ENCOURAGE

Embedded iNtelligentCOntrols for bUildings with Renewable generAtion and storaGE

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Glossary of Terms

Term	Description
AMI	Advanced Metering Infrastructure
DSM	Demand Side Management
EncBN	Encourage Building Network
HAN	Home Area Network
HEC	Home Energy Controller
HEG	Home Energy Gateway
HEM	Home Energy Management
HEV	Hybrid Electric Vehicle
HPC	High Performance Computing
HVAC	Heating, Ventilation and Air Conditioning
HW	Hardware
IHD	In-Home Display
IP	Internet Protocol
IR	Infrared
OS	Operating System
PAN	Personal Area Network
PLC	Programmable Logic Controller
RF	Radio Frequency
RSSI	Received Signal Strength Indication
SEP	Smart Energy Profile

SoC	System on a Chip
SW	Software
ZCL	Zigbee Cluster Library

Executive Summary

This document addresses the communication protocols and technologies applied to residential and non-residential buildings, within the scope of the four scenarios representing the project demonstrators [1].

Starting with the ENCOURAGE goals and requirements for optimizing energy use in buildings, using energy brokerage and supervisory controls, a thorough analysis of the different standards, protocols and hardware device characteristics, is made as a first step to an effective integration into the ENCOURAGE platform in order to guarantee compatibility between very different appliances and hardware devices, dealing with legacy devices, wired and wireless capabilities.

Following this analysis, the most suitable technologies for the ENCOURAGE platform will be chosen, together with an initial description of the platform architecture.

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1. Introduction

This document constitutes deliverable D3.1.Addressing Communication technologies and protocols, it supplements the other WP3 deliverables that deal with Network Configuration (D3.2), Control of energy consuming devices (D3.3) and Virtual Metering and Monitoring (D3.4).

It takes as input the efforts of WP2 and is one of the inputs to WP7 (Integration and Demonstration).

The document aims to provide a logical flow from problem statement to conclusion. It does so by first introducing background information about the domain in which this communication takes place. This takes place in chapter 2, where a background about the energy efficiency problems in buildings has been described, thus some examples of challenges and solutions achieved in the field of information and communication exchange in close related research projects. It is followed by the chapter 3 with a summary of the available techniques around smart grid and the energy value change transformation. Chapter 4 provides a thorough evaluation of each of the different techniques, each of them motivated and discussed with respect to their relevance in the Encourage system architecture.

Chapter 5 explains in detail the called Encourage Building Network, that is the communication infrastructure that supports the intelligent building´s capabilities.

2. Background

This section will give a background about the energy efficiency in buildings problem domain in general, and Encourage in particular, taking into account the requirements present in the scenarios. The focus will be on the challenges related to communication for buildings.

2.1. Energy efficiency in buildings

Residential energy consumption and the amount of pollution emitted from the electric generators create side effects that are not beneficial to public health and well-being, including increased pollution in the air and water (CO2 and other greenhouse gases, mercury, and other trace elements and particulate matter), and the depletion of finite resources [2]. Green smart home technologies are aimed at reducing the footprint of greenhouse gases by efficient energy management in residential buildings. Focusing at reducing the amount of energy required to provide products and services to the end user. Studies have shown that the display of real-time information on consumption can result in reductions of up to 30% by enabling end users to consume responsibly and manage effectively [3].Along with saving energy and money, wider ideas and solutions of efficient technologies could address expandable environmental concerns, as well as reducing the dependence of fossil energy sources. In recent times, more so than ever, the consumer has become more green-conscious and therefore is looking for real-time visibility of energy consumption [4]. Further, the market for residential energy management is poised to grow dramatically due to increased consumer demand and new government and industry initiatives [5]. Energy user in building has grown in the last 30 years, due to new services needs and technologic advances. The increased service demand has been moderated by the application of improved technology and better use of resources from the population. Smart homes have been studied since 1990s, and their primary focus has been resident comfort [6]– more air conditioning – more electrical equipment’s – larger houses. They employ energy efficiency by occupancy check or adaptability to outside conditions. However, they are not automatically a component of the smart grid. Their integration to smart grid is an active topic [7, 8, 9].

Nowadays, advanced technology can be employed to bring significant benefit to the capabilities of living environments. There is considerable potential to improve energy efficiency in buildings. In particular, the advances in buildings system technology have led to the concept of Intelligent Buildings. In general, an Intelligent Building can be defined as a building that uses technology to automate the operation of building systems to enhance the safety, efficiency, and comfort of occupants. The technologies set up in a smart building must allow the occupants a productive and economic improved interaction and collaboration.

In the case of ENCOURAGE, we specialize the capabilities of the Intelligent Building towards energy efficiency, without neglecting a sufficient level of comfort for the occupants of the Intelligent Building.

To achieve this goal, the proposed ENCOURAGE platform mediates between the top level actors (brokerage, supervisory control, energy providers) and the actual buildings with the various devices (HVAC, local generation, meters) installed there in. The interfaces with of the platform with the top actors and the building infrastructure, as well as the interfaces of the devices within the building infrastructure pose different communication challenges and requirements.

The top level actor interfaces are not in scope for this document.

2.2. Related projects

In order to broaden the view and to gain a better understanding of the challenges and possible means the address them, the progress and results of other, related projects have been studied. For example, the eDiana [10] project hierarchically organizes the deployment and interoperation of the embedded systems environment of buildings and intra building units as cell and macro-cells.

One of the main problems addressed here is how to deal with an ever changing configuration of devices in buildings. This is in line with the ENCOURAGE requirement of being able to seamlessly add or remove devices. The approach taken to solve this is by having the system perform adaptation by means of automatic reconfiguration of the components. For this, different industry standard solutions are proposed.

Other projects that deal with an abundance of information exchange, and thus communications, such as ICT4E2B [11], focus on Intelligent and Integrated control. One of the main challenges are that of integration, controlling and management of sensors – themes that are to be resolved with standardization (allowing the use of plug & play technologies) and the development of commercially innovative solutions.

2.3. Encourage General Requirements

This section aims to summarize the device communications and protocol needs based on the demonstrator’s high level requirements presented in [12].

A recurring requirement and key to gathering information about energy consumption is the ability to monitor the consumption of the devices. At the same time, devices may have to be switched remotely, disconnecting them from or engaging them to the grid.

In addition, supporting functionality such as configuration, upgrading and device diagnostics has been identified. Devices may be added or removed from the infrastructure, ensuring a seamless operation of the platform while these actions take place.

Devices may come from a plethora of manufacturers and in different configuration. To overcome the challenge of dealing with such a heterogeneous environment, the platform will be based on the premise that industry standard protocols will be used.

At all times, security and privacy plays a key role, so the protocols and communications must fully support these requirements.

2.4. Specific demonstrator requirements

The following table assesses the communication needs regarding the partner demonstrators equipment.

Demonstrator	**Devices**	**Interfaces**	**Requirement**
NEST Laboratory, Italy (Pisa)	Eurobongas 2 Triplex generator	N/A	Energy reading
	Multimeters	Modbus RTU over RS-485 Connected to LAN via Serial-Ethernet / Serial-WiFi interfaces	Energy reading
	Eurobongas 2 Triplex generator	N/A	Energy reading
Private Homes and office buildings, Denmark (Aalborg)	Kamstrup 382 generation L smart meter	IEC 61107 communication protocol	Energy reading and monitoring
	NILAN Ventilation system		Status reading and activation (on/off)
	Heat pump	RS232	
	Solar panels (the inverter)	RS485	

Private Homes and office buildings, Denmark (Jadewej)	Kamstrup 382 generation L smart meter	IEC 61107 communication protocol	Energy monitoring
	Solar panels (the inverter)	RS485	
UPC Urban Campus, Spain (Terrassa)	Schneider Electric heating control system		Energy monitoring and control
	Enistic Smart Meter (BBSP-SM16D)	Zigbee	Energy monitoring and control
	Enistic Smart Energy Controller Lite (BBSP-SECL)	Zigbee Pro	Energy monitoring and control
	Enistic Multi-Sensor (BBSP-MS)	Zigbee Pro	Energy monitoring and control
	Pyreos 4x4 sensor array (PYLCC 4x4-F8)		
	Enistic current sensors (BBSP-CT15 and BBSP-CT30)		

3. Building communication technologies

Addressing the challenges presented in Chapter 2, this section revisits the concepts of smart grid and smart home and summarizes the state of the art in home energy management communications and control technologies.

Smart grid is accelerating the energy value change transformation, and will enable electricity distribution systems to manage alternative energy sources, improve reliability, facilitate faster response rates to outages, and manage peak-load demands. Building a smart meter, the advanced metering infrastructure (AMI) is a first step and would enable processing and reporting usage data to providers and households via two-way communication with the utilities [13,14,15]. Recently, there have been a lot of initiatives on the part of the government, utilities companies, and technology groups (standards committees, industries, alliances, etc.) for realizing smart grids for green smart homes [16]. Government initiatives include mandating upgrades to the grid and adding intelligence to meters that measure water, gas, and heat. The market for smart home products (such as lighting and HVAC controls, and home security systems) is also on the rise, driven in part by the need to conserve energy and by the expansion of home automation services and standards-based wireless technologies. Then, energy directives and smart grid initiatives have attracted hundreds of companies with energy management systems (e.g. Cisco, Google, Microsoft, GE).

Efforts are underway to design new standards and protocols, optimization methods that efficiently utilize supply resources (conventional and renewable resources, and storage systems) to minimize costs in real time. Smart grid technologies so far focus on integrating the renewable energy resources to the grid to reduce the cost of power generation and integrating these resources requires storage systems. Smart grids can be potent tools in helping consumers reduce their energy costs, but consumers have several concerns that may hamper rapid adoption. In order to maximize smart grids, utilities and energy suppliers must educate consumers about the potential benefits of these systems and then provide a package to these solutions so that advantages are obvious to consumers and easily integrated into their lifestyles.

The concept Home Area Networks (HANs) has been used broadly speaking to describe all the intelligence and activity that occurs in home energy management systems (HEMs), this section describes the concepts of HEM systems and HANs. To make it simple, HANs can be pictured as extensions of the smart grid and communications frameworks much like the familiar local area networks (LANs), but within a home. Instead of a network of servers, and computers, the HAN connects devices that are capable of sending and receiving signals from a meter and/or HEMs applications. Wired or wireless, there are tradeoffs that involve power consumption, sensitivity to interference, and security issues. The relevant issue to point out here is that HANs are not energy management applications, but enable energy management applications to monitor and control the devices on the home network. With limited data input and display capabilities, in-home displays

(IHDs) function as a detailed visual indicator of the electricity rates. IHDs are one-way communication devices, meaning the user can only monitor, taking real-time actions and providing feedback is achieved by the HEM systems, not by the HAN system. HANs and IHDs need an energy management application, an HEM solution [17, 18], in order to gain the most benefit from these smart grid components. A web-based portal for an HEM system is the best interface to the utility billing and demand response programs, because it enables the easiest execution and control of intelligent appliances that can be enrolled into such programs.

A HEM solution would enable the user to recall the optimized presets for sustainable energy-saving, get suggestions on energy efficiency improvements, and see how particular energy management compares to others in a specific neighborhood or district.

3.1. Home Area Networks (HAN) and Home Energy Management systems (HEMs)

At the top of the smart grid elements may include the premises smart meter, consuming smart appliances, distributed energy generation systems, environmental sensing, energy storage systems, energy management systems and in-home displays. Elements across the grid include electricity utility services, control centers, power grid distribution systems, appliance manufacturers and other devices. All these elements must fulfill their particular role in order to fully manage the energy consumption of appliances. Elements have different requirements and constraints and the nature of these elements will inform the suitability of different communication and sensing. What follows is a brief introduction to the key elements that articulate a HAN system for energy management.

Home Energy Management System (HEMs)

Home energy management system is a software application for managing energy controllable appliances, such as, lighting, Heating Ventilation and Air Conditioning (HVAC) and various consumer electronics. HEMs may be a dedicated device or a collection of functions across appliance automation displays, laptops and so on. HEMS performs device and consumption monitoring, allows configuration of energy thresholds, constraints and policies and coordinates interconnection and meaningful communication between elements such as sensors, appliances, smart meters, generation and storage systems by executing the specified energy management policies.

