the 28 days simulated into a yearly electricity consumption, the electricity is reduced from 28.195 kWh to 23.198 kWh. This energy savings represent a decrease of 17,7%. The users could further reduce the electricity consumption by incorporating more rules to the HEMS. The new rules incorporated to the HEMS depend on the users' preferences and the home devices.

IV. Scheduling Algorithm

The aim of the implemented scheduling algorithm is to spread the electricity consumption and to keep the consumption under certain limit to reduced or even avoid electricity demand peaks. The scheduling bundle contains the scheduling algorithm and communicates with the Manager Bundle to handle the interaction with the rest of the bundles. The main concept behind this approach is the aggregation of home appliances into priority classes and the definition of a maximum power consumption limit, which is not allowed to be exceeded. If the user sets a maximum consumption, every time an appliance is turned on, a requests to consume is send to this bundle. This bundle will reply accepting or declining the request. This bundle is also capable of sending *pause* and *resume* commands to the household appliances. The *pause* command is used to force the appliance to go to into stand-by mode. The *resume* command is used to switch the appliance from stand-by mode to on, where the appliance will then continue its task. The Scheduling Bundle will decide which appliances can be paused and when they should continue their task by following the event driven scheduling algorithm illustrated in Fig. 3 and explained in detail in the next subsection.

A. Event Driven Scheduling Algorithm

The event driven scheduling algorithm showed in Fig. 3 is used to keep the total consumption of the household under the determined limit. The algorithm is triggered by two events: request to consume and end of consumption. An end of consumption event is send from Manager bundle when an appliance has been turned off.

The Manager bundle sends a request to consume to the Scheduling bundle when the users switch the appliance on. The Scheduling Bundle then calculates if there is enough power to switch on that appliance without exceeding the maximum consumption. If the consumption of the appliances already switched on, plus the consumption of the new appliance does not exceed the maximum consumption, then the appliance requesting to consume electricity is switched on. On the other hand, if switching on the new appliance would exceed the maximum consumption, the algorithm proceeds to examine the priorities of the appliances already switched on. The bundle tries to find a subset of the appliance(s) switched on, which have lower priority than the appliance requesting to consume. This subset of appliances should free enough electricity consumption so the new appliance can be switched on without exceeding the limit. If a subset fulfilling this condition is found, the appliances in the subset is paused and added to the paused appliances list. The bundle grants access to the new appliance without exceeding the maximum power consumption. In the case, a subset of appliances could not be found, the new appliance is added to the paused appliances list.

When an appliance is switched off, an end of consumption event is send to this bundle. The bundle then checks the paused appliances list. If one or more paused appliances can be switched on without exceeding the maximum power consumption, a *resume* command is send to the paused appliance(s).

In order to get users to accept that the users' low priority appliances will be paused and therefore take longer for them to finish their task, utilities could offer them a reduction in the electricity bill. This can be used as a commercial strategy by utilities to face a more homogeneous consumption by using attractive pricing schemes. It has to be taken into consideration that electricity bills are increasing along with the number of electrical appliances and users are interested in reducing their electricity bill. In particular, during the winter of 2007/08, 20%

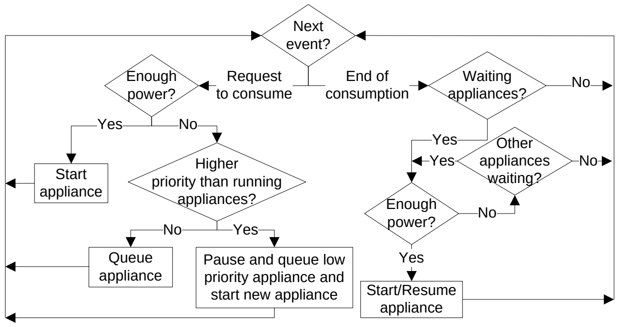

Fig. 3. Event Driven Scheduling Algorithm

TABLE III
RESULTS

	Scenario A	Scenario B
Max Consumption	1000 W	750 W
Mean waiting time	19,3 min	69,6 min

of Americans could not pay on time their electricity bill and 8.7 million American consumers were disconnected from their electricity utility services [14].

B. Evaluation

The delay suffered by the low priority appliances due to the fact that there is a limit on the maximum consumption and therefore, in some occasions, these appliances will have to wait before they can consume power is evaluated in this section. This delay is referred as *waiting time*.