Smart appliances

The primary role of an appliance is to provide a service or a collection of related services to its users or to other appliances. Appliances make a major and an increasing contribution to the load on the power grid and as such are a very important part of any strategy for energy management. There are efforts to enable users to change their consumption behavior or to configure automated consumption thresholds, but additionally, appliances must be enabled to consume efficiently and intelligently in accordance with their wider context.

Appliances should respond to their environmental context, it may not be appropriate to continue heating a cold room if the windows are open. To this end appliances must be connected with sensing elements and respond to the information they provide. Appliances should also respond to their energy grid context. They should provide their consumption and state information for the cooperative and responsive function of the smart grid. Appliance interaction setting will enable utilities to wisely manage supply in real time and enable the implementation of more effective demand response services for consumers. Appliances may be connected to a Home Area Network,

Smart Meters

Smart meters are part of the first remote communication technologies. Early devices record premises energy consumption at regular intervals. New generation of smart meters will be able to notify this information to utilities automatically across some kind of communications network. Demand Response is another mechanism by which appliances can act on direct grid state or utility pricing notifications and stop or delay consumption or switch to idle modes of operation. In the same way Dynamic Response enables the appliances to detect critical grid state and adjust behavior. Other potential capabilities incorporated into smart meters include visual indicator for user consumption monitoring, analysis, remote control and automation

Sensors

Sensors convert environmental stimulus into a signal that can be measured and stored. There are a variety of sensor types, like: temperature, humidity, light, presence, sound, magnetism. A sensor node is a device that incorporates a one or more sensors with computation capabilities and a communication system. Typically sensors are deployed in hard-to-reach locations, so they cannot be connected by wire and must communicate wirelessly and operate on low power. The role of sensing in an energy management system is to provide context information in which appliances can validate their operation mode, for instance adjusting the heating system according to a threshold temperature or turning on/off lights according to occupancy. Data from sensors (raw) cannot be used directly to control appliances some element of the system must provide functionality to read into this data to provide relevant environmental information. After this information can be communicated to appliances in order that they might respond with appropriate policies of operation. It is also possible that this contextual information could provide awareness to utilities of a risk of overload or provide policy makers with these information as well as consumption information to enable direct energy saving resources.

Sensors convert environmental information that can be measured and stored. There are a variety of sensor types. Progress in electronics and low power communications has seen the inception and advancement of the smart sensor. In [19] the author describes smart sensors, or sensor motes, as a low power devices equipped with one or more sensors, a processor, memory, a power supply, a radio, and often some kind of actuator. These motes can include a number of different sensors and are generally battery powered, though some devices may include a mechanism, such as photovoltaic cells, to harvest energy. Sensor motes generally form Wireless Sensor Networks (WSN) either as a large scattering of motes or as a smaller number of strategically placed motes. Motes can have different roles in the WSN, such as sensing, data relay or mote management,. The network also includes a base station or sink to gather data, usually connected to a wired network. The memory and processor added to sensors support storage and operating systems, enable protocols and provide services to enhance efficiency in sensor operation and routing.

Wireless Sensor Networks use their own protocols from PHY to Transport layer, optimized for ad-hoc and low power. Many protocols are implemented in published standards (or de-facto standards) such as IEEE 802.15.4, Zigbee, specified in [20], Wireless HART, ISA 100.11, IETF 6lowPAN, 2009 IEEE 802.15.1 Bluetooth Low-Energy. Services include synchronization saving energy by reducing collisions or retransmission or implementing duty-cycles, different techniques and methods and tools are used to balance the need for coverage with the cost of coverage. Other services include security, data compression and aggregation. The cost of sensor motes is coming down however number of parallel standards and the range of open and proprietary solutions mean that economies of scale and ubiquitous ad hoc interoperability still elude the sensor mote industry. The markets are very varied and still far less than common Bluetooth or WiFi devices with very mixed returns for stakeholders. These factors have precluded wide adoption and the realization of a ubiquitous sensing infrastructure so far.

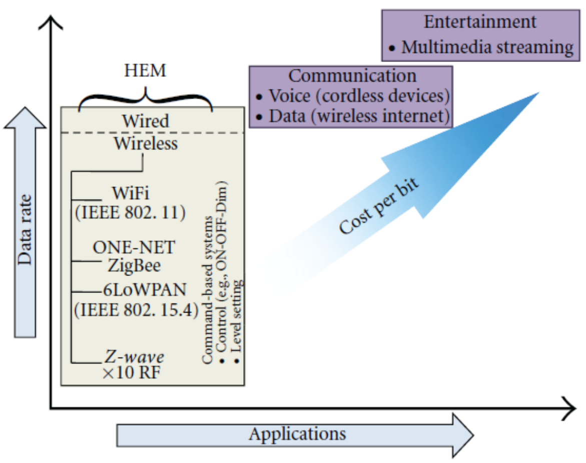
User Interface Devices

A user interface device referred to as in-home display (IHDs) works together with HEMs to present useful information to the users as detailed local consumption history, billing and energy management policies. The device may also provides an interface to HEMs for the configuration of local (or utility controlled) energy management programs.

3.2. HAN Communications and Network Technologies

The energy management system is at the core of green home/building concept, it enables home energy control and monitoring, providing benefits to both consumers and utilities. The energy management system intelligently monitors and adjusts energy usage by interfacing with smart meters, intelligent devices, appliances, smart plugs and other end devices, thereby providing effective energy and peak load management. The platform that articulates this communication is the Home Area Network and this section reviews the most suitable communications and network technologies for HAN support to interconnect the HEMs to end devices.

Figure 1 [22] illustrates the cost associated with HEM applications, as it can be seen the cost is significantly lower compared to other home applications because of the differing functionalities. HANs comprise command based systems that require very short acquisition time for sending data to multiple destinations and this cuts down the data rate and the bandwidth requirements compared to link based systems (communication and entertainment systems) that need a reliable point to point communication link for longer periods of time. Internet protocol (IP) is a protocol used for communicating data within a packet-switched internetwork and is responsible for delivering data from source to destination based on an IP address. Being the foundation on which the Internet is built and communication is achieved, IP can be used across a number of different heterogeneous network technologies, due to the ease of interoperability, ubiquitous nature, widespread adoption, and work being performed to create a lightweight interface, IP is being seen as essential to the success of HAN and smart grid development. As the significance of devices communicating within the HAN increases, so does the requirement for usable IP addresses. In a very generic way, the different technologies available can be classified based on the transmission medium into wired and wireless, as is shown in **Figure 2** [22]



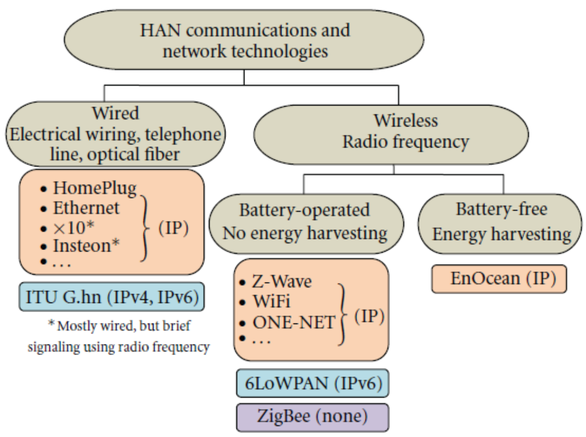


Figure 1. HEM applications associated cost **Figure 2. Technologies classification**

3.3. Wired HAN Technologies

In this section we assess wired communication technology suitable for energy management of appliances. Essentially there are two suitable mediums; dedicated local home and office data network wiring, typically Ethernet, and the power lines that supply power from an electricity distributor to the appliances in homes and buildings.

Power Line Communication (PLC)

Historically, Power Line Communication (PLC) [2, 3] has been a popular communication mean for appliance control. PLC technology uses power line infrastructures for data and control and its primary advantage over other wired network medium is its pre-existence in virtually every part of every building. PLC can use sockets for power and communication and provide a pre-existing line back to the Utility, though there can be performance issues over long distances and over complex legacy power networks. A number of open and proprietary standards exist for this medium.

While there is no doubt that new technology is beginning to manage power line problems better, this is still a legacy hostile and unstable medium often requiring the intervention of compensating devices. Much of the technology is proprietary and existing standards are limited. Devices are location restricted and the network is difficult to extend making this an unlikely medium for realizing context awareness.

- Universal Power line Bus (UPB)

UPB, described in [15], is a mature open low-rate PLC standard developed by PCS Power line Systems for implementation on general-purpose micro-controllers. Its use of Power line makes it a contender for ubiquitous deployment, but the lack of support for alternative mediums impact reliability and application. UPB's main competitor is X10 and while UPB is more reliable and faster, its cost is a prohibiting factor and its relatively low rate still limit its application. Though UPB is generally reliable, there are reports [16] that UPB has a vulnerability to being jammed by dimmer appliances. The technology requires manual installation and requires configuration dedicated device and software making wide adoption unlikely.

- Homeplug

The Homeplug Power line Alliance [17] was setup to standardize and encourage networks over power lines. Homeplug is a mature technology since 2001 and one of the few to overcome many of the inherent difficulties with this medium, providing easy installation, high speed and reliability. Another challenge for power line technologies has been universal standardization and this challenge was met when IEEE P1901, based on the Homeplug de-facto standard, was ratified in September 2010. However, despite its maturity Homeplug has not seen the cost reductions one might have expected. Homeplug was originally developed to extend or adapt an Ethernet network bus and its devices [3] making it perfect for communication over a common transport. Homeplug has since been extended to include Homeplug AV for Audio Visual (AV),Homeplug Command & Control (C&C) for control of Heating Ventilation and Air Conditioning (HVAC), lighting and security and Homeplug Access BPL for Broadband Power line (BPL) and recently Homeplug Green PHY (GP). Homeplug C&C and GP are aimed at appliance control and Smart Grid and Smart Energy applications. Work in the upper layers of these appliance and energy standards is ongoing, however in addition Homeplug Alliance have joined with the Zigbee Alliance in the development of ZigBee Smart Energy Profile which will support Homeplug and 6LowPAN RF networks. With Homeplug's use of power line, its stability and its universal standard make the technology a strong candidate for ubiquitous deployment, but devices are large form factor and integration with small and dispersed sensors has not been a common feature and there is not yet a clear catalyst for widespread adoption.

Ethernet

Less popular for appliance and energy management is Ethernet. Installation effort and cost are high due to the frequent requirement to introduce new wiring, particularly in homes and though common in offices, this effort would rule out ubiquitous deployment and discourage widespread adoption for energy management applications. Having said this, a number of relevant appliance communication standards support Ethernet. KNX protocol for building control includes Ethernet amongst its communication media and Homeplug was developed to extend or adapt an Ethernet network over power line. Ethernet also provides excellent support for common transport such as TCP/IP.

In the main however, Ethernet is the standard of choice for wired local area networks though it will provide high quality communication for building appliance monitoring and control where wiring already exists. Ethernet is mature and globally standardized by IEEE 802.3 [18] and defines the PHY and MAC layers of a wired Local Area Network. The MAC layer protocol operates Carrier Sense Multiple Access with Collision Detection and specifies half and full duplex operation. The PHY layer is over coaxial, twisted pair or optic and operation can be between 1Mbs and 10 GBps. Ethernet is a shared medium and relies heavily on upper layer protocols for security, though the risk is lessened by switched Ethernet. Although gateways and adapters exist to extend Ethernet to other media such as Wi-Fi, ADSL, PLC and RF, the technology does not have an inherent affinity with other media and form factor is still not small enough for ubiquitous environmental sensing

RS-485

RS-485 standard, also known as TIA/EIA-485 or EIA-485, presents electrical characteristics of drivers and receivers for implementation in balanced digital multipoint systems. The standard is published by the Telecommunications Industry Association/Electronic Industries Alliance (TIA/EIA). Using this standard allows to use long distances in digital communications networks and also in electrically noisy environments. RS-485 defines multiple receivers being connected to a network in a linear and multi-drop configuration. These characteristics made RS-485 a very used and well known technology in industrial environments and similar applications.

RS-485 only specifies electrical characteristics of the driver and the receiver. Nothing is specified or recommended about communications protocol. It can achieve data transmission speeds of 35 Mbit/s up to 10m and 100kbit/s at 1200m. The differential balanced line over twisted pair allows it to cover up to 1,200m. A practical rule is that the speed in bit/s multiplied by the length in meters should not exceed 10^8. This means that in a 50 meter cable we should not use more than 2 Mbit/s.

RS-232

RS-232,also known as EIA-232 or TIA-232, presents electrical characteristics the electrical characteristics, timing and meaning of signals, and the physical characteristics about the connectors (size and pin out). The current version of the standard is *TIA-232-F Interface Between Data Terminal Equipment and Data Circuit-Terminating Equipment Employing Serial Binary Data Interchange*, issued in 1997.

The Electronic Industries Association (EIA) standard RS-232-C (1969) states:

- Electrical signal characteristics such as voltage levels, signaling rate, timing and slew-rate of signals, voltage withstand level, short-circuit behavior, and maximum load capacitance.
- Interface mechanical characteristics, pluggable connectors and pin identification.
- Functions of each circuit in the interface connector.
- Standard subsets of interface circuits for selected telecom applications.

Nothing is specified about elements as the character encoding or the framing of characters, or error detection protocols. The standard does not specify bit rates for transmission, but it says that it is intended for bit rates lower than 20,000bit/s. Although this, it is widely used at speeds up to 115,200 bit/s or even above. RS-232 does not provide power to devices connected to the line.

Presently, the RS-232 is used far beyond the original purpose application of interconnecting a terminal with a modem. New standards have been developed to overcome some limitations and issues like:

- Large voltage swings and requirement for positive and negative supplies increases power consumption of the interface and makes it harder to design power supply. The voltage swing requirement also limits the upper speed of a compatible interface.
- Single-ended signaling referred to the common signal ground restricts the noise immunity and transmission distance.
- Connecting more than two devices is not defined (multi-drop connection). While multi-drop "workarounds" have been found, they have restrictions in speed and compatibility.
- The asymmetrical definitions of the two end points of the link make the assignment of the role of a newly developed device problematic; the designer must take a decision on the type of interface (DTE or DCE) and which connector and pin assignments to choose.
- Handshaking and control lines are intended for the setup and takedown of a dial-up communication; the use of handshake lines for flow control is not reliably implemented in many cases.

- Nothing is specified about supplying power to a device. But the DTR and RTS lines can provide a weak current.

Modbus and Modbus TCP/IP

Modbus is a serial communications protocol issued by Modicon in 1979 for use with its programmable logic controllers (PLCs). Because it simplicity and robustness, it has been accepted as *a de facto standard* communication protocol. It is one of the most used protocols to connecting between industrial electronic equipments.

The key advantages for the success of Modbus in the industrial area are:

- It was idealized keeping in mind the industrial environment
- Free and openly published
- Easy to deploy and maintain
- It is not restrictive about moving the basic information, being vendor-friendly

The network Modbus supports about 240 devices. Modbus is often used to connect a server computer with a remote terminal unit in supervisory control and data acquisition (SCADA) systems.
Because of its genesis on industrial environment, the data types are named from the industrial lexical: a single-bit physical output is called a coil, a single-bit physical input is called a discrete input, etc.
Modbus Organization, formed of independent users and suppliers of Modbus compliant devices, develop and update the Modbus protocols

Modbus TCP/IP, also known as also Modbus-TCP, is a variant of the MODBUS family of simple, vendor-neutral communication protocols intended for supervision and control of automation equipment.
It is about the use of Modbus protocol under an 'Intranet' or 'Internet' environment using the TCP/IP protocols. The most common use of the Modbus TCP/IPis for Ethernet attachment of PLC's, I/O modules, and 'gateways' to other simple field buses or I/O networks.

BACnet

BACnet is a data communication protocol for building automation and control networks.BACnet defines from what kind of cable to use to how to make a request or command. What makes BACnet special is that the rules relate specifically to the needs of building automation and control equipment, i.e., they cover things like how to ask for the value of a temperature, define a fan operating schedule, or send a pump status alarm.

BACnet messages are called "service requests" because it is based on a "client-server" model. A client machine sends a service request to a server machine that then performs the service and reports the result to the client. BACnet currently defines 35 message types that are divided into 5 groups or classes. A common one is the "ReadProperty" service request that causes the server machine to locate the requested property of the requested object and send its value back to the client. Other classes of services deal with alarms and events; file uploading and downloading; managing the operation of remote devices; and virtual terminal functions.

BACnet is often associated to HVAC systems but BACnet already contains most of the capabilities required for non-HVAC communications. These include the ability to read and write binary, analog, and text data; schedule control actions; send event and alarm notifications; and so on. However, the committee realized that these capabilities might not cover all situations and developed the standard considering toward accommodating future, unknown building automation and control applications. This way, one of the real strengths of the BACnet model that emerged from this consideration is that it can be easily extended. If a vendor comes up with some new functionality for which communication is required, the vendor can add new properties to existing object types or create new object types that are accessed in exactly the same way as the eighteen defined in the standard. This is not only expected, it is encouraged. Proprietary features may not be interoperable without vendor cooperation.

3.4. Wireless HAN Technologies

A home automation network (HAN) can also be made using wireless technology. This kind of technology exists over a hundred years, but increased considerably in popularity over the last decade. With wireless technology the network becomes more adaptable, being relatively easy to add or remove devices without the need to change or have a dedicated wire installation. The main factors that contributed to the increasing use of wireless devices is the low cost and smaller size, allowing longer lifetime and sensing density.

Infrared

Infrared technology works using an IR source and anIR receiver, usually a LED and a phototransistor or photodiode. Each pair components allow communication only in one direction, so for bidirectional communication the device need to have both an IR source and an IR receiver. The signal used is modulated allowing data to be transmitted and rejecting ambient light at the same time. This kind of technology is mainly used for short range communications, since both devices need to be in line of sight in order to work because IR, this can be a limitation, or can be viewed as an advantage since devices in different rooms don’t interfere with each other’s.

There are two proprietary protocols by Philips RC-5 and RECS-80 adopted internationally in remote controls, But with the appearance of parallel proprietary protocols the technology was starting to be threatened for the lack of compatibility. To solve this problem InfraRed Data Association (IrDA) was created in 1993 with about 70 companies.

In terms of network speed, considering a range less than 5 meters infrared has 3 modes:

- **IrDA-SIR** (slow speed) – data rates up to 115 kbps;
- **IrDA-MIR** (medium speed) – data rates up to 1.15 Mbps;
- **IrDA- FIR** (fast speed) – data rates up to 4 Mbps.

The range achievable is directly influenced by the viewing angle of the LED, narrower beam equals more range, but higher directionality too, requiring better aim between the devices in order to work properly. IrDA provides no security, but with the nature of IR communications can be blocked if necessary. For a local area network (LAN) this protocol lacks some features since IrDA doesn't offer any TCP/IP configurations protocols like DHCP and DNS.
To use in energy management this technology seems unlikely, because of the line of sight and range limitations, for this reason many manufacture are favouring RF solutions over IR.

Wi-Fi

Wi-Fi (short for wireless fidelity) is term used for wireless local area networks (WLAN) using IEEE 802.11 specifications. The term Wi-Fi was created by an organization named Wi-Fi Alliance, which is supervises tests that certify product interoperability. The standard specifies the physical layer including frequency and modulation method as well as the MAC (Media Access Control) layer using CSMA/CA with binary exponential back off algorithm. There are two coordination functions supported by the standard Distributed Coordination Function (DCF) and Point Coordination Function (PCF). DCF have asynchronous communication and PCF have synchronous communication for time critical data like voice or video. There is a third coordination function called Hybrid Coordination function which is uses both DCF and PCF. The standard is an extension to the Ethernet media providing an access point allowing wireless mobility still using the usual protocols TCP/IP.
This technology is not widespread to use in energy management, since the power consumptions is high and the components are not small enough in some cases. For example in environment logging this option would not be feasible if it was battery powered, because of the low battery life achievable. Power consumption exceeds that of Bluetooth, 802.15.4 and other Wireless Personal Area Networks (WPAN). Using A-MPDU and Greenfield preamble can help to decrease the power consumption.
Wi-Fi is a good alternative to cables, making the creation of a LAN cheaper, being directly compatible with other devices like a laptop or cell phone. As the technology spreads the prices will continue to decrease making a Wi-Fi a good network choice for even more devices. There are some limitations in terms of radio channels legally available worldwide in the 2.4 GHz and 5 GHz bands. The usual range is 100 m outdoors, but the real value depends on factors that must be considered like the antenna used, type of obstacles, temperature, power of transmission, etc. In terms of bandwidth it depends on the 802.11 variant used below are some speeds depending on the norm used:

- **802.11b**– 11 Mbps;
- **802.11g and 802.11a** – 54 Mbps;

- **802.11n** – 300 Mbps.

To secure the connection there are three solutions WEP (Wired Equivalent Privacy) WPA (Wi-Fi Protected Access) and WPA2. WEP is the least secure being easily overridden even when configured properly. WPA (Wi-Fi Protected Access) is based on EAP (Extensible Authentication Protocol) and AES (Advanced Encryption Standard). The WPA2 is an improved version WPA with a new AES-based encryption CCMP (Counter Mode CBC MAC Protocol). Wi-Fi is the certification for WLAN IEEE 802.11 standard compliant devices.

Bluetooth

Bluetooth didn't grow as fast as predicted, but enough to maintain the production costs low. It is used in keyboard or mouse, remote printer, wireless games controller, cell phones and many other applications with short range communications. It uses a proprietary open wireless technology in the 2400-2480 MHz band (ISM) with 79 channels, allowing PANs (Personal Area Network) with high levels of security. The main purpose this technology is to replace cables in a variety of applications. There are 3 Bluetooth classes with different ranges and transmitting powers which are:

- **Class 1**: range up to 100m with 20 dBm (100 mW) transmitting power;
- **Class 2**: range up to 10m with 4 dBm (2.5 mW) transmitting power;
- **Class 3**: range up to 1m with 0 dBm (1 mW) transmitting power;

Class 2 devices range can be increased when used with a class 1 device, compared to a system with only class 2 devices. This is possible because class 1 has more transmitting power and higher sensibility than class 2, thus increasing the achievable range.
The Bluetooth standard has been evolving with some features added as well as increasing data rate, the current versions in use are:

- **Version 1.2**: data rate up to 1 Mbit/s;
- **Version 2.0**: data rate up to 3 Mbit/s;
- **Version 3.0**: data rate up to 24 Mbit/s;
- **Version 4.0**: data rate up to 24 Mbit/s.

When compared with Wi-Fi, Bluetooth is less expensive and more power efficient, but with lower coverage and data rates. Even using the same transmission frequency in some cases, since Wi-Fi can work on 5GHz range, the technologies use different methods to send the data. Bluetooth is a packet based protocol in a master slaver structure, using originally Gaussian frequency-shift keying (GFSK) modulation, with π/4-DQPSK and 8DPSK used on the version 2.0 + EDR (Enhanced Data Rate).
There could be up to 7 devices in an ad-hoc computer network using Bluetooth (piconet) and all devices need to be paired prior to any communication. Piconets are not formed through any central control, but are started by a master and can include slaves which will register with the master. Pairing is a security method using a password and/or MAC address to allow the connection to be

made, this is only necessary the first time devices are connected being automatic afterwards. It's possible to exclude a paired device at any time if wanted. Devices share information like device name, class, list of services and technical information in order to identify which dispositive is what and their respective functions. During the pairing process a key is generated (link key) and used to encrypt the data that travels thru the air making the connection more secure.
Bluetooth low power is a variant of classic Bluetooth made with power consumption in mind. This variant has slower data rates then classic Bluetooth decreases from 3 Mbits/s to 1 Mbit/s max. In contrast power consumption can decrease considerably compared to Bluetooth classic, being a better solution for battery powered devices. Bluetooth has a range of adopted protocols including TCP/IP making it a strong candidate for integration into a common data transport, however Bluetooth provides no direct support for energy management applications.