As the priorities of appliances can considerably vary from user to user a simplified scenario that contains a television set, a computer, a washing machine, a dryer and a dishwasher has been considered. In addition, the appliances have been septated into these two priorities: high priority appliances (television set, computer) and low priority appliances (washing machine, dryer and dishwasher). The high priority appliances are considered to need electricity as soon as they are turned on, they cannot be denied power and cannot be paused or delayed in any way. On the other hand, the low priority appliances can be paused and/or delayed as it has been considered that their task duration could be prolonged without affecting the users' comfort. This scenario has been evaluated separately from the energy management system as it does not affect the total consumption, it only limits the instant power consumption.

The household appliances considered in this scenario are presented in Table II. This table also includes the consumption of each appliance, the average usage of the appliance and the duration of this usage. The average usage of the appliance has been taken from [15]. This data attempts to model the appliances usage of a typical day of a family (4-6 persons) between 17:00-00:00, when most of electrical consumption takes place.

100 test cases of one day have been done for each two different maximum consumption 750W and 1000W. The mean waiting time of the low priority appliance for both scenarios is summarized in Table III. The waiting time is the time the low priority appliances have been in *pause* mode, which can happen before the appliance even starts its task or during the task. The waiting can be seen as some extra time the low priority appliances will take to finish their task. For instance, for Scenario A, the washing machine will take in average 149,3 min minutes instead of 130 minutes, which means an increase of 14,8%. For Scenario B, the waiting time is considerably higher, 69,6 minutes.

V. CONCLUSION

The main motivation was to create a simple Home Gateway which would be easily scalable and that had the necessary capabilities to create a HEMS. The HEMS developed will not only offer control of devices through a GUI and run rules to reduce energy consumption, but it will also use web services to communicate with their components and also to

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TABLE II
HOME APPLIANCES CHARACTERISTICS

Appliances	Model	Power Consumption	Average Usage [15]	Usage Duration
Television Set	Television: 42LE4900 LG [16] DVD player: DVX550 LG [17] Home theater: S-HS111US Pioneer [18]	239 Watt	4,3 hours/day	120 min
Computer	PC: HP Pavilion Slimline s5670t [19] Monitor: BX2340 Samsung [20]	242 Watt	3,5 hours/day	100 min
Washing machine	WM12S32XEE Siemens [21]	733 Watt	3,1 times/week	131 min
Dryer machine	WTW8658XEE Bosch [22]	609 Watt	4,4 times/week	134 min
Dish washer	SMS69T25EU Bosch [23]	720 Watt	4,1 times/week	100 min

communicated with other components and offer remote access. The HEMS also includes an event driven scheduling algorithm for regulating electricity demand peak. The developed Home Gateway uses web services to offer communication with external devices, such as the Smart Meter and Energy Rules Server, in addition to remote access to the system. Using this remote access the user can change the settings of the energy management system and the scheduling algorithm. The user can modify, delete, or download new rules from the Energy Rules Server to reduce the electricity consumption using the GUI of this HEMS. Basic rules obtained from the Energy Rules Server are downloaded to the HEMS to test if the household electricity consumption is reduced. In the considered scenario, the electricity consumption for a 4 people household consuming 28.195 kWh/year is reduced a 17,7%.

The scheduling algorithm to reduce demand peaks is also tested. In this case, two scenarios are considered, one with a maximum power consumption of 750 W and the other with 1000 W. This scenario will happen when the Home Gateway receives a request to limit the household consumption from the Smart Meter through web services. Using the scheduling algorithm will ensure that the maximum consumption is not exceed, and demand peaks intensity can be reduced. This, however, comes with a cost for the customer, which will have to accept that the low priority appliances take longer to finish. This waiting time depends on the allowed maximum power consumption. The lower the maximum consumption is the longer the low appliances will take to finish their task. For the first scenario, where the limit was set to 750 W, the waiting time of low priority appliances is of 69,6 minutes, which is considerably high, an increase of 53,5%. However, when the limit is set to 1000 W, this waiting time is reduced considerably, 19,3 minutes. This represents an increase of 14,8%, which is a more feasible scenario.

This article has proved that the HEMS developed successfully carry out its two main objectives: reduction the electricity consumption and reduce electricity demand peak in home environments without significatively disturbing the users' comfort.

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