Visible Light Communication

Visible light communications share the same working principle as infrared communications needing an emitter and receiver of light, switching on/off and transmitting a modulated signal with data.
The difference is the visible light source used with wave lengths between 380 nm and 750 nm instead infrared light. This technology concentrated their efforts to create a physical and MAC layer for communication with visible light. Until today there are few known problems induced by visible light wavelengths compared to traditional wireless technologies. LEDs are good candidates for this type of communication since they can change their state between on and off quickly, without degrading the LED. The transitions are fast enough that the human eye can't perceive any changes appearing to be in the on state all the time.
Not every environment is good to use radio waves, in those cases light could be a viable alternative since it isn't affected by electromagnetic radiation. Some good examples for this technology would be:

- Environments where radio reception is difficult like tunnels and factories;
- Sensitive rooms in hospitals where radio frequency waves would be undesirable;
- Areas with high risk of explosion like mines or oil rigs for example;
- Secure communications, since light can't penetrate thru walls limiting data access and reducing the chances of eavesdropping;
- Underwater communications, because visible light (especially blue) can propagate better than radio waves.

VLC has in most cases a high SNR up to 50dB but with low bandwidth. The data rate can be improved with optical filtering and using blue light for transmission, improving data rate and/or range. Other way to improve bandwidth is using RGB LEDs, this way three signals are transmitted at the same time but it requires a more complex circuit on the receiver side capable of separating the 3 colours like a CMOS sensor. Data rates of up to 100 Mbit/s can be achieved using RGB LEDs. VLC is not the best choice for massive data transmission, even with high data rates achieved with

meticulous setups, in real life scenarios the average rate would be about 5 Kbit/s with reasonable ranges up to 6 meters.
In terms of standards for VLC Japan Electronics and Information Technology Industries Association (JEITA) created two standards JEITA CP-1221 and JEITA CP-1222. The IEEE 802.15.7 Visible Light Communication Task Group has also completed a physical and MAC standard for Visible Light Communications (VLC).

IEEE 802.15.4

IEEE 802.15.4 standard is used in Wireless Personal Area Networks (WPAN) and is intended for low power, low cost and low speed communications, defining the lower network layers. WPAN networks are used in applications like remote identification, home and industrial automation. The standard defines the physical layer as well as the Media Access Control layer (MAC). In terms of data rates the basic framework can achieve 250Kbits/s in a 10m range, but lower rates can be achieved in order to reduce power consumption with 100 Kbit/s data rate being added to the current revision.
On the physical layer are defined the frequencies where the protocol can operate, which are:

- **868.0 – 868.6 MHz:** used in Europe, allowing one communication channel;
- **902 – 928 MHz:** used in North America with up to 30 channels;
- **2400 – 2483.5 MHz:** used worldwide with up to sixteen channels.

The signal can be modulated using Direct Sequence Spread Spectrum (DSSS) or instead Phase Shift Keying (PSK) types may be used. Interface with Wi-Fi and Ethernet is common, but not with other media like PLC, IR or VLC.
The network can have two types of nodes, Full Function Device (FFD) and Reduced Function Devices (RFD). FFD can work as the coordinator of network or as common node, being able to talk to any other device peer to peer. RFD on the other way can’t act as coordinators, only communicate with FFDs, since this network node is meant for simple devices with modest resources. Networks can be made in two topologies peer-to-peer and star, but in either case one device must act as a coordinator.

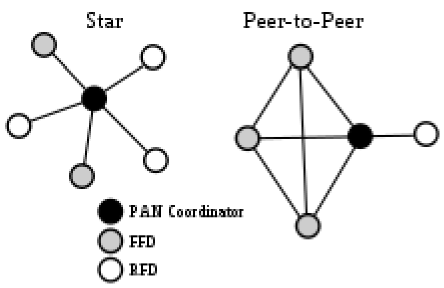


Figure 1 – Star and peer-to-peer topologies

For data transport architecture there are four fundamental frames, data, acknowledgment, beacon and MAC command frames. The network can operate in beacon or non-beacon management. With beacon enabled the coordinator will periodically send a frame with information about the network segment and possibly guarantee time-slots for certain nodes. In the time between beacon frames the network may send data controlled by CSMA-CA (Carrier Sense Multiple Access with Collision Avoidance). In non-beacon networks data is sent using only CSMA-CA. Security is implemented for the upper layers by the MAC, but extra security is implemented in the higher layers.
IEEE 802.15.4 is used as basis in protocols like ZigBee, WirelessHART, Miwi, RF4CE, 6LoWPAN. In the following text some protocols that use IEEE 802.15.4 will be analysed.

- ZigBee

ZigBee open wireless network with the standard ratified in 2004 by ZigBee Industry Alliance and is used mostly in mesh networks to transmit data over long distances. Mesh networks work by transmitting data to the nearest device, then to the next nearest device and so on until the destiny is reached. With this mode of cooperation, it's possible to create a large network without the need that all devices exchange data directly with the standard being optimized for a medium range of 10 – 75m, with data rates up to 250 Kbits/s. This protocol was targeted for applications with low data rate, secure networking and long battery life like embedded sensing, home/building automation and energy management. The maximum number of nodes in a ZigBee network is 1024. The network layer of ZigBee defines the stack profile and network rules, addressing, routing, maintenance and implements discovery. The stack defines rules like security, size, timeouts, maximum routers, children and depth of the network.
Depending on the area where ZigBee will be implemented there are application profiles specified which are:

- Building Automation;
- Remote Control;
- Smart Energy;
- Health Care;
- Home Automation;
- Input Device;
- Light Link;
- Retail Services;
- Telecom Services;
- Network Devices.

There are 3 types of devices in a ZigBee network the coordinator, the router and the end device. The coordinator is the main component of the system where all devices will connect to defining the network ID, stack profile and RF channel, it also stores information about the network and may bridge to other networks. There could be only one coordinator in each network. Routers are not always necessary in a small network and their main function is passing on data from other devices, they also maintain their own set of end devices and routing tables. The end device is the least functional device on the network but in most cases cheaper to produce. This kind of devices cannot relay data from other devices and can only talk to the parent node, because of this the node can be asleep a considerable amount of time resulting in a long battery life. Cost of entry set by the Alliance is certainly a factor in the level of adoption. ZigBee networking standard does not support a common transport, but there are signs that the ZigBee Alliance may be moving away from this part of the standard or at least breaking the sole dependency on IEEE 802.15.4.

- 6LoWPAN

6LoWPAN is an IPv6 Low power Wireless Personal Area Networks and appeared to apply the internet protocol even to the smallest devices making them able to join the internet of things. 6LoWPAN provided mechanism in header compression and encapsulation in order to allow IPv6 packets to be sent over low power networks and low bandwidth like the IEEE 802.15.4.This protocol converts 60 bytes of headers down to 7 bytes and allows communication with devices across the internet without the need of ZigBee-to-IP translation. This protocol can be used for example on smart grids, home automation/entertainment applications and office/factory environments. The protocol operates in the 2.4 GHz frequency range with up to 250 Kbit/s. It can have up to 100 nodes with a maximum range of 200 m.

RF4CE

RF4CE was developed to overcome the infrared remote control limitations by using RF technology, allowing two way communications and eliminating the line of sight range problem. It was founded by Panasonic Corporation, Royal Philips Electronics, Samsung Electronics Co., Ltd. and Sony Corporation on June 12 2008. Even being the build of a RF remote control the main reason for RF4CE's, it could also be used to other purposes like sensor or small form automated controllers. It can work over 3 channels, with security features like key generation mechanism and industry standard AES-128 scheme all on the operational frequency of 2.4 GHz. The network can have two types of nodes, controllers and targets, but the controllers can be other things besides remote controls like for example appliances. There is also the possibility that multiple controllers join the networks by pairing with targets. Targets can communicate with each other and join PANs on a RF4CE network. Power management can be achieved by a range of configurations for enabling or disabling power saving mode, including operating a receiver duty cycle where the sender targets the active period. After creating their PAN and the connection has problems, devices will try other channels until the communication is re-established, this feature is called channel agility and helps to overcome noisy RF environments.
RF4CE supports application profiles that define standardized command sets for multi-vendor interoperability, as well as vendor specific extensions to standard application profiles for vendor specific customization and only authorized devices are able to communicate with each other.
Even with RF4CE not supporting energy management applications directly, there is support for additional profiles over the same network layer. With ZigBee Smart Energy Profile there may be room for dual function.

Z-Wave

Z-Wave is a wireless communications protocol specifically designed for remote control application in residential and light commercial environments. It is optimized for reliably send/receive small packets with low latency and works on ≈900 MHz with GFSK modulation achieving a bandwidth up to 40 Kbits/s. In terms of communication range it can reach up to 30m in open air. This technology is used for example in lighting, HVAC and access control. It is optimized for low overhead commands like ON-OFF-DIM in light switches with the possibility of including metadata in the communications. All this results in a solution with low power and low manufacture costs which is easily integrated in embedded systems, even if they are battery operated.
Z-Wave is a meshed network which can have one or more masters controlling routing and security. Since each device can retransmit packets, even when devices aren't in direct range they can communicate with each other using the Z-Wave network, but the delay introduced by each hop must be considered too. There could be up to 232 devices with the option of bridging networks if further expansion is needed.

EnOcean

EnOcean is used to build a sensor network using radio frequency. The system can work with 868 MHz frequency for Europe or 315 MHz for North America. Data packets are 14 bytes long and are transmitted at 125 Kbit/s. In terms of range it can achieve up to 300 m outdoor or 30 m indoor, but the range can be extended using repeaters. There are some EnOcean devices that don't use batteries harvesting their energy from environment (using motion, solar and temperature), reducing the device life cost and making it maintenance free. There is no encryption included yet, but that feature is being developed to be included in the products.

Private Proprietary protocols

There are also proprietary protocols provided by the manufactures in order to enhance and/or add features when compared to the existing solutions. Most of the time proprietary protocols use part of an existing solution changing it in order to fulfil their requirements. These changes can result in change on battery consumption, smaller messages and so on.
One advantage of this approach would be keeping rivals from copying the product since the protocol is kept secret, giving some advantage manufacture on new products. On the other hand customers like interoperability in their products, even being made by different manufactures which is not possible using two different protocols. Because of this limitation developers use more and more common standards in order guarantee interoperability. For example if the customer wanted to build a system with scalability in mind, using a proprietary for the system wouldn't be a wise choice since it would limit the market options for new devices.

Others

A number of self-published open standards exist [19, 20], whose alliance partners include a number of proprietary technologies.

3.5. Background on Home Energy Management systems

The penetration of HEM systems in green homes has created a new market segment for embedded hardware providers.

Cisco

In 2010, Cisco System unveil edits home energy controller (HEC), which is part of a larger smart grid infrastructure that spans solutions for utilities, substation networks, smart meter networks, and the home network. The HEC has user interface Tablet that runs Ubuntu Linux, powered by a 1.1 GHz Intel Atom processor. Supplementing the HEC on the utility side is Cisco's Home Energy Management Solution, which gives utility companies the right tools to enhance customer satisfaction and effectively implement demand/management, load shedding, and pricing programs for residential deployments.

Figure 3 shows Cisco's HEC architecture. Using the HEC, consumers can take advantage of special energy pricing programs, demand response can be managed, and electric vehicle integration becomes a reality. The HEC provides:

- the user engaging and easy-to-use energy management applications to monitor and budget energy use and control thermostats and appliances
- the utility of the ability to provision and manage a home area network (HAN) that monitors and controls energy loads
- highly secure end-to-end data communications across wired and wireless media and networking protocols.

The HEC is a networking device that coordinates with the networks in the home and the associated security protocols, such as ZigBee (communication with smart appliances),Wi-Fi (communication with the home network), and PLC and ERT (communications with utilities). To monitor and control energy loads such as heating, ventilating, and air conditioning (HVAC) systems, pool pump, water heaters, TVs, computers, and other devices, consumers will need to wirelessly connect the appropriate compatible, tested peripherals to the HEC. Cisco is currently in trials with utilities for the home energy controller to scale and support devices implemented in residential deployments,

Energy management software is deployed in utility facilities and its hosted services help utilities provide personalization and data to increase customer satisfaction for energy programs, with the following services:

- provisioning and management capabilities,
- unique, customized look and feel for devices,
- mass firmware updates to thousands of devices,
- integration with utility back-end applications and third party software.

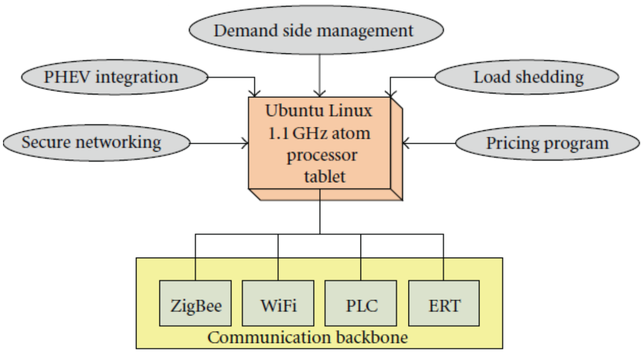


Figure 3. HEC architecture and interface

Freescale

During the last quarter of 2010, Freescale Semiconductor has announced reference designs targeting the HEM market. Freescale demonstrated its Home Energy Gateway (HEG) reference platform in September 2010 in Europe. Freescale's Home Energy Gateway reference platform is based on the MX ARM9 SoC that is both flexible and scalable and based on ZigBee Smart Energy1.0 mesh architecture for bidirectional control **Figure 5**. The HEG's controller integration allows for a low bill of materials cost. Freescale's HEG includes a central hub that links smart meters, smart appliances, and smart devices in the home area network (HAN) and collects and reports power usage data. The Freescale HEG allows every point of the smart home to be connected and controlled from a central point, enabling power efficiency and energy optimization. The HEG links to a Wide Area Network (WAN) for remote control and monitoring by the utility and communications service provider.

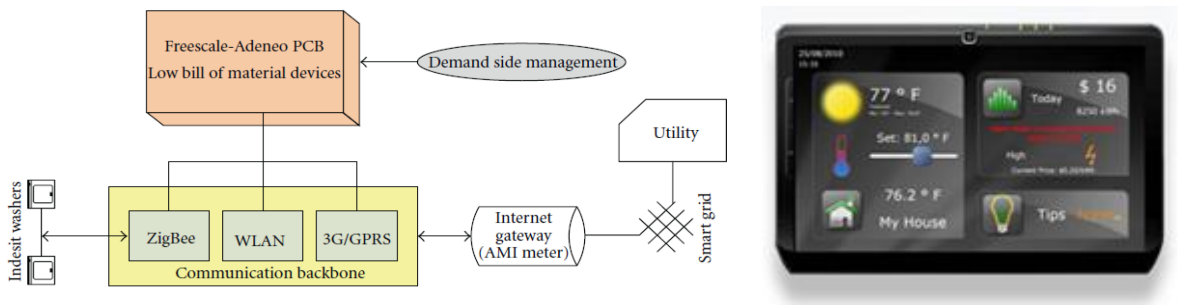


Figure 5. HEG architecture and interface

Functions of the Home Energy Gateway include

- collecting real-time energy consumption from smart meter and power consumption data from various in-house objects
- controlling activation/deactivation of home appliances
- generating dashboard to provide feedback about power usage
- providing control menus to control appliances
- providing a ubiquitous link to the broadband Internet.

Freescale reference platform is available now through its systems integrator partner Adeneo Embedded

In Europe, Freescale announced a smart grid demonstration project with the Indesit Company, an Italian manufacturer of smart appliances. Indesit's Smart Washer was equipped with a Freescale ZigBee node that enables it to adjust its cycle starting time according to energy cost and availability of green power. The washer retrieves this information from the local utility via a ZigBee-enabled internet connection to the smart grid.

Intel Corp.

Intel announced its Home Energy Management the acronym HEM reference design earlier in October 2010, **Figure 6**. HEM reference design is based on the Atom processor Z6XX series and Intel's Platform Controller Hub MP20. The reference design is manufacturing ready and supports both Wi-Fi and ZigBee. The processor integrates a DDR2 memory controller that can accommodate up to 2Gbytes of memory. Intel is marketing the reference design as providing more than just energy management, with the ability to add new applications as they are available. Embedded apps on the dashboard currently include a family message board, weather reports, and home security.

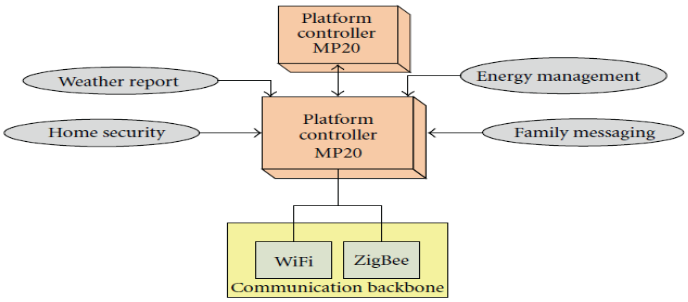


Figure 6. HEM architecture and interface

The existing commercial platforms outlined above are the first-generation platforms for HEM. As standardization of control and communication protocols is better outlined, and the penetration of HEM use among consumer households increases exponentially in the near future, research into designing the optimally efficient and scalable hardware platforms for the next generation HEM hardware will be paramount. There is a believe that the next generation HEM devices will also provide various value added services to the consumers, such as bill payment and security monitoring, besides the expected Demand Side Management (DSM). These HEM devices will be truly embedded in the HANs, and as is the case with such platforms, the applications and the operating system (OS) which will run on these platforms should be developed and optimized alongside with the emerging HEM device architectures.

Nucleos

Nucleos was designed by ge appliances (http://www.geappliances.com/home-energy-manager) to monitor and control electricity consumption. Once installed Nucleos allows remote control of appliances, temperatures and near real time energy consumption reports. This system is made of a concentrator (Nucleos energy manager) where all the peripheral devices (like plugs) will connect to.

The main features of this product are:

- Shows energy use in kWh and in estimated dollars spent, to reveal trends over days, weeks and months-up to 3 years;
- Accumulates daily/monthly/yearly historical trends up to a span of three years;
- Concentrator-peripheral communications made with ZigBee protocol;
- Monitor and manage energy used by individual appliances;

- Track electricity rates in order to lower the energetic bill;
- PC and smart phone apps;
- Thermostat control, allowing set and adjust temperatures remotely;
- Anticipate appliances behaviour in response to the changing electricity rates;
- Allow automated responses from appliances during peak pricing times;
- Override automatic settings, allowing to manually choosing when and how to use the energy;
- Led indicators: Power On, Wi-Fi Connected, Energy Network 1 (ZigBee® from meter), Energy Network 2 (ZigBee to devices);
- Wi-Fi radio for in-home LAN 802.11;
- ZigBee compatible radio receiver: 2 SEP 1.0, ZigBee radio ESI 802.15.4 and ZigBee HAN 802.15.4;
- Ethernet connection: 1 Ethernet port for in-home LAN 802.11;
- Works with Internet Explorer 8, Chrome 4, Safari 4 and Firefox 3.6.8.

GreenWave Reality

This platform was developed by GreenWave Reality (http://www.greenwavereality.com/) on industry standard Internet Protocol based communications allowing the highest level of compatibility and connectivity allowing interoperability with systems like:

- NXP GreenChip – enabled smart light bulbs;
- Electric cars;
- Heat pumps;
- Digital thermostats;
- Smart meters gas and electric;
- Other Z-Wave and ZigBee mesh-networking products;
- IP-Cameras;
- Motion and light sensors.

Figure 7. Gateway

The gateway is the main component of the system, since is the equipment where all devices have to connect to in order to make a domestic sensor network. This network may have plugs (Power nodes), illumination and in-home displays. In terms of communication this device supports Z-Wave, ZigBee and 6LoWPAN.

Figure 8. Power Nodes

PowerNodes have two versions, one with 6 plugs and another with a single plug. Each plug can be individually monitored and controlled, considering they are connected to the gateway.

Figure 9. Display

The display allows the consumer to monitor the electricity consumption as well as activate custom energy profiles.

Wiser

Wiser was developed by Schneider electric to allow the user to know where and when the energy was being used. Only knowing where the energy is being used the user can take measures to improve efficiency. Besides monitoring, this system allows remote control of the devices too. All devices communicate using ZigBee wireless technology. This system can also be access thru the internet via the "Wiser Web Application" where is possible to manage the system, set system limits and view real time energy usage, but is not yet possible to access the platform using a smart phone.

Figure 10. Wiser Smart Thermostat

Wiser Smart Thermostat is a programmable thermostat monitoring HVAC systems, working together with other Wiser equipment like displays and load controls. The thermostat shows information like energy usage and price alerts changing the background color of the screen. Another information showed is the temperature indoors and outside. It's also possible to use the device as a programmable thermostat with four events per day and check the energy consumption from real time to years.

Figure 11. Wiser In-Home Display

Wiser In-Home Display is the main component of a Wiser energy management system. This device shares functionalities with the Wiser Smart Thermostat like changing the background color with the energy price rate, as well as showing the energy consumption from real time to years. All Wiser devices can be controlled from this display being possible to turning devices on or off, adjust the temperatures and create simple timer functions.

Figure 12. Wiser Smart Plug

The Wiser Smart Plug manages energy to lamps and small appliances up to 15A 120VAC 60Hz, turning the attached loads on or off. When installed it can also work as a repeater increasing the network range. Allows up to four events per day programmed using Wiser In Home Display or related software.

Figure 13. Wiser Internet Gateway

Wiser Internet Gateway allows remote access and control to the Wiser devices data using internet.

Figure 14. Wiser Load Control

Wiser Load Control works similarly to Wiser Smart Plug but for fixed and usually higher loads (between 15 to 60A) like HVAC, compressors, water heaters, etc. It can also work as a repeated increasing the network range.

TED

TED (http://www.theenergydetective.com), The Energy Detective is a monitoring system developed by a company called Energy, Inc to help consumers understand how much energy they are spending. This system works with two current transformers connected to a MTU (Measuring Transmit Unit) measuring the energy consumption and transmitting data over the power line (PLC) to a gateway. This gateway then sends the data thru wireless to a display (made by the manufacturer) and/or another wireless device like a router for example.

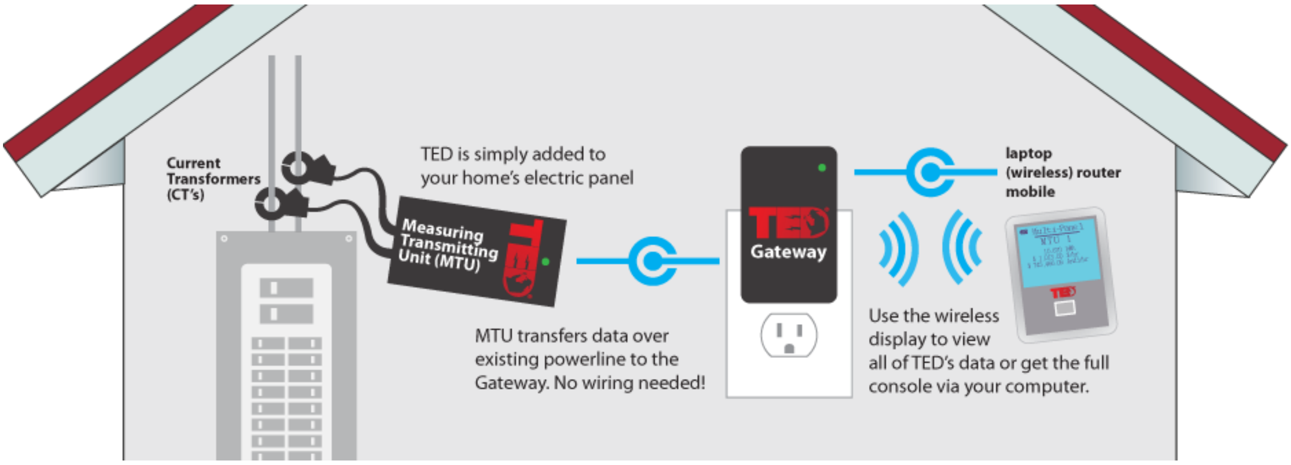


Figure 15. TED installation diagram

This solution has the disadvantage of only measuring the total energy usage in the break panel entrance, but the manufacturer says it's possible thru software to estimate the individual consumption of each device. An alternative to software estimations would be the purchase of another TED kit. Another disadvantage is the system being passive, meaning it only monitors power usage but cannot turn on/off any appliance. Some of the main features of the system are:

- Instant text/email alerts when the rate changes or the budget limit is getting close;
- View data remotely thru the wireless display included in the kit, computer or internet;
- "Teach" to the system the consumption of up to 5 devices and the software will estimate the individual consumption and costs associated, considering the global energy usage;
- Export data to spreadsheets;
- Monthly bill projection, estimates the value of the electricity bill;
- Interactive charts and graphs with electricity usage, CO2 emissions and voltage readings;
- Gateway stores up to 10 years of data.

EnergyHub

EnergyHub (http://www.energyhub.com) creates a HAN connecting all the devices in a way it's possible monitor and control each dispositive in the installation. The system allows the user to control the devices even outside of home through a computer or a smart phone. All the components in EnergyHub communicate using ZigBee Home Automation technology.

Figure 16. Home base

Home base is the systems brain where all devices will connect to. With it the user can see the energy usage in real-time of individual devices and projections of electricity costs/usage. Data can be seen in charts and it's possible to add devices to the system like for example socket strips. It's also possible to create consumption profiles that can be changed on demand. The interaction with the user is made using a capacitive touch-screen with 4.3". Besides the ZigBee Home Automation Home base can also connect to the internet using Wi-Fi 802.11 b/g.

Figure 17. Wireless thermostat

Wireless thermostat receives set point and schedule commands for Home Base and the web, but if wanted can be override temporarily until the next scheduled program begins.
It can adjust temperatures to 28-108ºF ambient, 35-95ºF setpoint with +/- 1ºF of temperature accuracy.

This device supports the following systems:

- 1- and 2-stage gas/oil/electric heat;

- 1-stage compression heat pumps and 1-stage auxiliary heat;
- Zone forced air and zoned hot water;
- mVolt systems (with 24VAC adapter);
- 1- and 2-stage cooling;
- C, B, O, W, W2, Y, Y2, RH, RC, G, and A wire connections.

Figure 18. Sockets and strips

Sockets and strips behave in a similar way being different only in the number of plugs per device, the socket has only one plug and the strip has more. These devices were designed to be plugged into the existing outlets, be modular and expandable allowing the user to add as many as wanted. They can be programmed to shut off automatically if energy prices cross a pre-set threshold. Can be controlled remotely from Home Base, web portal or smart phone and allow wireless monitoring in real time. In terms of electric specifications the status indicator is made using a RGB, and up to one per second can be made with +-5% accuracy at maximum load. Both devices support 100-132V AC, 60Hz single phase with a maximum current of 15A for the socket and 5A per outlet for the strip with the limit of 15A max for the whole strip.

Figure 19. Heavy duty control

Heavy duty control was designed for hard-wired installation by a trained electrician, meeting the needs of a variety of 240V appliances. It also can be controlled using Home Base, web portal or a smart phone. The device status can be seen with an RGB LED and measurments can be made up to 1 read per second with an accuracy of +- 5% at maximum load. In terms of electrical characteristics the device supports 30A max current and 187-264V AC 60Hz.

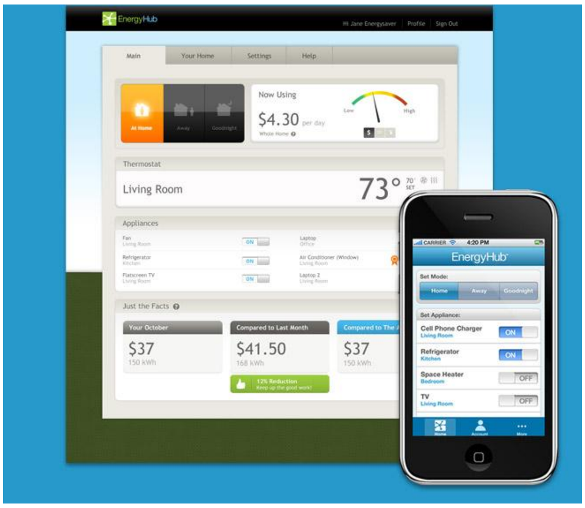


Figure 20. Web and mobile apps

With the web and mobile apps it's possible to change the energy profile remotly and control the state of each device. It is also possible to consult data remotly. The system supports browers Internet Explorer 8.0 or later, Firefox, Safari and Google Chrome.

3.6. Challenges designing Encourage HEM system

Going forward, it is envisioned that Encourage home energy management system will be based on an open, non-proprietary and standards-based platform. This will facilitate the ability to control and network intelligent appliances manufactured by different vendors.

While some of the capabilities envisaged for the Encourage (HEMs) might be available now from a number of providers, others are future possibilities and will be for quite some time before they hit the market.

The main challenges concerning basic devices (sensors and control devices) facing the deployment of an home energy management system are: (a) *accuracy*, for an HEM system, the power detection device should not only give an approximation of the current value, but also accurately measure the current value in the device to enable the intelligent management platform to perform effective appliance recognition function and to determine whether the appliance is operating efficiently using the appliance power source data, (b) *compatibility*, networking normal home appliances requires to enable a bidirectional control link between the sensors and the control device, (c) *low power cost,* it is essential that these detection devices have low power consumptions and costs and good power management standards

The ENCOURAGE core system will require a certain level of complexity to make the decisions on energy management processing all the context aware data provided by the HAN. Additionally, designing an integrated platform that will make the appliances from different vendors operating using different standards interoperable is an open research issue. The simplicity and intuitiveness of the user interface should be a key factor to the success of smart grids and HEMs in homes. Further, the ease of deployment and upgrading when necessary should preserve the customer base for smart home technologies.

4. Technologies evaluation

4.1. Analysis and evaluation of the different technologies

In this section the different technologies previously presented will be evaluated, in order to have a good basis for establishing a classification and determine which would be the best to use in the Encourage system. The criteria will be presented at first, followed by the actual evaluation. The criteria are defined regarding the high level requirements specification of the Encourage project defined in deliverable D2.2. They have then been mapped with the criteria that have been used by the Association of Home Appliance Manufacturers (AHAM) that have performed an evaluation of the most well-known and popular home automation protocols and technologies.

This analysis tries to extend the AHAM evaluation for the technologies that were not defined in this document, namely Infrared, Visible Light Communication, and RF4CE. For this reason, the evaluation of these technology slightly defer from the other ones, as they were evaluated by the partners of the project. In order to simplify this evaluation, the technology will be given a grade from 1 to 3 (corresponding to low, medium high), based on the grades that were given in the AHAM evaluation. Since using only a sub-part of the criteria, the grades have been recalculated to remove the weighting that was applied to them.

4.2. Evaluation criteria

Compatibility, interoperability and standards
D2.2 Ref: ATOS 1.1.2 , EZM 1.1.2, EZM 1.1.3

The first requirement states that the Encourage platform should be able to manage already existing energy management systems. from other European projects aiming at improving energy consumption, like for example the ENERsip project. The second that all common household devices compatible with the Encourage implemented standards can be added to the system. Finally, the last requirement has to do with the use of well recognized industry standards and protocols. These have been mapped with the interoperability and market place perception criteria from AHAM.

Interoperability

This criterion evaluates the interoperability of a technology, as the use of common and open standard widely supported. This is also to determine if a technology is supported by several companies, and if a user can expect to be able to buy products from different vendors.

Marketplace perception

The marketplace perception determines the maturity of a technology, its success in the consumers' environment. It is in fact important to choose a successful and durable technology, in order to make a good investment.

Investment costs and energy saving
D2.2 Ref: ESV 1.1.7

The high level requirement ESV 1.1.7 states that measures should be suggested in order to reduce the investment costs and increase the energy savings. For the technologies, this means that their initial cost should be low, as well as their energy consumption, and that the cost induced by their implementation in an existing infrastructure should be as low as possible. This requirement has been mapped with the two following AHAM criteria.

Cost trade-off

This criterion evaluates the trade-off between the consumers' expectations and the cost of a technology.

Minimizes enabling infrastructure

When choosing a technology, it is important to determine which quantity of material, whether hardware or software, is necessary in order to setup an installation. Less material means lower cost.

(re)configuration, discovery and upgrades
D2.2 Ref: ADV 1.1.12 & EZM 1.1.41

The first requirement concerns the possibility of configuring and reconfiguring monitoring devices, while the second one is about the possibility of easily add new devices and upgrade them. They have been mapped with the compatibility and future proof criteria of the AHAM study.

Forward/Backward compatibility/Future proof

This criterion evaluates how a technology is able to upgrade itself to correct bugs or security issues, in order for the technology to be able to maintain itself in the future.

Secure communication
D2.2 Ref: EZM 1.1.42

This requirement states that all data communication should be transmitted over a secured connection. It is thus important that the technologies used for measuring and managing the consumption implement a high level of security. This has been mapped with the security criterion of the AHAM.

Security

Security is an important issue for consumers, and it is important that a technology provides enough mechanisms to ensure the privacy of the data and protect the HAN from attackers.

4.3. Wired technologies

Universal Power Line Bus	**UPB**
Interoperability	1.4
Marketplace perception	1.6
Cost trade-off	1.25
Minimizes enabling infrastructure	2.25
Forward/Backward compatibility/Future proof	1
Security	1
Score	**1.4**

If UPB is easy to install thanks to the use of power line communication, its lack of standards integration, its high price and the lack of security mechanisms leads to a medium grade for this technology.

HomePlug	HomePlug AV2	HomePlugGreenphy
Interoperability	2	2.3
Marketplace perception	1	2
Cost trade-off	2.5	3
Minimizes enabling infrastructure	2.25	2.75
Forward/Backward compatibility/Future proof	2.33	2.66
Security	3	3
Score	**2.18**	**2.61**

The good results for the HomePlug's technology comes from the fact that even though HomePlug is a wired technology, effort have been made to provide a high security in the communication. The use of standards, the participation and compliance with the SEP 2.0 protocol, as well with a low cost and a good compatibility for legacy and future devices explain the high grade received by these two technologies.

4.4. Wireless technologies

Infrared	
Interoperability	1

Marketplace perception	2
Cost trade-off	1
Minimizes enabling infrastructure	2
Forward/Backward compatibility/Future proof	1
Security	1
Score	**1.3**

Infrared communication is a very mature technology but, although it is very used in current applications, it seems at the end of its life span. When it is possible to integrate an IR controller with an existing appliance, usually it takes no efforts to enable the infrastructure. It is also important to notice that infrared is the only way to communicate with a lot of common appliances like televisions, until a new technology replace it.
Anyway, the drawbacks of this technology are related to its closed nature and to the low degree of integrability of infrared-based solutions. In fact, it is usually difficult and expensive to perform an integration of new equipments, and some of the functionalities we need in ENCOURAGE cannot be integrated since infrared is not a general communication solution. Moreover, even if its low range confines the risk of hacking, no encryption is used in this technology, hence its lack of security concurs to the low grade we have given it.

EnOcean	
Interoperability	1.6
Marketplace perception	1.4
Cost trade-off	2
Minimizes enabling infrastructure	3
Forward/Backward compatibility/Future proof	1
Security	1.5
Score	**1.75**

The use of a proprietary protocol, the lack of compatibility and the low security lower the grade of EnOcean which provides however a good stack for communication and average priced devices.

Wi-Fi (IEEE 802.11)	802.11n	802.11a	802.11g	802.11b
Interoperability	2.6	2.6	2.6	2.6
Marketplace perception	2.8	2	2.6	2.4
Cost trade-off	2.75	2.5	2.75	2.25
Minimizes enabling infrastructure	2.5	2.25	2.25	2.25
Forward/Backward compatibility/Future proof	3	1.66	2.33	1.66
Security	3	2.66	2.66	2.66
Score	**2.78**	**2.28**	**2.53**	**2.3**

The maturity of the 802.11 technologies explains the high grade that they receive. Being an IEEE standard, and using the best known security mechanisms for wireless communication make them one of the best.

Bluetooth	Bluetooth 3.0	Bluetooth 4.0
Interoperability	1.8	2
Marketplace perception	1.2	1
Cost trade-off	2.75	3
Minimizes enabling infrastructure	2.5	2.75
Forward/Backward compatibility/Future proof	2.66	2.66
Security	1.83	2.16
Score	**2.12**	**2.26**

If Bluetooth is now well standardized and known, it has however difficulties to impose itself in the home automation area. However, nothing seems to lack in it, except maybe a bigger communication distance

802.15.4	ZigBee (SEP 2.0 capable)	ZigBee Pro	IETF 6lowPan
Interoperability	2.6	2.1	1.9
Marketplace perception	2.4	2.2	1.6
Cost trade-off	2.5	2.75	2.75
Minimizes enabling infrastructure	2.75	2.75	2.75
Forward/Backward compatibility/Future proof	2.66	2.33	1.66
Security	3	2.66	2
Score	**2.65**	**2.46**	**2.11**

The 802.15.4 stack has been developed for personal area network with focus on low-cost, low-speed, in order to achieve low power consumption. For this reason it is a good basis for sensor network in which energy consumption is an important matter.
The ZigBee specification that defines the network and application layers on top of the 802.15.4 stack has got popular in the home automation area, and the support of the ZigBee alliance makes it one of the most used technologies for Home Area Network.
The 6lowPan technology also implements network and application layers on top of the 802.15.4 stack, trying to make use of the IP protocol for sensor network. However, because not supported by important actors of the market, it does not currently encounter big success

RF4CE (802.15.4 based)	
Interoperability	2
Marketplace perception	1
Cost trade-off	3

Minimizes enabling infrastructure	3
Forward/Backward compatibility/Future proof	2
Security	2
Score	**2.16**

RF4CE is a standard supported by the ZigBee alliance, and it comes along with a lot of good features from ZigBee, such as its energy efficiency, the potential low cost of the chips, and the support for encryption, key generation and pairing, which are already part of the standard. Even though it is not yet widely adopted in the market, it will be a good candidate to replace the infrared technology in the future. Anyway, for the goals of ENCOURAGE, its limited acceptance in the market, delayed by its lack of compliance with older standard for remote control such as IR, concur to its low grade.

Z-Wave	
Interoperability	**1.9**
Marketplace perception	**1.8**
Cost trade-off	**2.5**
Minimizes enabling infrastructure	**2.75**
Forward/Backward compatibility/Future proof	**2.33**
Security	**2**
Score	**2.21**

Z-Wave is probably the second most famous technology for home automation after ZigBee, and we can see that it is not unjustified. If it lacks standardization, and is not widely used on the market, it has good arguments in cost, compatibility and security.

Visible Light Communication	VLC
Interoperability	2
Marketplace perception	1
Cost trade-off	2
Minimizes enabling infrastructure	3
Forward/Backward compatibility/Future proof	2
Security	3
Score	**2.16**

VLC is a promising technology for the future, since it mixes:

- low cost, since it is based on LEDs, which are getting cheaper as technology evolves, and it provides both illumination and communication, hence contributing to money saving
- low energy consumption, since LEDs are cheapest illuminating technology on the market, and building communication on top of it would not raise its energy consumption
- PHY layer security, since on the PHY layer communication cannot cross walls, hence adding up to the privacy.

The minor drawbacks of the technology are:

- it has got a low communication bandwidth
- it needs line of sight, hence it imposes constraints on the locations for access points and other network elements.

Anyway, the real weakness of VLC is that it has just started being accepted in the market, and it doesn't have a globally accepted standard. A global standard is being developed by IEEE 802.15.7, and only Japan has got a standardized VLC technology. Thus, VLC still has to reach the right level of maturity to get accepted by the general public, hence we don't suggest to adopt this technology in Encourage.

4.5. Hybrid technologies

X10	
Interoperability	**1.2**
Marketplace perception	**1.6**

Cost trade-off	**1.75**
Minimizes enabling infrastructure	**2**
Forward/Backward compatibility/Future proof	**1**
Security	**1**
Score	**1.4**

Defining its own standard, X10 did not completely succeed to convince the market. A relatively high cost, combine with a lack of compatibility and good security mechanisms gives X10 a low grade

INSTEON	
Interoperability	**1.7**
Marketplace perception	**1.8**
Cost trade-off	**2.25**
Minimizes enabling infrastructure	**2.25**
Forward/Backward compatibility/Future proof	**1**
Security	**1**
Score	**1.66**

Similar to X10, INSTEON suffers the same problem. If it ends up with a higher grade, it is mostly due to the lower cost of its equipment

LonWorks	**LonWorks PLCS**	**LonWorks TPC**
Interoperability	**2.4**	**2.4**
Marketplace perception	**1.4**	**1.8**

Cost trade-off	**1.5**	**2**
Minimizes enabling infrastructure	**2**	**1.5**
Forward/Backward compatibility/Future proof	**2**	**2**
Security	**1.16**	**1.16**
Score	**1.74**	**1.81**

Because it succeeded to have their communication protocols standardized, and because it provides more security for a lower price, LonWork ends up with a medium grade.

4.6. Results

Rank	Technology	Score
1	802.11n	2.78
2	ZigBee (SEP2.0 capable)	2.65
3	HomePlugGreenPhy	2.61
4	802.11g	2.53
5	ZigBee Pro	2.46
6	802.11b	2.3
7	802.11a	2.28
8	Bluetooth 4.0	2.26
9	Z-Wave	2.21
10	HomePlug AV2	2.18
11	RF4CE	2.16

12	VLC	2.16
13	Bluetooth 3.0	2.12
14	6lowPan	2.11
15	LonWorks TPC	1.81
16	EnOcean	1.75
17	LonWorks PLCS	1.74
18	Insteon	1.66
19	X10	1.4
20	UPB	1.4
21	IR	1.3

Throughout the evaluation, we could see that all technologies have pros and cons. Because none of them is perfect, and because the Encourage system has for aim to be accessible by the most, the choice of which technology to use inside a house or a building will be left to the user. In that way, each user can choose upon this list of technology the one that fits the best its needs, and can then connect to the Encourage system with a gateway that is compatible with Encourage.

Throughout the evaluation, it is possible to see that every technology has pros and cons. Because none of them fit all the requirements, and because the Encourage system has the aim to be accessible by most of them, the choice of which technology to be used in a house or a building will be decided by the user. In that way, each user can choose upon this list of technologies the one that best fits their needs, and the technology that is able to connect to the Encourage system with a gateway that is compatible with Encourage.

However, as a conclusion of this evaluation, we can issue recommendation for the technologies to be used.

ZigBee

Even though this technology ends up only in the second position of the ranking, it would be our first recommendation. In fact, if its grade is a bit lower than the 802.11n one, according to [21], it would be a better choice in term of energy consumption, when used as a technology for sensor networks.

802.11n

This technology, which ends up in the first rank of this evaluation, seems to be the most complete one in terms of interoperability, compatibility, and security. It also has one advantage compared to the others, that it is a technology that already exists in many households, and would therefore reduce the cost for the end users.

HomePlugGreenPhy

Regarding the results of the evaluation, the HomePlug standard seems to be the best wired technology available, and could thus provide a good alternative to ZigBee and Wi-Fi, for situation in which wireless transmissions might not be suitable. The fact that the HomePlug alliance developed a specific standard to be used in Smart Grids with lower cost and energy consumption even improves this feeling.

5. ENCOURAGE Building Network (EncBN)

The Building Network is the communication infrastructure that supports an intelligent building's capabilities. This chapter considers the functionalities that must be exposed by the Home Gateways, and it completes the discussion of this deliverable, by

- extending the analysis on the suitability of communication technologies for the HAN (lower layers of the protocol stack) to the application layer;
- providing a bridge between the functional architecture of ENCOURAGE, and the standardized approach to smart grids that is proposed in ZigBee Smart Energy Profile, which follows IEC specifications.

ICT has a key role to empower the ENCOURAGE building capabilities, since the transport of data and commands is instrumental to separate the politics (decision processes) from the mechanisms (sensors and actuators). In this sense, we can consider that the Home Area Networks (HANs) presents in the building are linked together, and to the internet, to create the ENCOURAGE Building Network (**EncBN**). In particular, ENCOURAGE considers moving to a High Performance Computing (HPC) platform all the heavy computation that regards the smart grid, which comprises for example the profiling of the user needs, the response to changes in the energy prices, the analysis of the overall performance of the Intelligent Building, the signal processing related to virtual metering and non-intrusive load monitoring, and the setup of the thresholds for switching on/off the HVAC system. The cloud will host also all the operations that make more sense when performed in a centralized manner, like the storage of the HAN configuration, and the orchestration of the recharging times for the HEVs to prevent the schedule of all recharging at the same time and the consequent blackout of the neighborhood.

Even in front of moving much decisions to the HPC provider, ENCOURAGE will be exposed to low-level details regarding the application of the politics decided in the cloud, and on that respect it is possible to adhere to two different paradigms:

- To keep in the HAN the implementation of the chosen actions, as well as simple choices like turning on the HVAC when a user moves into a room and when a given temperature/humidity threshold is reached, and switching on/off energy-consuming appliances at given times;
- To take all the decisions in the cloud, even the ones characterized by the lowest complexity.

In the first case, it is necessary to engineer the decisions in a proper way to delegate to the gateways only the easiest parts of the decision making, hence mapping the decisions taken regarding the whole house to the wireless network related to a single gateway. The second approach is free from that level of complexity, since all the decisions are taken in the cloud, but presents different problems since all actions must be initiated by transporting a command from the cloud to the gateway to the device, causing more network traffic, possibly more delay, and certainly a dependency of the HAN on the connection to the cloud. ENCOURAGE project is still considering which of the two approached to take.

This section considers the requirements that must be coped with when creating an EncBN, which is the networking infrastructure for an ENCOURAGE building.

5.1. Basis for the definition of EncBN 2-way communication system

The EncBN has the basic goal of exchanging data to and from the building appliances: monitor data must be collected on the sensors and brought to the gateways, then relayed through the ENCOURAGE messaging system towards data storage and processing systems; control packets must be brought from the application producing them, down to the actuators. Moreover, the system must take into account scalability (a large number of ENCOURAGE buildings can communicate with the ENCOURAGE Service Provider at once), reliability (some messages, in particular the commands, must be subjects to guaranteed delivery), and flexibility (different devices, gateways, and applications must be able to be added to the system at any time).

The ENCOURAGE Building will use sensors and control devices that operate behind a gateway. These sensors and control devices are installed throughout the facility. Even if new installations will use standard protocols, current individual systems have their own set of protocols, both wireless and wired, to connect the devices to the gateway. In particular, older installations lack converged networks that act as a single communications backbone for multiple systems, and instead offer different communication technologies to each set of devices that are connected to the different installed gateways.

Lately, Internet Protocol (IP)-based network systems are becoming increasingly common as a communications backbone for facility systems. Many facilities are now starting to deploy multiple Intelligent Building systems as well as administrative Local Area Networks on a single IP-based network. Most manufacturers of intelligent appliances are designing their products to operate on an IP network.

The EncBN will offer a unique building network for all the devices composing its intelligent infrastructure, which will provide a number of benefits to both vendors and users:

- Cost efficiency: Multiple gateways can be deployed in the house still one network connection is used to offer services to the user.
- Easier development of products: ENCOURAGE provides guidelines for the communication of the devices with the ENCOURAGE Service Provider, easing the technical design of the product.
- More vendors options: The user can decide between different vendors when deciding its intelligent devices, hence he will be able to look for devices that better suit his needs.

- Greater flexibility: new gateways can be added to the ENCOURAGE building, since they will be accepted into the EncBN without having to add cables or configuring the network side.

Thus, the EncBN will define the characteristics of the network that will bind together all the devices in the building, possibly by crossing the relative gateways to bring messages to and from the devices.

5.2. EncBN - Device Management: supported capabilities

Requirements to create a EncBN regard the while set of conditions that must be satisfied for the devices (sensors and actuators) to be merged into a network that transports monitoring data and control messages to and from the sensors and actuators, and up to the gateways.

The main blocks of the EncBN are:

- The monitoring devices' set, composed mainly by sensors that collect information regarding the energy consumption patterns.
- The control actuators' set, which receives messages to implement energy efficient changes in the system.
- The configuration mechanisms for both the devices and the EncBN itself.
- The upgrade and expansion system, used both to add novel devices to the EncBN in a seamless way, and to upgrade the capabilities of already deployed devices by the re-configuration of them.

The approach followed by ENCOURAGE is to adhere to the ZigBee specifications in terms of defining all the interaction with the HAN as service-based. Each main block defined above is thus mapped onto a set of services, which will be enumerated in the rest of this section, while providing recommendations on their deployment on the architecture. The description will be articulated into subsections, one for each main block defined above, to separate capabilities that are semantically unrelated, even though it implies that the main blocks will have a different cardinality of functionalities. For example, the upgrade and extension system has got only one service that configures a new device, while the control actuators' set has got different services for HVAC, HEVs, etc.

ENCOURAGE is expressing the functionalities of the devices of the HAN by means of the ZigBee specification. On the other hand, ENCOURAGE is faced with the option of using the ZigBee specifications (ZigBee Cluster Library and Smart Energy Profile 2.0) for the encoding of the data and command messages, but this option is still under consideration. This section provides the requirements the devices must respond to, and leverages on ZigBee to attain this goal, while a future deliverable produced by Task 6.1 (Intelligent Building Gateway) will take the final decision on the encoding of ENCOURAGE sensed data and commands.

ZigBee is an ever-expanding specification suite of high-level communication protocols, which is divided into profiles. Each profile specifies the formats and protocols for a specific set of applications. The information related to an application profile is divided into a set of information clusters, which are concerned with just one aspect of the application at hand. An example of information cluster is the temperature cluster, used to query information regarding the temperature measured by a sensor, with the value comprised in a range; the cluster is also used to command a sensor to report every change of temperature that is larger of a programmable threshold. To this goal, the ZigBee Cluster Library contains the Alarm cluster, which contains mechanisms for sending alarm notifications and configuring alarms. The conditions for a notification to be generated are then described in the other clusters, which focus on the particular conditions for the alarms to be raised.

Regarding the clusters that are adopted by ENCOURAGE for the management of the EncBNs, the involved information is contained in two profiles, the basic ZigBee profile, implemented in the ZigBee Cluster Library (ZCL), and the Smart Energy Profile 2.0 (SEP), the former for sensing capabilities, and the latter for functionalities tightly coupled with the smart grid concept. Even though ENCOURAGE is not bound to adhere to the ZigBee specifications for the encoding of the data that is exchanged during the operation of the smart grid, we will define the related services in terms of ZigBee clusters, since the EncBN is prone to present strong similarities with the architecture underlying the ZigBee principles.

The data regarding each cluster can be retrieved by both explicit queries, and by setting up an alarm, which will produce a notification whenever an event happens, such as a change in the temperature. An application will receive the notification, and will be able to act accordingly, for example by switching on/off a HVAC system.

The rest of this subsection will describe the most generic clusters, which are used to get or set basic information regarding the device, hence they are devoted to manage the components of the EncBN. Next subsections will focus on matters more explicitly related to smart grids.

A list of the clusters considered for the EncBN is reported in Table 1. The table reports all clusters that COULD be implemented by the HAN devices in ENCOURAGE. Anyway, not all clusters will be implemented by each device. For example, a sensor will not implement clusters related to actuators. Thus, the implementation of the clusters is optional, and it becomes mandatory only when the functionalities described in the cluster are necessary for the execution of ENCOURAGE techniques.

EncBN block	Cluster	Description	Methods
Generic	Basic	HW version, SW version, power source, location, state (on/off)	Set/get
	Power	Power source, remaining battery	Get
	Device temperature	Current temperature, temperature threshold to generate an alarm	Get (set for the alarm)
	RSSI location	RSSI-based localization, channel condition	Get
Monitoring	Value	Measurement unit	Set
	Illuminance, Temperature, Pressure, Flow, Humidity, Occupancy	Data collected by the sensors	Get
	Metering	Usage information for energy/gas/water; setup for SEP's reports	Get
	Price	Price for energy/gas/water	Get
Control actuators	Level Control	Controlling a device that can be set to a level, e.g.: brightness of light, degree of closure of a port, power output of a heater	Set
	Lighting, Color, Dimmer	Specialized control for illumination	Set
	HVAC	Heating, Ventilation, Air Conditioning control, access to logs on energy usage	Set (control) / Get (logs)
	Demand response and load control	Setup of threshold (e.g.: temperature) to switch on/off devices (e.g.: HVAC)	Set
Configuration	Information, Basic	Name, location, power source, etc of a device, stored on the cloud, downloaded by the gateways	Set
Upgrade	Over-the-Air Bootload	Manage and serve up upgrade images for devices from different manufacturers. Servers provide firmware images to clients to download, clients can control the timing and rate for the download.	Get (performed by gateway on the server in the cloud)

Table 1. Information clusters employed in the EncBN

A first cluster that is taken into account in ENCOURAGE, is the Basic cluster, which contains basic information about a device, such as the kind of sensors or actuators, its location, and its state (on/off), which is used to enable or disable the device.

Other clusters of general utility are the Power configuration cluster, and Device temperature configuration, and the RSSI location cluster, used respectively to determine detailed information regarding the device's energy source and the energy left in its internal battery, to set up internal alarms regarding the internal temperature of device, and to query the condition of the wireless channels the device is communicating into. It is possible to set up alarms on all of these clusters, for example to switch off a device when the voltage of its mains power source is higher than a threshold to ensure the survival of the device to a power outage.

5.2.1. Energy Consumption monitoring

An intelligent building envisioning by ENCOURAGE, must have access to the sensors and actuators in the most flexible way. We describe here the characteristics of the sensors part, and the next subsection will consider the actuators. When not further specified, the services related to the sensors expose just a "get" operation to let the data consumer get access to the sensors' readings.

The monitoring data must be brought to the gateway, and then multicast to the components that subscribe to the data. Usually, this set of components include application on the ENCOURAGE Service Provider (on the cloud) and data viewer in the building. In the first case, raw data will be transported at the fastest possible speed to give every possible detail to the application consuming the data. In the second case, data will be possibly aggregated to facilitate its visualization.
A first cluster that is used in this context is the Value cluster, which is used to define the measurement unit used to report data.

Most sensors pertaining to a EncBN are covered by a few basic clusters from the ZCL, such as Luminance, Temperature, Pressure, Flow, Humidity, and Occupancy Sensing.

A central cluster for this set of functionalities is the Metering cluster. Client devices, such as an energy gateway, smart thermostat, or in-home displays can monitor changes to energy saving settings within the premises and give users near real time feedback and results. The Metering cluster can support this by using the reporting capabilities described in the introduction of this section. The device will implement these mechanisms by sending updates at a much faster rate for a short period of time. On the other hand, applications could also perform a series of read accesses to attributes to accomplish the same task.

The Price cluster is used to provide price information to applications. In particular, the cluster focuses on the mechanism for communicating Gas, Energy, or Water pricing information within the premises. This pricing information is distributed to the EncBN from either the utilities or from regional energy providers. The data can be communicated via either secure methods, or by anonymous communication in an unsecure network, to very simple devices that may not be part of the Smart Energy network. The price data can be different tariffs for different time of the day, and can be displayed to show pre-processed information from the server, like a prediction of the cost of a day with the current behavior of the user, or can be used to present some information about the contracts with the utilities (Electricity + Gas + water: available power, voltage to be considered in current measuring devices, etc.)

These clusters have got strong interaction with the control interface of the EncBN, since for example a temperature sensor or a humidity sensor can be part of a hysteresis function, to control an on / off heater. For instance, the radiator can be turned off when the temperature reaches 20 degrees, but will not turn on again until the temperature has dropped to below 18 degrees. Therefore the hysteresis would have 2 parameters: a “high to low” value and a “low to high” value, corresponding to scenarios for turning the radiator *off* and *on* respectively.

5.2.2. Control interface

ENCOURAGE system must allow the user to control the sensors and actuators in the most flexible way. The actuators are used both to switch on/off (and possibly dim) the energy consuming devices, and to orchestrate energy production, storage, and exchange with both neighbouring building and the energy grid. When not specified, it is supposed that the services related to the control interface expose a “set” operation to let a command flow down from the decision-taking application to the actuators that implement the decision.

An important but generic cluster for the control of the devices is the Level Control Cluster, which is part of the ZCL. This cluster provides an interface for controlling a characteristic of a device that can be set to a level, for example the brightness of a light, the degree of closure of a door, or the power output of a heater. This cluster will be used in all the cases not covered explicitly by SEP 2.0.

The ZCL provides the Lighting cluster, which is used in conjunction with the Color cluster and the Dimmer cluster to manage the lighting in a house. Even though this is a more general cluster than most smart grid clusters, the Lighting cluster can be used to schedule and/or manage at run-time the lights in a smart house, to realize energy saving by dimming off, or even powering off, the lights in empty rooms. The lighting can be controlled via multiple sensors: Light sensor, switch and calendar. A priority handler allows the user to supersede events from e.g. the light sensor or calendar, thereby using the event that was applied lastly.

Another cluster from the ZCL is the HVAC cluster, which has got a number of attributes used to control heating, ventilation, and air conditioning system with fine tuning. The attributes range from the pressure of the ventilation air, to the target temperature for the heating system, to the speed of a fan. The cluster supports also the LifetimeEnergyConsumed attribute, used to keep trace the quantity of energy that has been used by the HVAC system, and can be traced to understand the quantity of energy that has been consumed in a given day by the HVAC system.

The interaction with devices that can be switched on/off is done by the usage of the Demand Response and Load Control cluster. Most of the control exercised by WP5's results will be transported down to the devices in the EncBN by using this cluster.

5.2.3. Configuration interface

The configuration of the EncBN is composed by the configuration of the networks managed by each gateway. Each gateway will cache its configuration locally, but the configuration will also be replicated in the cloud for reliability concerns. The configuration of the EncBN will be possible by the computer access to the ENCOURAGE-enabled gateways, or also by the access to the cloud-based configuration repository.

The configuration of the device is stored on the cloud, and replicated either on the gateway or in other parts of the device vendor's network, depending on the device. The configuration of the devices is done by using custom panels of the device vendor, but it is also possible to operate on the device configuration by contacting the cloud.

This set of functionalities is strictly related to the basic clusters described in the introduction of this section, like the Information cluster, which can set/get the name of a device.

5.2.4. Support for upgrade

Modern gateways already support on-the-fly configuration and updating. ENCOURAGE move this capability a step forward by providing a system to drive the gateways to downloading the new firmware and/or configuration from the cloud without accessing directly the gateway, but only using a computer access to the ENCOURAGE Service Provider.

The use of standard protocols allows new devices to be added to the EncBN safely and easily, as long as they are supported by one of the gateways installed in the house. In fact, contextually with the addition of a new device, configured by accessing the Middleware interface, the device will be added to the set of devices controlled by the gateway, and the device will be included in the EncBN .

Even in the context of system upgrade, it is possible to adhere to the vision of ZigBee specifications. In fact, the SEP provides a cluster that is used to upgrade the system. This Over-the-Air Bootload cluster provides a common mechanism to manage and serve up upgrade images for devices from different manufacturers in the same network. Servers provide firmware images to clients to download, controlling the timing for downloads and when the actual upgrade to a new version of software is made. Clients periodically query the server for new images and then can download the image at a rate according to their capabilities or policies.

6. Conclusions

This document investigates the communication protocols and technologies for the Home Area Network, and relates them to the requirements of the ENCOURAGE project in general, and its pilots in particular.

A thorough description of the communication technologies is followed by a discussion on current Home Energy Management Systems. After that, a chapter is focused on the evaluation of the technologies, by considering Interoperability, Marketplace perception, Cost trade-off, Minimizes enabling infrastructure, Forward/Backward compatibility/Future proof, and Security. The goal was facilitating the effective integration of the elements composing the ENCOURAGE platform, by guaranteeing compatibility between very different appliances and hardware devices, dealing with legacy devices, wired and wireless capabilities.

The characteristics we studied hint that the best technologies are 802.11 and ZigBee. Anyway, wi-fi has got the drawback of the energy consumption, and a device (e.g.: a light switching) not connected to the mains would soon deplete its internal battery. Thus, we decided to adopt the ZigBee flavor of IEEE 802.15.4.

A final chapter considered the functional architecture of the HAN and expressed the functionalities in terms of ZigBee clusters, to ease the design of the interface between the home gateways and the ENCOURAGE project.

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